International Journal of
Electrical and Computer System Design
ISSN: 2582-8134 www.ijecsd.com

Effect of surface roughness on the mechanical performance of a 3D printed PLA Component

M. Navaneetha Krishnan*[1] Sundar Vettumperumal [2], Arockia Jayadhass [3], S. Suresh [4], C. Vijaya Nanthini S [5]

[1] Department of Mechanical Engineering, Amrita College of Engineering and Technology, Amritagiri, Erachakulam (Po), Nagercoil, Tamil Nadu 629 901, India, mrnkkrishnan@gmail.com

[2]Department of Mechanical Engineering, St Joseph University in Tanzania, Dar es Salaam, Tanzania,

sundar.perumal@sjuit.ac.tz

[3]Department of EECE, St Joseph University in Tanzania, Dar es Salaam, Tanzania,

arockia.jayadhas@sjuit.ac.tz

[4]Department of Mechanical Engineering, University College of Engineering, Nagercoil 629004, Tamil Nadu, India,

ssuresh2009@gmail.com

[5]Department of Science, Mathematics and Education, St Joseph University in Tanzania, Dar es Salaam, Tanzania,

vijayananthini1995@gmail.com

Abstract: The well-known additive manufacturing technique, known as Fused Deposition Modelling (FDM), is employed in many different sectors. The main disadvantage of the FDM technique is the increased surface roughness. The laser polishing method has been used to get around the challenge. The laser polishing method may be used to prepare the accurate and smooth FDM component surfaces. In this study, laser polishing was used to refine Polylactic Acid-Aluminum Fibre (PLA-Al fibre) composites made using the FDM process. At various speeds of laser scanning, the polished PLA-Al fibre composite's surface properties and mechanical effects were examined. The results indicate that the surfaces of PLA-Al fiber composites, when polished, exhibit lower surface roughness compared to unpolished samples. Dynamic mechanical analysis revealed an enhanced storage modulus in laser-polished specimens.

Keywords: Additive Manufacturing; Fused Deposition Modelling; laser surface irradiation; Surface roughness; Mechanical characteristics.

1. Introduction

Additive manufacturing stands out as a significant manufacturing process due to its rapid processing and broad applicability. [1-8]. Due to its low operating costs, superior environmental friendliness, affordable equipment, etc., the Fused Deposition Modelling method is primarily adopted by numerous industries [8-19]. The Fused Deposition Modeling (FDM) technique employs thermoplastic and thermosetting polymers as its primary constituents. Among the thermoplastic polymers utilized are Polycarbonate, Polyamide, Polylactic Acid, and Acrylonitrile Butadiene Styrene. [20]. Pure polymers, however, are not appropriate for novel uses [21]. Polymer composites thereby resolve these problems. For polymer composites, metal and glass fibers in particular are used as reinforcement [22–27].

The laser polishing technique was used to reduce the part's surface roughness. A laser source is used to heat the material surfaces during this operation. By remelting the surfaces, it is a non-contact process with customizable polishing velocity [28, 29]. To reduce the oxidation of the inert gases used in the laser polishing process. Due to fluid pressures in the melt area, the laser source quickly polishes the material surfaces. The portions that can't be polished using traditional methods, like intricate parts, can be easily polished by laser irradiation [30]. These advantages led to the replacement of the traditional method by the laser polishing method in a number of applications.

Chai et al. found that the FDM technique significantly reduced the surface roughness of the PLA by 68%. This was accomplished using a CO2 laser and a scanning velocity of 150 mm/s [31]. Yung et al. found that the laser-polished specimens exhibited an 8% increase in hardness compared to those processed with the SLM equipment. [32] T. He et al. developed an effective method to reduce the roughness of CoCr alloys with complex geometrical surfaces by up to 93%. [33] Attained the highest reduction in roughness, reaching 0.156 nm, without causing any degradation for bonded silica, as reported by L. Gurau et al [34], In contrast to some mechanically treated specimens, laser-polished Additive Manufacturing (AM) CoCr alloy devices demonstrated a surface roughness of 0.45 µm and approximately 30% improved corrosion resistance.

In this study, laser polishing was used to refine Polylactic Acid-Aluminum Fiber (PLA-Al fiber) composites made using the FDM process. The existing literature indicates a gap in research regarding the mechanical characteristics and surface roughness of PLA-Al fiber composites in earlier studies. This prompted an investigation into the surface properties and mechanical effects of laser-polished PLA-Al fiber composites at different scanning speeds. Energy-dispersive spectrum (EDS) analysis was used to characterize the produced samples. Profilometry was used to examine the PLA-Al composites' surface roughness. The goal of the dynamic mechanical analysis study was to examine the behavior of polished and unpolished specimens moving at different speeds.

2. Experimental features

2.1. Materials and specimen formulation

The samples were made using 1.5 mm diameter PLA/Al filament. Al fiber makes for 6.7 weight percentage of the PLA/Al filament. The FDM-style 3D printer was used to create the PLA/Al composites. The DMA samples were prepared in accordance with ASTM D5023-15 standards. The bed was kept at a temperature of 59°C while the nozzle was heated to 199°C. at a rate of 1000 mm/min, the nozzle feeds the necessary amount of melted filament along the path.

2.2. Laser polishing technique

A fiber laser and 200 W of powder were used to polish the created specimen. A diode employing an on/off mechanism was utilized to control a pulse laser for the purpose of polishing the object. The scanning path and the depositing position are vertical to one another. The surfaces of the PLA/Al composites were melted after the laser was applied. The liquid substance that comes from the top surfaces flooded the valley regions. The laser source was then turned off, solidifying the PLA/Al composites. This method helps to reduce the surface's roughness. The three different scan rates used for this procedure are 40, 80, and 120 mm/s.

2.3 EDS Characterization

Characterizing a polished PLA/Al composite and an unpolished PLA/Al composite was conducted using EDS at a scan velocity of 80 mm/s. is shown in Fig. 1(a) and (b), respectively. The two main components seen in Fig. 1(a & b) are Al and Au. Gold splutter caused Au to show up in the EDS. Along with Al and Au, the elements C and O are also present. The element is thus present in the PLA/Al composites, according to EDS data.

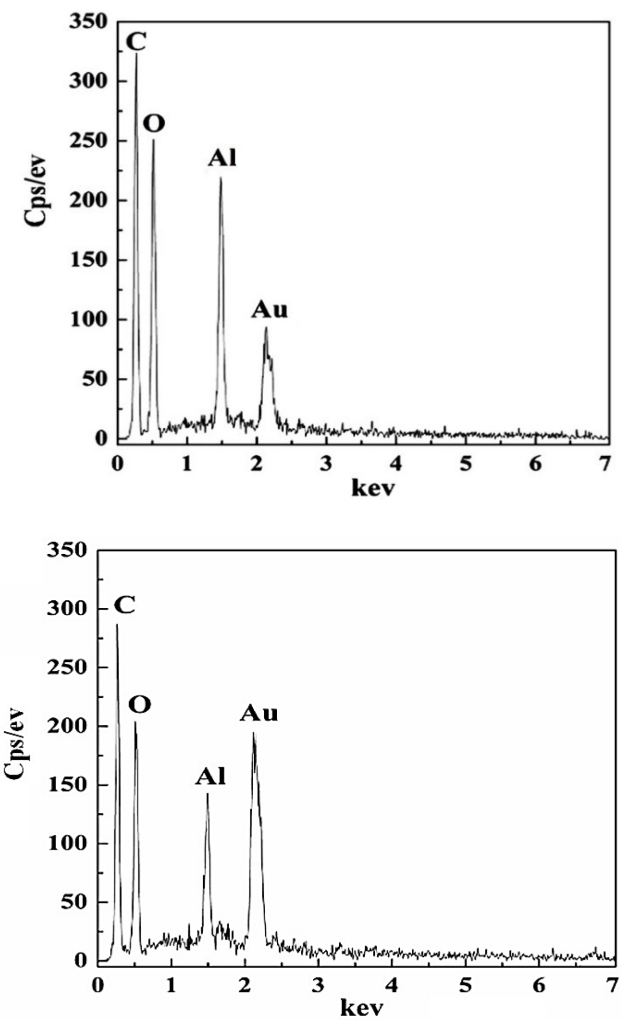

Fig. 1 Analyzing PLA/Al composites using EDS involved examining an (a) unpolished specimen and (b) polished specimen 2 at a scan velocity of 80 mm/s.

2.4 Experimentation

2.4.1 Surface roughness examination

The profilometry tester was used to assess the PLA/Al composites' roughness. The stylus type contact profilometer was used to measure the arithmetic mean height and arithmetic mean deviation parameters. Conducting experiments at a speed of 0.5 mm/sec, the trials utilized a diamond stylus probe with a radius of 5 m.

2.4.2 Dynamic mechanical examination

The dynamic mechanical behavior of the PLA/Al composites is examined using the DMA device. The temperature was examined via DMA analysis over a 30 mm span. The experiment was carried out at a frequency of 1 Hz and a temperature range of 29 to 174^{o} C.

3. Results and discussion

3.1 Surface roughness examination

Fig. 2 (a) shows (c) npolished PLA/Al composite's 2D roughness data. Fig. 2(b-d) Illustrating the impact of laser scanning velocity on the roughness of PLA/Al composite surfaces, Figure 2(b) displays the roughness profile of laser-polished surfaces at a speed of 40 mm/s. Similarly, Figure 2(c) depicts the roughness profile at a speed of 80 mm/s, while Figure 2(d) shows the roughness profile at 120 mm/s. The FDM 3D printing allowed for the identification of the valley and peak in Fig. 2 (a), which has a Ra value of 24.42 µm.

Similar to this, the Ra values of the 40, 80, and 120 mm/s laser polished PLA/Al composites are 4.62 µm, 3.11 µm, and 3.42 µm, respectively. It was established that the surfaces of the polished PLA/Al composite have Ra values that are much lower than those of the unpolished composite. Lower Ra values are especially prevalent in 100 mm/s laser polished composites.
The unpolished composite exhibits an Sa value of 23.82 µm. In contrast, the Sa values for laser-polished PLA/Al composites at speeds of 40 mm/s, 80 mm/s, and 120 mm/s are 6.52 µm, 5.51 µm, and 5.84 µm, respectively. This confirms that the surfaces of the polished PLA/Al composite have significantly lower Sa values compared to the unpolished composite. Specifically, composites subjected to laser polishing at 80 mm/s demonstrate the lowest Sa values. Despite achieving the lowest possible roughness rating, minor valleys and peaks are present in the laser-polished composites, attributed to the limited solidification time during laser polishing, resulting in the formation of small valleys and peaks.

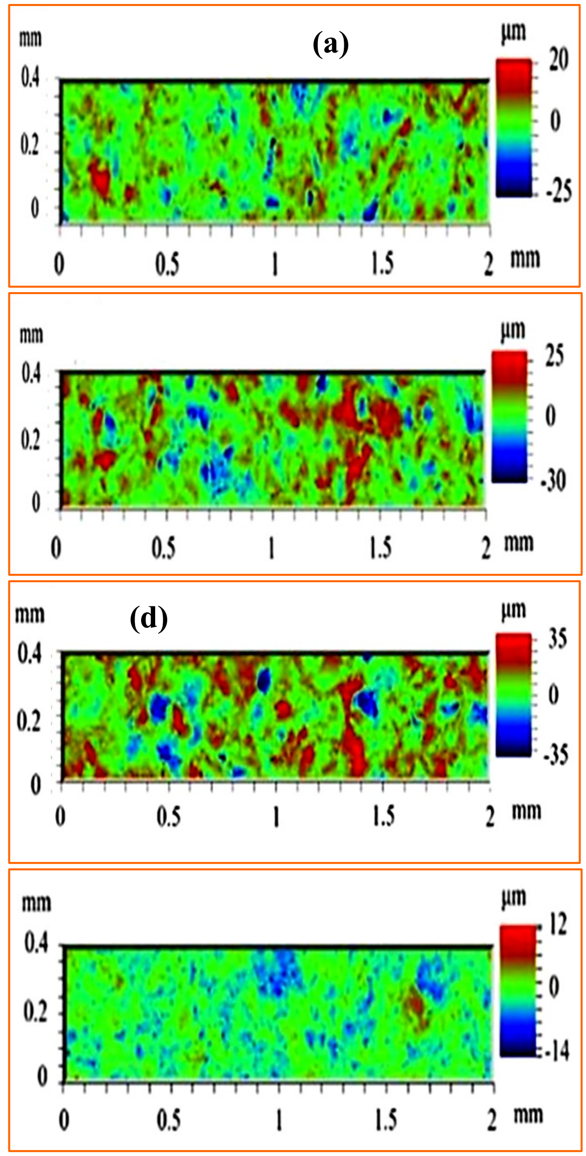

Fig. 2. The surface roughness profiles of PLA/Al composites under varying laser scanning velocities are depicted in Figure (a) for the unpolished PLA/Al composite, (b) at 40 mm/s, (c) at 80 mm/s, and (d) at 120 mm/s

Initially, the quality of the PLA/Al composite improves with an increase in scanning velocity. However, as the scanning speed continues to rise, the quality of the PLA/Al composite deteriorates. This was brought on by the extra time needed for the minimum solidification scanning velocity. These outcomes precisely reflect the sources [35, 36].

3.3 Dynamic mechanical performance

The dynamic mechanical behavior of the PLA/Al composites is depicted in Fig. 4. It conveys the discrepancy between E′ (the storage module) and the temperature change. The polished PLA/Al composites had a greater E′ value than the unpolished composites at the lowest temperature. Compared to other PLA/Al composites, those subjected to a scanning velocity of 80 mm/s exhibited a higher E′ value. This phenomenon can be attributed to the strong bonding between the PLA and Al layers. [37]. Unpolished composite has an E′ of 3.29 Gpa. However, the E′ of the 40, 80, and 120 mm/s laser polished PLA/Al composites is 4.81, 4.89, and 4.51 Gpa, respectively. It verified that the tensile strength had the same effects.

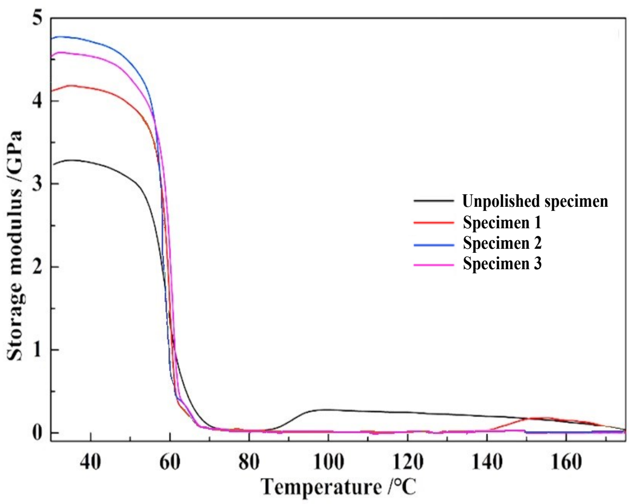

Fig. 4 Conducting DMA analysis on PLA/Al composites involved using laser scanning speeds of 40 mm/s for specimen 1, 80 mm/s for specimen 2, and 120 mm/s for specimen 3.

4. Conclusion

In this study, the dynamic mechanical properties and surface roughness of PLA/Al composites that had been laser polished and unpolished were compared. The findings that followed were drawn.

- The FDM 3D printing method was used to create the PLA/Al composites. PLA and Al elements are confirmed to be present by the EDS analysis.
- Through the application of laser polishing, the surface roughness of the PLA/Al composites was reduced. Better surface quality is displayed by the laser-polished composite with 80 mm/s scanning velocity. The laser polishing procedure decreased the roughness characteristics of the PLA/Al composites by 88%.
- Due to their greater modulus value regarding temperature, laser polished PLA/Al composites behave more mechanically dynamically than unpolished composites.

5.Acknowledgements

The authors express their appreciation to the Management and the Department of Mechanical Engineering at St. Joseph University in Tanzania, Dar es Salaam, United Republic of Tanzania, for providing the necessary facilities to conduct this investigation. The authors are also thankful to the Department of Mechanical Engineering, Amrita College of Engineering and Technology, Nagercoil, India for their support.

6. References

[1] W. Gao, Y. Zhang, D. Ramanujan, K. Ramani, Y. Chen, C.B. Williams, C.C.L. Wang, Y.C. Shin, S. Zhang, P.D. Zavattieri, The status, challenges, and future of additive manufacturing in engineering, Comput. Aided Des. 69 (2015) 65–89.

[2] D. Dimitrov, Advances in three-dimensional printing – state of the art and future perspectives, Rapid Prototyp. J. 12 (3) (2006) 136–147.

[3] L.E. Murr, Frontiers of 3D printing/additive manufacturing: from human organs to aircraft fabrication, J. Mater. Sci. Technol. 32 (10) (2016) 987–995.

[4] P. Jiang, Z. Ji, C. Yan, X. Wang, F. Zhou, High compressive strength metallic architectures prepared via polyelectrolyte-brush assisted metal deposition on 3D printed lattices, Nano Struct. Nano Objects 16 (2018) 420–427.

[5] I. Zein, D.W. Hutmacher, K.C. Tan, S.H. Teoh, Fused deposition odelling of novel scaffold architectures for tissue engineering applications, Biomaterials 23 (4) (2002) 1169–1185.

[6] Y. Liu, A Preliminary Research on Development of a Fibre-Composite, Curved FDM System, National University of Singapore, 2008.

[7] S. He, Z. Yu, H. Zhou, Z. Huang, Y. Zhang, Y. Li, J. Li, Y. Wang, D. Li, Polymer tubes as carrier boats of thermosetting and powder materials based on 3D

printing for triboelectric nanogenerator with microstructure, Nano Energy 52 (2018) 134–141.

[8] G. Cicala, G. Ognibene, S. Portuesi, I. Blanco, M. Rapisarda, E. Pergolizzi, G. Recca, Comparison of Ultem 9085 used in fused deposition modelling (FDM) with polytherimide blends, Materials 11 (2) (2018) 285.

[9] X. Zhang, L. Chen, C. Kowalski, T. Mulholland, T.A. Osswald, Nozzle flow behavior of aluminum/polycarbonate composites in the material extrusion printing process, J. Appl. Polym. Sci. 136 (12) (2019) 47252.

[10] R. Singh, P. Bedi, F. Fraternali, I.P.S. Ahuja, Effect of single particle size, double particle size and triple particle size Al2O3 in Nylon-6 matrix on mechanical properties of feed stock filament for FDM, Compos. B Eng. 106 (2016) 20–27.

[11] M. Ramesh, K. Panneerselvam, PLA-based material design and investigation of its properties by FDM, in: M.S. Shunmugam, M. Kanthababu (Eds.), Advances in Additive Manufacturing and Joining, Springer Singapore, Singapore, 2020, pp. 229–241.

[12] L. Chen, X.Z. Zhang, S.Y. Gan, Effects of laser polishing on surface quality and mechanical properties of PLA parts built by fused deposition odelling, J. Appl. Polym. Sci. 137 (3) (2020) 48288.

[13] L. Chen, B. Richter, X. Zhang, X. Ren, F.E. Pfefferkorn, Modification of surface characteristics and electrochemical corrosion behavior of laser powder bed fused stainless-steel 316L after laser polishing, Addit. Manuf. 32 (2020) 101013.

[14] A. Lamikiz, J.A. Sanchez, L.N. Lopez de Lacalle, J.L. Arana, Laser polishing of parts built up by selective laser sintering, Int. J. Mach. Tool Manufact. 47 (12–13) (2007) 2040–2050.

[15] Andó, M., Birosz, M., & Jeganmohan, S. (2021). Surface bonding of additive manufactured parts from multi-colored PLA materials. Measurement, 169, 108583.

[16] Hanon, M. M., & Zsidai, L. (2021). Comprehending the role of process parameters and filament color on the structure and tribological performance of 3D printed PLA. Journal of Materials Research and Technology, 15, 647-660.

[17] Kharmanda, G. (2023). A Review on Uncertainty Cases in Additively Manufactured Polylactic Acid Using Fused Filament Fabrication Technique. Int. J. Addit. Manuf. Struct, 2(1).

[18] L. Gurau, A. Petru, A. Varodi, M.C. Timar, The influence of CO2 laser beam power output and scanning speed on surface roughness and colour changes of beech (fagus sylvatica), BioResources 12 (4) (2017) 7395–7412.

[19] P.-R. Jang, C.-G. Kim, G.-P. Han, M.-C. Ko, U.-C. Kim, H.-S. Kim, Influence of laser spot scanning speed on micro-polishing of metallic surface using UV nano second pulse laser, Int. J. Adv. Manuf. Technol. 103 (1) (2019) 423–431.

[20] Rouf, S., Raina, A., Haq, M. I. U., Naveed, N., Jeganmohan, S., & Kichloo, A. F. (2022). 3D printed parts and mechanical properties: Influencing parameters, sustainability aspects, global market scenario, challenges and applications. Advanced Industrial and Engineering Polymer Research, 5(3), 143-158.

[21] Almeshehe, M., Murad, N., Rahim, M., Ayop, O., Samsuri, N., Aziz, M. A., & Osman, M. (2022). Surface roughness impact on the performance of the 3D metal printed waveguide coupler at millimeterwave band. Engineering Science and Technology, an International Journal, 35, 101129.

[22] Tripathy, C. R., Sharma, R. K., & Rattan, V. K. (2022). Effect of printing parameters on the mechanical behaviour of the thermoplastic polymer processed by FDM technique: A research review. Advances in Production Engineering & Management, 17(3), 279-294.

[23] Peloquin, J., Kirillova, A., Rudin, C., Brinson, L. C., & Gall, K. (2023). Prediction of tensile performance for 3D printed photopolymer gyroid lattices using structural porosity, base material properties, and machine learning. Materials & Design, 232, 112126.

[24] Rouf, S., Malik, A., Raina, A., Haq, M. I. U., Naveed, N., Zolfagharian, A., & Bodaghi, M. (2022). Functionally graded additive manufacturing for orthopedic applications. Journal of Orthopaedics, 33, 70-80.

[25] Khan, I., Tariq, M., Abas, M., Shakeel, M., Hira, F., Al Rashid, A., & Koç, M. (2023). Parametric investigation and optimisation of mechanical properties of thick tri-material based composite of PLA-PETG-ABS 3D-printed using fused filament fabrication. Composites Part C: Open Access, 12, 100392.

[26] Raza, A., Altaf, K., Ahmad, F., Shahed, C. A., & Ahmed, S. W. (2023). Study And Analysis Of Metal Parts Fabricated Through Fused Deposition Modelling, De-Binding And Sintering Processes. Journal of Engineering Science and Technology, 18(2), 827-843.

[27] Fiľko, M., Kessler, J., Semrád, K., & Novotňák, J. (2022). Manufacturing of the Positioning Fixtures for the Security Sensors Using 3D Printing. Transportation Research Procedia, 65, 98-105.

[28] Rao, G. S., Paul, R., Singh, S., & Debnath, K. (2023). Influence of conventionally drilled and additively fabricated hole on tensile properties of 3D-printed ONYX/CGF composites. Journal of Materials Engineering and Performance, 32(13), 5849-5861.

[29] Ojha, K. K., Gugliani, G., & Francis, V. (2022). Impact and tensile performance of continuous 3D-printed Kevlar fiber-reinforced composites manufactured by fused deposition modelling. Progress in Additive Manufacturing, 1-15.

[30] Subramaniyan, M. K., Thanigainathan, S., & Elumalai, V. (2023). Fabrication and mechanical behavior of structurally graded material (ceramic-reinforced polylactic acid/polylactic acid) for integrated engineering application. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 09544089231205791.

[31] Y. Chai, R.W. Li, D.M. Perriman, S. Chen, Q.H. Qin, P.N. Smith, Laser polishing of thermoplastics fabricated using fused deposition modelling, Int. J. Adv. Manuf. Technol. 96 (9–12) (2018) 4295–4302.

[32] K.C. Yung, T.Y. Xiao, H.S. Choy, W.J. Wang, Z.X. Cai, Laser polishing of additive manufactured CoCr alloy components with complex surface geometry, J. Mater. Process. Technol. 262 (2018) 53–64.

[33] T. He, C.Y. Wei, Z.G. Jiang, Y.A. Zhao, J.D. Shao, Super-smooth surface demonstration and the physical mechanism of CO2 laser polishing of fused silica, Opt. Lett. 43 (23) (2018) 5777–5780.

[34] Birosz, M. T., Andó, M., & Safranyik, F. (2021). Layer adhesion test of additively manufactured pins: a shear test. Polymers, 14(1), 55.

[35] Akderya, T. (2023). Effects of Post-UV-Curing on the Flexural and Absorptive Behaviour of FDM-3D-Printed Poly (lactic acid) Parts. Polymers, 15(2), 348.

[36] Medibew, T. M., & Ali, A. N. (2023). Analysis and optimization of FFF process parameters to enhance the mechanical properties of 3D printed PLA products. International Polymer Processing, 38(1), 61-76.

[37] KN, M. R. K., Kishore, G., Lokesh, V., & Mullaivananathan, R. K. (2023). Influence Of The Build Axis And Angle On The Properties Of 3d Printed Pla. Materials and Technology, 57(5), 495-499.