INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING (IJAME)
ISSN: 2229-8649 e-ISSN: 2180-1606
VOL. 19, ISSUE 3, 10028 – 10038
DOI: https://doi.org/10.15282/ijame.19.3.2022.14.0774

ORIGINAL ARTICLE

Investigation of Fused Deposition Modelling Process Parameters in 3D Printing for Composite Material (Poly Lactic Acid and Banana Fibre)

R. Patel, V. Z. Dhimmar, S. A. Kagzi*, and M. R. Patel

S. N. Patel Institute of Technology and Research Center, Umrakh, Bardoli, 394601 Gujarat, India

ABSTRACT – Additive manufacturing is gaining popularity nowadays due to its applications in the automotive, medical, aerospace industries, and sports to manufacture complex parts. Fused deposition modelling is an additive manufacturing process utilised widely due to its lower cost, fast prototyping and faster production time. The present study focuses on applying FDM to the composite material filament and the impact of parameters of FDM on the part quality. A composite filament material was prepared to combine PLA (Poly-lactic Acid) and banana fibre. Specimens were prepared using this composite filament by varying various parameters such as layer thickness, infiltration and build orientation. Flexural and tensile tests were performed as per standards. It was found that the material properties considered are significantly affected by percentage infill and build orientation. The 'on edge' build orientation provides better material properties as compared to the other two orientations. The tensile strength is observed to be 73% and 77% more in flat orientation and 'on edge' orientation, respectively, as compared to upright orientation. Also, the flat orientation and 'on edge' orientation respectively showed 60% and 70% more flexural strength than the upright orientation.

ARTICLE HISTORY
Received: 18th May 2022
Revised: 21st Sept 2022
Accepted: 30th Sept 2022
Published: 8th Nov 2022

KEYWORDS
Fused deposition;
Tensile strength;
Flexural strength;
Modulus of elasticity;
Percentage elongation

INTRODUCTION

As compared to the material removal process, such as machining, additive manufacturing (AM) adds the material layer by layer to form a replica of a three-dimensional model [1]. It also eliminates the use of costly dies and moulds. These techniques are useful when customisation is required. AM is used in many industrial applications, including medical, civil, automotive and aerospace industries [2]. Some of the intentions of this process are to manufacture complex shapes and quick prototyping with improved mechanical properties. With the AM process, the mechanical properties are mainly affected by raster orientation, layer thickness, nozzle temperature and building orientation. Fused deposition modelling (FDM) is one of the AM processes where three-dimensional modelling can be obtained mainly using polymer filaments. The schematic diagram of FDM process is shown in Figure 1. The filament is wound on the spool and mounted on the machine. Through a mechanism provided, the nozzle can be moved to a plane to deposit a layer at the desired location on a printing bed. After the deposition of a layer, the bed can be lowered as per the requirement to print another layer. The filaments are extruded through the nozzle after being heated, following the controlled path, to deposit material layer by layer forming the required shape [2,3].

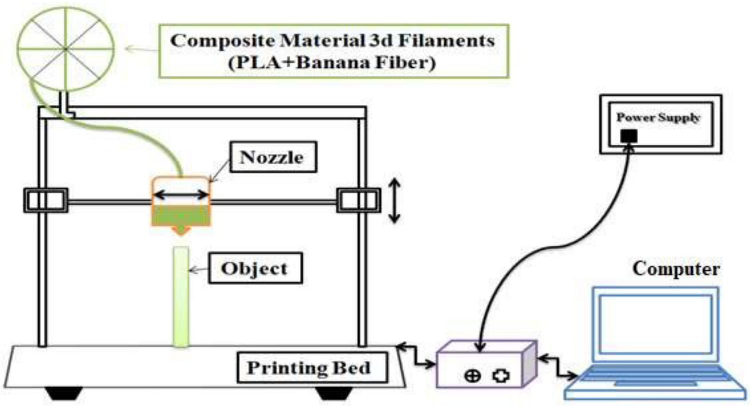


Figure 1. Schematic diagram of FDM.

Many works have been reported on the dimensional accuracy, mechanical properties and surface characteristics of polymers such as Polycarbonate (PC) and Acrylonitrile butadiene styrene (ABS) [4] considering different parameters of FDM. Singh and Gupta [5] found that the flexural strength and tensile strength of acrylonitrile butadiene styrene (ABS) are maximum at 240 °C printing temperature and 0.08 layer thickness. Rankouhi et al. [6] reported work on ABS and

*CORRESPONDING AUTHOR | S. A. Kagzi | shakil128@gmail.com

reported that its properties are greatly affected by layer thickness and orientation. Kamoona et al. [7] reported that the flexural strength of Nylon 12 is significantly affected by an air gap and raster angle. Three-dimensional printing of Z Corp.'s ZP102 powder and Zb56 binder was carried out by Vaezi et al. [8] and they reported that with the rise in the binder saturation level from 90% to 125%, the properties such as flexural and tensile strength increases, but the dimensional accuracy decreases.

In regards to PLA, Vălean et al. [1] studied FDM on poly-lactic acid (PLA) and observed decreased tensile strength and modulus of elasticity with an increase in the number of layers. Bardiya et al. [9] examined the effect of orientation of the part, infill, and layer height on the flexural strength and tensile of PLA. They found that an increase in the infill and layer thickness increases strength. Higher tensile and flexural strength were observed at an Infill of 80%. García et al. [10] applied FDM on PLA and studied the effect of extruder movements, feed rate and build orientation on the flatness, surface texture and accuracy. It was found that lowering the layer thickness increases dimensional accuracy, whereas feed rate has a minor influence on accuracy. Khan et al. [11] reported that the rectilinear infill pattern gives maximum tensile and flexural strength of PLA. Yao et al. [12] showed that the strength of PLA increases as the printing angle increases and layer thickness decreases. Rajpurohit et al. [13] found that the maximum strength of PLA was achieved at a raster angle of 0°. They also noted the reduction in layer thickness results in rising in the strength. They reported that strength gets improves with the increase in raster width to some extent, but due to the presence of voids, it decreases at higher raster width. Akhoundi et al. [14], through their extensive work on PLA, reported that the filling pattern and infill percentage greatly affect the mechanical properties of printed products. They found the highest strength with the concentric pattern of filling. Birosz et al. [15] studied the bending performance of printed specimens with novel infill patterns, viz., grid, honeycomb and gyroid.

Thus, considerable work has been reported for PLA and other pure polymers, but work on the composites fibre is found to be scarce. Lamberti et al. [16] reported the effect of graphene nanoparticles and carbon nanotubes on the conductivity of PLA-Graphene and PLA-carbon nanotube composites, respectively. Using PLA-Graphene nanoparticle composite, the mechanical properties of 3D-printed parts were determined by Caminero et al. [17]. They noted the reduction in impact strength and the rise in shear strength due to the addition of these nanoparticles. They noted the best performance in upright build orientation. In regards to biodegradable polymers, a study on fibre orientation and its size were made by Pannu et al. [18] for PLA/banana fibre composite material. The demands of agencies for environmental protection were fulfilled by a green composite fibre prepared by Shih and Huang [19]. They prepared a composite from banana fibre and PLA by the melt blending method. They noted that the addition of banana fibre to PLA causes a rise in mechanical properties and thermal stability. Solomon et al. [20] also recommended that in addition to the conventional process parameters, the different material combinations, composites of metal and conventional materials are used for 3D printing. In the present work, the composite fibre was prepared with PLA and natural banana fibre. This fibre was utilised for the formation of specimens using FDM. Mechanical properties of the prepared specimen were tested, and results are reported in the subsequent section.

PREPARATION OF FIBER

For the present study, 3D 850 PLA pallets were used as this grade reveals quicker crystallisation rates and develops better heat resistance in printed parts (Ingeo biopolymer technical data sheet, [24]). The thermal contraction of PLA 3D850 is less, has good adhesion, and its mechanical properties are better than traditional PLA. Hence, this makes it ideal for accuracy, resolution, and good performance of 3D printed parts [16, 17]. The chopped and dried banana fibres were pulverised and used for the preparation of PLA/ banana fibre composite filaments through the extrusion process. Figure 2 shows the extrusion line of a filament. In a hopper, 3D 850 PLA pellets and pulverised banana fibre were taken, dried to remove moisture and extruded at a temperature of 180°C. For the ratio of 60:40 of PLA and banana fibre, respectively, the mechanical properties of this composite fibre were found to be the maximum [19]. For the present study, this composition was considered. A screw extruder was used to extrude the composite fibres with a nozzle diameter of 1.75mm. After extruding the filament was passed through a vacuum chamber for sizing and then a water tank for cooling. The filament was pulled through pull-out assembly and finally wound in a spool. This spool was later mounted on a 3D printing machine for printing specimens.

To improve the fluidity and the toughness of the materials, a toughening agent, polyolefin elastomer (POE) and a lubricant (TPW604) were used. POE fills the voids left by banana fibre powder in PLA. It increases banana fibre powder and PLA interface compatibility [18]. The mechanical properties of this composite fibre were tested as per ISO 527 and ISO 178 [25, 26]. Table 1 shows the properties of the material.

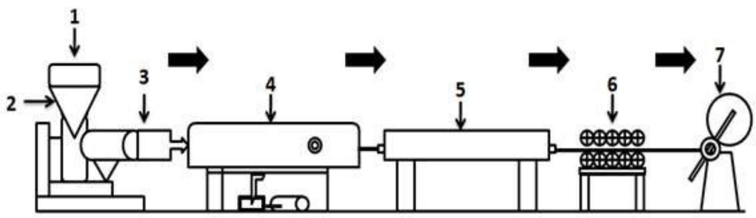


Figure 2. Extrusion line of the PLA-banana fibre composite filament (1. hopper, 2. dryer, 3. extruder, 4. Vacuum sizing chamber, 5. Water cooling tank, 6. Pull-out assembly, 7. Spool).

Table 1. Mechanical properties of composite fibre.

Tensile strength (MPa)	Modulus of elasticity (MPa)	Percentage elongation	Flexural strength (MPa)	Flexural modulus (MPa)
47	2900	6.5	64	2950

PREPARATION OF SPECIMEN

The mechanical properties of the product made from PLA/banana fibre composite filament were determined through FDM, where the test specimens were prepared. The CAD models of the specimen were made as per the standard dimensions and converted to STL format. This format was used by custom machine programming for printing the specimen layer by layer. Finally, the cleaning was carried out as post-processing after the completion of printing. Three different positions were taken into consideration for the build orientation through FDM. These positions are shown in Figure 3. Percentage infill is the amount of material that is internally occupied during printing. Table 2 shows the levels of each factor to find the effect of these factors on responses. All specimens were prepared through the inline infill pattern, as shown in Figure 4.

Table 2. Levels of different factors considered for the preparation of the specimens.

Parameter	Units	Level-1	Level-2	Level-3
Build Orientation	-	Flat	On-Edge	Up-right
Infill	(%)	40	60	80
Layer Thickness	(mm)	0.12	0.16	0.20

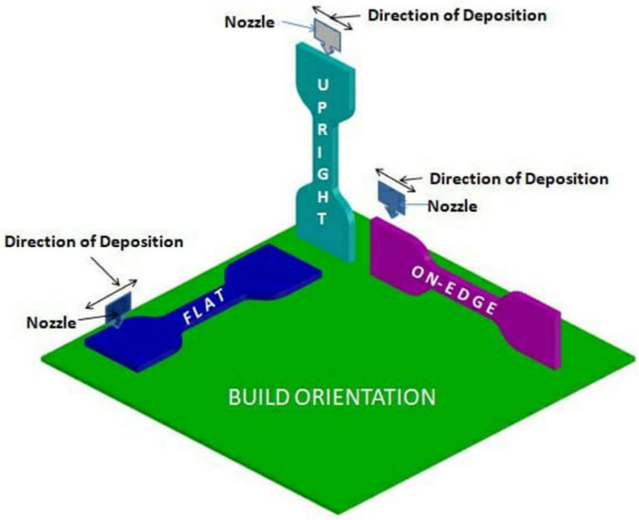


Figure 3. Different build orientations of the specimen preparation and direction of deposition.

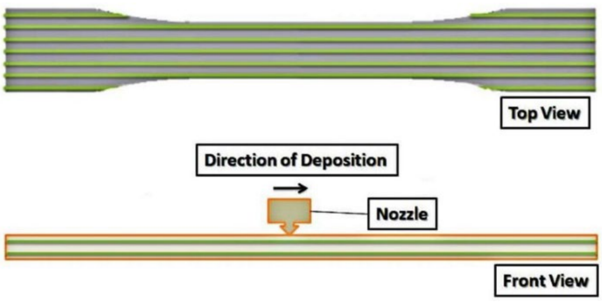


Figure 4. Inline infill pattern used for the preparation of the specimen.

The thickness of a deposited material during the formation of each layer is termed as layer thickness. The levels of infill (%) control the internal defects in the printed parts. A too low value of infill will result in to structure with internal defects while 100% infill results in to excessive material consumption [21]. Hence, the levels of infill are selected as 40%, 60% and 80%. The thickness of a deposited material during the formation of each layer is termed as layer thickness. Sood et al. [22] reported that by increasing the value of layer thickness the residual stresses are reduced and improved mechanical properties can be achieved. Hence, the level of layer thickness should not be below and above the critical value to achieve good mechanical properties of the specimen [20].

The specimens were prepared through FDM, based on the L27 orthogonal array considering the levels of the factors as shown in Table 2. The dimensions of the specimen for the tensile and flexural tests were kept as per ASTM D638 and

ASTM D790 standards, respectively. Figure 5(a) and 5(b) show the twenty-seven specimens prepared, with different combinations of factors.

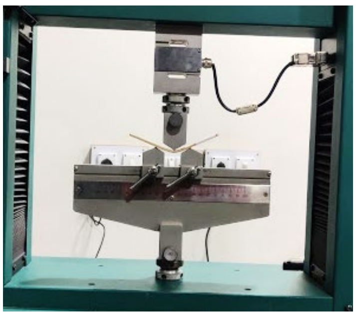
(a)

(b)

Figure 5. (a) Tensile test specimen and (b) flexural test specimen prepared considering L27 orthogonal array.

MECHANICAL TESTING

For the tensile and flexural tests, the specimens were prepared and tested as per ASTM D638 and ASTM D790. A universal tensile testing machine (Model: Tinius Olsen/L-series H50kl) was used for performing these experiments. Tests were performed at a speed of 5mm/min. The tensile testing and the flexural testing for one of the specimens are shown in Figures 6(a) and 6(b) respectively. The results and the analysis are discussed in a subsequent section.

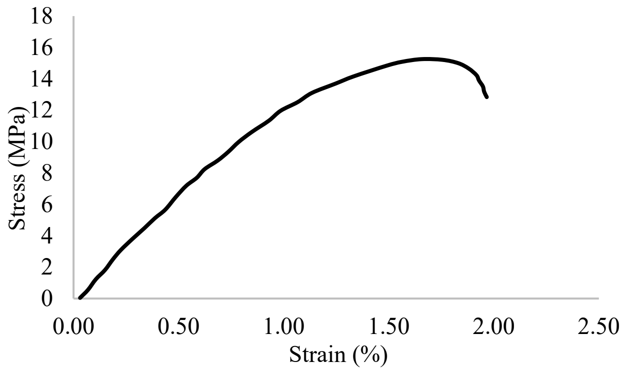


(a) (b)

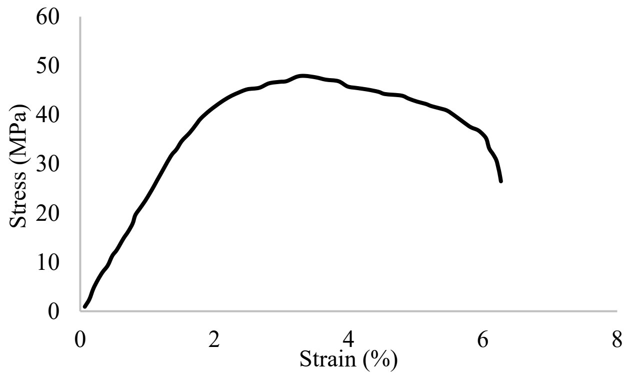
Figure 6. (a) Tensile test performed on specimen to determine the modulus of elasticity, percentage elongation and tensile strength and, (b) flexural test performed on specimen to determine flexural strain and flexural strength.

RESULT AND DISCUSSION

The specimens were prepared and tested, considering different levels of combinations of the factors (in Table 1) as per the L27 orthogonal array. The true stress-strain curve obtained through the tensile test of one of the specimens (serial number 6, Appendix I) is shown in Figure 7(a). Percentage elongation is taken as the percentage strain at the maximum stress obtained during the experiment. The tensile strength was considered to be the maximum stress obtained during testing. Modulus of elasticity was obtained as the slope of the line in the elastic region.



(a)



(b)

Figure 7. (a) Stress-strain curve obtained from (a) tensile test of a specimen (Serial number 6, Appendix I) with a percentage infill of 60%, layer thickness of 0.20 mm and flat type build orientation, and (b) flexural testing of a specimen (Serial number 10, Appendix II) with a percentage infill of 40%, layer thickness of 0.12 mm and 'on edge' type build orientation.

The stress-strain curve obtained during the flexural test of one of the specimens (Serial number 10, Appendix II) is shown in Figure 7(b). The maximum stress reached in the stress-strain curve is taken as the flexural strength. The flexural strain is taken as the percentage strain where the flexural strength is reached. The different level combinations of the factors and their corresponding results for the flexural and tensile test are shown in Table 8 and Table 9 of the Appendices, respectively.

The Analysis of Variance (ANOVA) of the results for the modulus of elasticity is shown in Table 3. It is seen that the layer thickness does not have a significant effect on the modulus of elasticity as P-value is much greater than 0.05 for 95% of the confidence interval. However, the infill percentage and the build orientation have a significant effect on the modulus of elasticity. Figure 8 shows the main effect plot of the modulus of elasticity obtained during the tensile testing. The modulus of elasticity is found to increase with the rise in the infill percentage. While during 'on edge' build orientation, the modulus of elasticity is found to be maximum. The maximum value of modulus of elasticity is observed in the sixteenth experiment (Appendix I), having a maximum infill percentage (80%) with an 'on edge' position.

Table 3. ANOVA analysis for the modulus of elasticity during tensile testing.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Infill	2	656916	328458	6.45	0.007
Layer thickness	2	66143	33071	0.65	0.533
Build orientation	2	2507151	1253576	24.63	0.000
Error	20	1017732	50887		
Total	26	4247942			

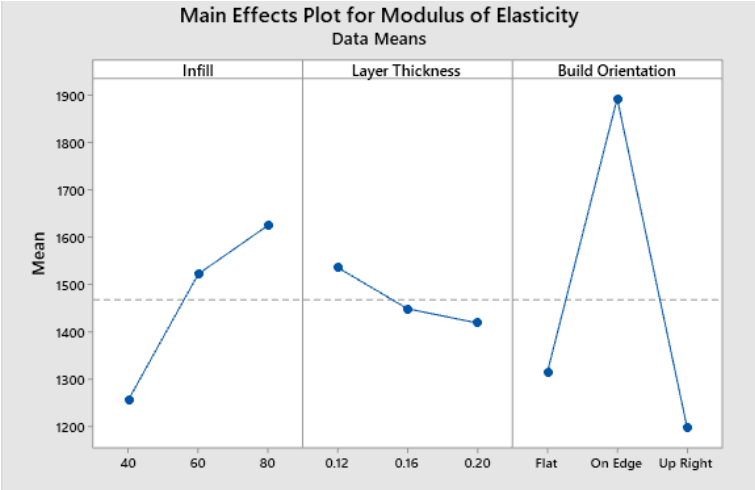


Figure 8. Main effect plot of the modulus of elasticity (MPa) with respect to infill (%), layer thickness (mm), and build orientation.

The analysis for percentage elongation and tensile strength is shown in Table 4 and Table 5, respectively. Similar to the case of modulus of elasticity, for percentage elongation as well as tensile strength, the layer thickness is found to be insignificant. While, the infill percentage and the build orientation have a significant effect on these two responses. From Figure 9 and Figure 10, it is seen that the tensile strength as well as percentage elongation increases with the rise in the infill percentage. These results are in line with the results reported by Yu et al. [21]. Percentage elongation is found to be maximum in the seventh experiment (Appendix I) with 80% infill and flat orientation, while the tensile strength is found to be maximum in the sixteenth experiment (Appendix I) with 80% infill and ‘on edge orientation’. Thus, percentage elongation was found to be greater for the flat position as compared with the other two positions. While, maximum tensile strength is obtained for the ‘on edge’ position.

Table 4. ANOVA analysis for the percentage elongation during tensile testing.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Infill	2	0.7055	0.35273	4.63	0.022
Layer thickness	2	0.0034	0.00170	0.02	0.978
Build orientation	2	9.7913	4.89567	64.24	0.000
Error	20	1.5242	0.07621		
Total	26	12.0244			

Table 5. ANOVA analysis for the tensile strength during tensile testing.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Infill	2	223.31	111.654	19.21	0.000
Layer thickness	2	2.18	1.091	0.19	0.830
Build orientation	2	1286.48	643.240	110.66	0.000
Error	20	116.26	5.813		
Total	26	1628.22			

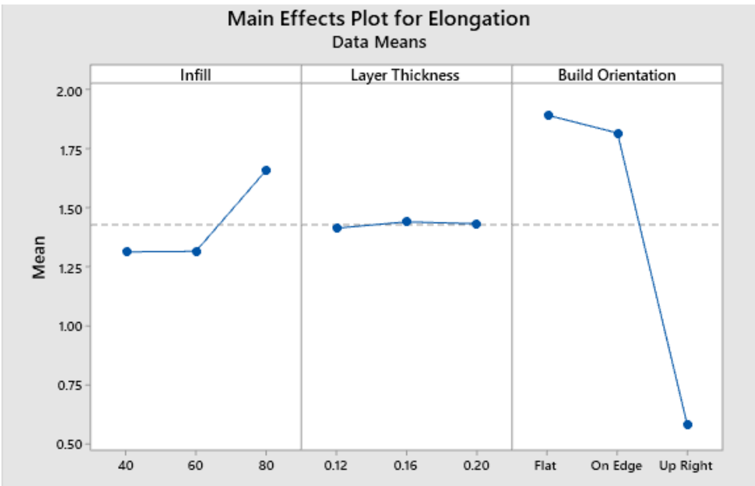


Figure 9. Main effect plot of the percentage elongation (%) with respect to infill (%), layer thickness (mm) and build orientation.

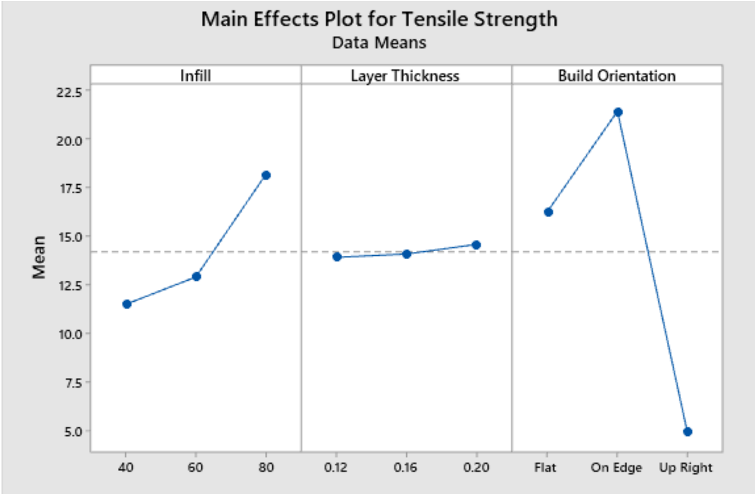


Figure 10. Main effect plot of the tensile strength (MPa) with respect to infill (%), layer thickness (mm) and build orientation.

Figure 11 and Figure 12 show the main effect plot of flexural strain and flexural strength with respect to considered parameters. Table 6 and 7 shows the ANOVA analysis of flexural strain and flexural strength respectively. It is seen that layer thickness does not have a significant effect on flexural strength as well as flexural strain as the P-value is greater than 0.05. While, infill and the build orientation have a significant effect on both properties. Out of these three factors, build orientation has the maximum effect on these two properties, which can be noted from the maximum F-Value. Flexural strain is found to be having a maximum value in the seventh experiment (Appendix II) with 80% infill with flat orientation. While flexural strength is found to be having a maximum value in the sixteenth experiment (Appendix II) with a maximum infill of 80% and 'on edge' orientation. From the result, it can be seen that flat orientation showed 73% and on edge orientation showed 77% more tensile strength as compared to the upright orientation. The results of flexural strength are 70% more in 'on edge' position and 60% more in flat orientation compared to upright orientation. Thus upright orientation is found to be the least effective for all parameters.

The amount of the printing material (PLA-banana fibre composite) increases with an increase in the percentage infill, resulting in a more dense structure at a higher infill percentage. This results in the enhancement of the material properties such as modulus of elasticity, percentage elongation and tensile and flexural strength. However, it is seen that all these three properties obtained during the test by varying the infill or the build orientation are less than the properties of composite filament (Table 1). In composite filament, the infill can be taken as 100 per cent. In an experiment, the amount of the material (with different infill percentages) is less than 100 per cent. Hence the properties are found to have a low value compared with the filament.

The maximum value of flexural strength, modulus of elasticity as well as tensile strength are found in the 'on edge' build orientation (Figures 8, 10, and 13). This observation can also be concluded from the experimental results in Appendix I and II. In 'on edge' build orientation, the area that needs to be covered in a layer is less than that of flat orientation (refer to Figure 3). Therefore, the deposition of the material of another layer occurs before the previous layer gets completely solidified. This results in better bonding between the two layers and hence better flexural and tensile strength as well as modulus of elasticity in an 'on edge' position as compared with a flat position.

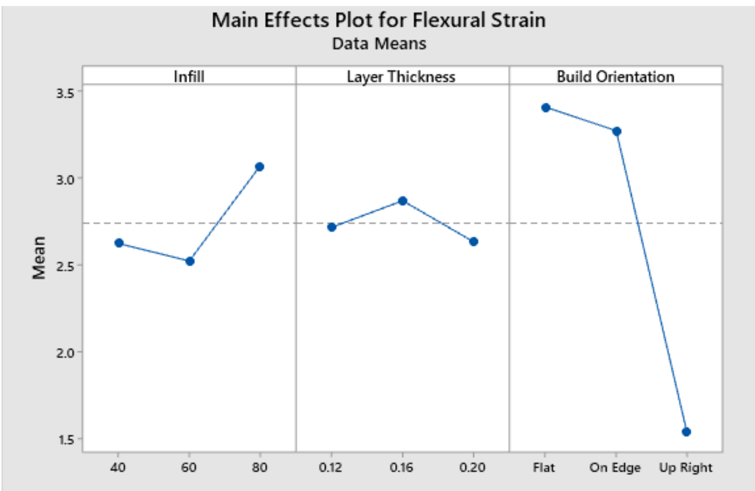


Figure 12. Main effect plot of the flexural strain with respect to infill (%), layer thickness (mm) and build orientation.

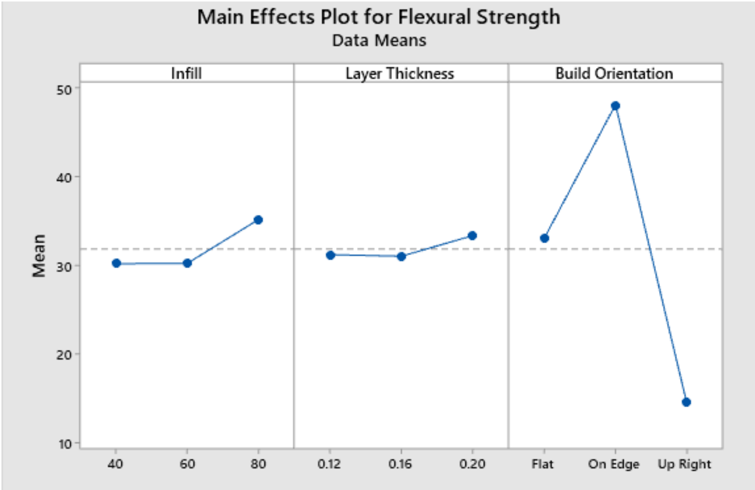


Figure 13. Main effect plot of the flexural strength (MPa) with respect to infill (%), layer thickness (mm) and build orientation.

Table 6. ANOVA analysis for the flexural strain during flexural testing.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Infill	2	1.5294	0.7647	6.38	0.007
Layer Thickness	2	0.2615	0.1308	1.09	0.355
Build Orientation	2	19.6563	9.8281	82.04	0.000
Error	20	2.3959	0.1198		
Total	26	23.8431			

Table 7. ANOVA analysis for the flexural strength during flexural testing.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Infill	2	148.02	74.01	9.53	0.001
Layer Thickness	2	30.07	15.03	1.94	0.170
Build Orientation	2	5102.06	2551.03	328.36	0.000
Error	20	155.38	7.77		
Total	26	5435.52			

For the build orientation of ‘on edge’ and flat orientation, the load is shared by the deposited layer as well as the bounding region between the two deposited layers. Therefore, the variation of modulus of elasticity in flat and ‘on edge’ build orientation is very small (Figure 8). As the bonding region would be more in ‘on edge’ build orientation as compared to the flat, the region of a layer remains smaller as compared to flat build orientation. This may be the reason for flexural strength being slightly higher in flat orientation as compared to ‘on edge’ orientation. In addition to this, the “on edge” orientation yields a smaller number of voids between the printed rows. Hence, this orientation results in low volumetric errors resulting in improved mechanical properties of specimens [23]. Similar nature of results for tensile properties of specimens was observed by Reddick et al. [23] in which the SEM images were analysed to reach this conclusion.

When the specimen is made through upright build orientation, the specimen would be loaded in the transverse direction (perpendicular to the layer deposition). As compared with other positions, though the deposition area for a layer in the upright position is lesser, the tensile and flexural properties are found to be having lower value in this position. This shows that the material would be weak in the transverse direction. The failure of the materials occurs at the bond between the two layers rather than within the deposited layer. This results in the weakening of the material in an upright build orientation. Thus the amount of the material can be reduced by changing the infill percentage, which will have an impact on the strength. The infill percentage can be set to a level where the minimum requirement of the strength is satisfied. At the same time, the ‘on edge’ build orientation may be selected to have better material properties at a particular infill percentage level.

CONCLUSION

A tensile test, as well as the flexural test, have been performed on the PLA-banana fibre composite specimen. These specimens were prepared at the different combinations of the factors such as layer thickness, build orientation and infill percentage. In comparison to the upright orientation, the flat orientation showed 73% and on edge orientation showed 77% more tensile strength. Similarly, in comparison to the upright orientation, the flat orientation showed 60% and ‘on edge’ orientation showed 70% more flexural strength. The maximum tensile strength and modulus of elasticity found are 28 MPa and 2380 MPa respectively, at maximum infill (80%) with ‘on edge’ orientation, While the maximum percentage elongation observed was 2.76 at maximum infill with flat orientation. The highest value of flexural strength of 56.1 MPa was observed at ‘on edge’ orientation, and a maximum flexural strain of 4.49% was observed at flat orientation. Thus, The infill percentage is significant for all the considered parameters and the results are better at maximum infill. The build orientation is found to be a significant parameter, with 'on edge' to most favourable for tensile strength, flexural strength and modulus of elasticity. The upright orientation is found to be the least effective. Thus layer thickness is found to be insignificant for all the responses. An increase in infill percentage will give better material properties but it causes a rise in material consumption. The level of infill percentage may be set for the required properties. The build orientation of 'on edge' gives better properties as compared to the other two orientations. Therefore, the 'on edge' orientation may be used for a particular infill percentage for obtaining better properties for PLA-banana composite fibre. In the present manuscript, encouraging results regarding the combination of PLA-banana fibres are reported. However, more material combinations along with more process parameters can be explored to enhance the properties of printed specimens.

ACKNOWLEDGEMENT

Authors appreciate and acknowledge the valuable support provided by Dream Polymers, Ahmedabad and Yantrah Edutech Solutions Pvt. Ltd., Surat for the manufacturing of composite filament and its 3D printing

REFERENCES

[1] C. Vălean *et al.*, "Effect of manufacturing parameters on tensile properties of FDM printed specimens," *Procedia Struct. Integr.,* vol. 26, pp. 313–320, 2020, doi: 10.1016/j.prostr.2020.06.040.

[2] S.H. Masood, "Intelligent rapid prototyping with fused deposition modelling," *Rapid Prototyp. J.,* vol. 2, no. 1, pp. 24-33, 1996, doi: 10.1108/13552549610109054.

[3] S. Bardiya, J. Jerald, and V. Satheeshkumar, "The impact of process parameters on the tensile strength, flexural strength and the manufacturing time of fused filament fabricated (FFF) parts," *Mater. Today: Proc.,* vol. 39, no. 4, pp. 1362–1366, 2020, doi: 10.1016/j.matpr.2020.04.691.

[4] O.A. Mohamed, S.H. Masood, and J.L. Bhowmik, "Optimisation of fused deposition modeling process parameters: a review of current research and future prospects," *Adv. Manuf.,* vol. 3, pp. 42–53, 2015, doi: 10.1007/s40436-014-0097-7.

[5] R. Singh, and AK. Gupta, "Analysis of mechanical properties of 3D printed ABS parts by varying process parameters," *Int. J. Latest Trends Eng. Technol.,* vol. 9, pp. 252–256, 2018, doi: 10.21172/1.94.39.

[6] B. Rankouhi, S. Jvadpour, F. Delfanian, and T. Letcher, "Failure analysis and mechanical characterisation of 3D Printed ABS with respect to layer thickness and orientation," *J. Fail. Anal. Prev.,* vol. 16, pp. 467–481, 2016, doi: 10.1007/s11668-016-0113-2.

[7] S.N. Kamoona, S.H. Masood, and O.A. Mohamed, "Experimental investigation on flexural properties of FDM processed Nylon 12 parts using RSM," *IOP Conf. Ser.: Mater. Sci. Eng.,* vol. 377, pp. 1-6, 2018, doi: 10.1088/1757-899X/377/1/012137.

[8] M. Vaezi, and C.K. Chua, "Effects of layer thickness and binder saturation level parameters on 3D printing process," *Int. J. Adv. Manuf. Technol.,* vol. 53, pp. 275–284, 2011, doi: 10.1007/s00170-010-2821-1.

[9] S. Bardiya, J. Jerald, and V. Satheeshkumar, "The impact of process parameters on the tensile strength, flexural strength and the manufacturing time of fused filament fabricated (FFF) parts," *Mater. Today: Proc.,* vol. 39, pp. 1362–1366, 2021, doi: 10.1016/j.matpr.2020.04.691 .

[10] G.E. Plaza, P.N.J. López, M.A.C. Torija, and J.M.C. Muñoz, "Analysis of PLA geometric properties processed by FFF additive manufacturing: Effects of process parameters and plate-extruder precision motion," *Polymers* vol. 11, p. 1581, 2019, doi: 10.3390/polym11101581.

[11] S.F. Khan *et al.*, "Effect of infill on tensile and flexural strength of 3D printed PLA parts," *IOP Conf. Ser.: Mater. Sci. Eng.,* vol. 429, pp. 1-6, 2018, doi: 10.1088/1757-899X/429/1/012101.

[12] T. Yao *et al.*, "Tensile failure strength and separation angle of FDM 3D printing PLA material: Experimental and theoretical analyses," *Compos. B. Eng.,* vol. 188, no. 1, p. 107894, 2020, doi: 10.1016/j.compositesb.2020.107894.

[13] S.R. Rajpurohit, and H.K. Dave, "Effect of process parameters on tensile strength of FDM printed PLA part," *Rapid Prototyp. J.,* vol. 24, no.8, pp. 1317-1324, 2018, doi: 10.1108/RPJ-06-2017-0134 .

[14] B. Akhoundi, and A.H. Behravesh, "Effect of filling pattern on the tensile and flexural mechanical properties of FDM 3D printed products," *Exp. Mech.,* vol. 59, pp. 883–897, 2019, doi: 10.1007/s11340-018-00467-y.

[15] M.T. Birosz, D. Ledenyák, and M. Andó, "Effect of FDM infill patterns on mechanical properties," *Polym. Test.,* vol. 113, p.107654, 2022.

[16] P. Lamberti, "Evaluation of thermal and electrical conductivity of carbon-based PLA nanocomposites for 3D printing," *AIP Conf. Proc.,* vol. 1981, p. 020158, 2018, doi: 10.1063/1.5046020

[17] M.A. Caminero *et al.*, "Additive manufacturing of pla-based composites using fused filament fabrication: effect of graphene nanoplatelet reinforcement on mechanical properties, dimensional accuracy and texture," *Polymers*, vol. 11, no. 5, p. 799, 2019, doi: 10.3390/polym11050799.

[18] A.S. Pannu, and S.A. Singh, "Review paper on biodegradable composites made from banana fibers," *Asian Journal of Engineering and Applied Technology* (AJEAT) vol. 7, pp. 7–15, 2018.

[19] YF. Shih, and CC. Huang, "Polylactic ac[id (PLA)/banana fiber (BF) biodegradable green composites," *J. Polym. Res.,* vol. 18, pp. 2335–2340, 2011, doi: 10.1007/s10965-011-9646-y.

[20] I.J. Solomon, P. Sevvel, and J. Gunasekaran, "A review on the various processing parameters in FDM. *Mater. Today: Proc.,* vol. 37, pp. 509-514, 2021.

[21] Z. Yu *et al.*, "Study on effects of FDM 3D printing parameters on mechanical properties of polylactic acid," In *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 688, no. 3, p. 033026, 2019.

[22] A.K. Sood, R.K. Ohdar, and S.S. Mahapatra,. "Parametric appraisal of mechanical property of fused deposition modelling processed parts," *Mater. Des.*, vol. 31, no.1, pp.287-295, 2010.

[23] J.C. Riddick *et al.*, "Fractographic analysis of tensile failure of acrylonitrile-butadiene-styrene fabricated by fused deposition modeling," *Addit. Manuf.,* vol. 11, pp.49-59, 2016.

[24] Ingeo biopolymer 3d850 technical data sheet 3d printing monofilament – high heat grade. Mar. 25, 2019 [Online]. Available: https://www.natureworksllc.com [Accessed Oct. 25, 2020]
[25] International Organization for Standardization, "Plastics - Determination of tensile properties." ISO 527-1:2019, July 2019.
[26] International Organization for Standardization "Plastics - Determination of flexural properties." ISO 178:2019, April 2019.

APPENDICES

Table 8. Results of tensile test in terms of modulus of elasticity, % elongation and tensile strength.

Sr. No.	Infill (%)	Layer thickness (mm)	Build Orientation	Modulus of elasticity	Sr. No.	Infill (%)
1	40	0.12	Flat	1210	1.98	12.6
2	40	0.16	Flat	1250	1.41	12.1
3	40	0.20	Flat	1200	1.42	12.9
4	60	0.12	Flat	1370	1.49	12.7
5	60	0.16	Flat	1450	1.67	13.9
6	60	0.20	Flat	1290	1.63	15.3
7	80	0.12	Flat	1420	2.76	23.5
8	80	0.16	Flat	1270	2.42	21.1
9	80	0.20	Flat	1360	2.24	22.3
10	40	0.12	On Edge	1820	1.75	18.2
11	40	0.16	On Edge	1190	1.88	17
12	40	0.20	On Edge	1230	1.8	17.5
13	60	0.12	On Edge	1950	1.72	19.6
14	60	0.16	On Edge	1970	1.64	19.4
15	60	0.20	On Edge	1980	1.79	19.5
16	80	0.12	On Edge	2380	1.9	28
17	80	0.16	On Edge	2270	1.91	26.7
18	80	0.20	On Edge	2250	1.95	26.9
19	40	0.12	Up Right	1440	0.281	3.59
20	40	0.16	Up Right	998	0.715	5.21
21	40	0.20	Up Right	960	0.578	4.4
22	60	0.12	Up Right	1170	0.37	3.63
23	60	0.16	Up Right	1300	0.772	5.81
24	60	0.20	Up Right	1220	0.752	6.32
25	80	0.12	Up Right	1060	0.465	3.42
26	80	0.16	Up Right	1340	0.54	5.56
27	80	0.2	Up Right	1280	0.725	6.15

Table 9. Results of flexural test in terms of flexural modulus, flexural strength and tensile strain.

Sr. No.	Infill (%)	Layer thickness (mm)	Build orientation	Flexural strain (%)	Flexural strength (MPa)
1	40	0.12	Flat	3.26	28.3
2	40	0.16	Flat	3.39	29.4
3	40	0.20	Flat	3.17	33.6
4	60	0.12	Flat	3.05	28.3
5	60	0.16	Flat	3.38	29.4
6	60	0.20	Flat	3.15	33.6
7	80	0.12	Flat	4.49	34.7
8	80	0.16	Flat	3.60	36.7
9	80	0.20	Flat	3.20	43.0
10	40	0.12	On Edge	3.20	47.2
11	40	0.16	On Edge	3.42	44.0
12	40	0.20	On Edge	2.80	47.0
13	60	0.12	On Edge	2.97	46.2
14	60	0.16	On Edge	2.69	44.1
15	60	0.20	On Edge	2.94	45.1
16	80	0.12	On Edge	3.74	56.1
17	80	0.16	On Edge	4.35	51.4
18	80	0.20	On Edge	3.35	51.4
19	40	0.12	Up Right	1.29	13.6
20	40	0.16	Up Right	1.48	13.6
21	40	0.20	Up Right	1.61	14.7
22	60	0.12	Up Right	1.23	13.6
23	60	0.16	Up Right	1.63	14.7
24	60	0.20	Up Right	1.67	16.8
25	80	0.12	Up Right	1.22	12.6
26	80	0.16	Up Right	1.89	15.7
27	80	0.2	Up Right	1.80	14.7