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Effect of Infill Density and Infill Pattern on the Compressive Strength of Parts Printed by PLA Filament using FDM

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Abstract*: The field of additive manufacturing is growing and discoveries are being made. The 3D printing machines are also being developed to accommodate a wider range of 3D printing materials, including plastics, metals (metal AM powders), composites, filaments, and other materials. There are numerous printing materials available for industrial additive manufacturing. Such materials have their unique characteristics, advantages, and disadvantages. In order to avoid errors in Additive Manufacturing, key elements such as 3D printing material type, texture, cost, printing technique and procedure, and so on must be examined. It can be complex to select the best material for a particular job. PLA (Polylactic acid) is made from sugar cane or cornstarch, both of which are renewable resources. "Black plastic" is another name for it. Because it is safe to use and print, it is frequently used in primary and secondary schools. This is also how FDM screen printing is done. PLA is simple to print because of its low warping impact. It's also possible to print it on a cold surface. When opposed to ABS, it allows for sharper edges and features to be printed. This material comes in a wide range of colours. Polylactic acid (PLA) is the most common material used in fused deposition modelling (FDM). PLA can be used to print a wide range of components including medical implants, household items, and mechanical parts. The mechanical behaviour of the printed item is affected by variations in infill pattern are subjected to compressive tests in the current investigation to examine their behaviour under compressive stresses.

***Keywords*: Fused Deposition Modelling (FDM), Polylactic Acid (PLA), Infill Density, Infill Pattern, Compressive Strength**

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I. Introduction

One of the most significant advantages of 3D printing technology is the ability to produce components with various infill geometries and patterns. Not only does this save material, but it also lowers the overall component cost. Biostructure [1], scaffold constructions [2], micro fabrication [3], light weight UAV (unmanned aerial vehicles) [4], and design of police whistles [5] have all benefited from the 3D printing technique. This method is also employed to investigate the compressive and tensile properties of Natural Sand Stone [6]. Several previous studies have revealed that this approach can be utilized to print a wide range of polymers [7] and composites [8], as well as multi-nozzle extrusion printing [9], [10]. This technique can also print pieces with varying densities [11] and other types of infill generation [12][22]. A review of previous research shows that printing orientation, density, and filler pattern [13], layer thickness and raster angle [14], [15], [16], [3] have a significant impact on mechanical performance of parts such as compressive performance [13], fatigue performance [17], surface roughness tensile strength [18], [19], and maximum flexure properties [20], [21]. This approach can also be connected with design and production data, according

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to the research [1]. According to studies, the most important 3D printing parameters are the layer thickness, infill density, and heat treatment [23, 24]. Other studies showed how to optimize the parameters in the Fused Deposition Modeling (FDM) process to increase accuracy and efficiency [25, 26]. The air gap has a significant impact on the wear strength of an FDM-fabricated component [27]. Additionally, the performance of FDM printed parts was examined in relation to other process factors, including building orientation [28, 29] and raster angle [30, [31], [32]. Additionally, it was discovered that the raster angle has less of an impact than print orientation [33].

Additionally, there are a variety of ways whereby processing conditions might affect bonding degree [34]. The mechanical behavior of components created with FDM is also influenced by the raster width and the quantity of contours [35]. In comparison to high density, Baich et al. (2015) showed that low density had cost savings and comparable strength performance for tensile loading [36]. According to Onwubolu et al. (2014), layer and raster thickness should be raised in order to improve the tensile strength of acrylonitrile butadiene styrene (ABS) [37]. In contrast to the other factors, Attaran (2017) asserted that the layer thickness impact on the mechanical properties of ABS material is minimal [38]. Ziemian et al. (2012, 2015) shown experimentally that it is preferable to assign the rasters longitudinally rather than diagonally in order to get the best tensile strength [39, 40].

II. WORK METHODOLOGY

A. *Test Specimens*

Test specimens were printed using FDM technology. The cross section of the specimen used was 12.7 mm × 12.7 mm with a length of 25.4 mm. The specimens were printed with three different infill patterns i.e. hexagonal, triangular, and linear and three different infill percentages i.e. 20%, 30%, and 40%. The general values for the material properties are following:

TABLE 1. Test Specimen

PROPERTY	VALUE
Bulk Density (g/cm3)	1.24 g/cm 3
Infill (%)	20% , 30% , 40%
Shell Thickness	0.3 mm
Layer Thickness	0.3 mm
Printing method	FDM
Printer	TEVO-Trantula I3
Printing firm	Tulsiramji Gaikwad- Patil College of Engineering and Technology, Nagpur
Infill Pattern	Hexagonal, linear and triangular
Colour	White
Extruder temperature	220^{o} C
Bed Temperature	80^{o} C

B. *Printer Specifications*

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TABLE 2. **Printer Specimen**

Name	TEVO-Trantula I3
Number of Extruder	1
Print Technology	Fused Filament Fabrication(FFF)
Build Volume	22.3cm(length) * 22.3 cm (width)* 30.5cm (Height)
Layer Resolution	0.40 mm Nozzle: 200 to 20 Micron
Build Accuracy	±0.2mm
Positioning Accuracy	Z axis 0.0025mm; XY axis 0.011mm
Filament Diameter	1.75mm（±0.02）
Nozzle Diameter	0.4mm
Print Speed	100 mm/s

C. Universal Testing Machine

The Universal Testing Machine used for performing compressive test was model AMT 100 Sold and Serviced by ASI Sales Private Limited Karampura Complex, New Delhi). The specifications of the UTM are:

Max. Capacity 1000 kN

Measuring range - 0 – 1000 kN

Loading unit - Hydraulic Control panel - Electronic Extensometer – Electronic

D. Compressive Test

- Three specimens of each combination were evaluated, with the average value used to draw conclusions. When either plastic deformation or printing layer separation was observed, the specimen was regarded to have failed. The following was the procedure:
- Load the specimen on the UTM
- Start the machine
- Record the load and corresponding deflection
- Plot the curve using excel.

E. Formula used

- Stress = Load applied / cross section area of the specimen
- Strain = Deformation / original length
- Strength to weight ratio = Strength / Mass of specimen
- Young's Modulus = Stress/ Strain

III. RESULTS AND CONCLUSION

1) Compressive strength.

After conducting several experiments the results obtained are gathered in tabular form below: Failure compressive load

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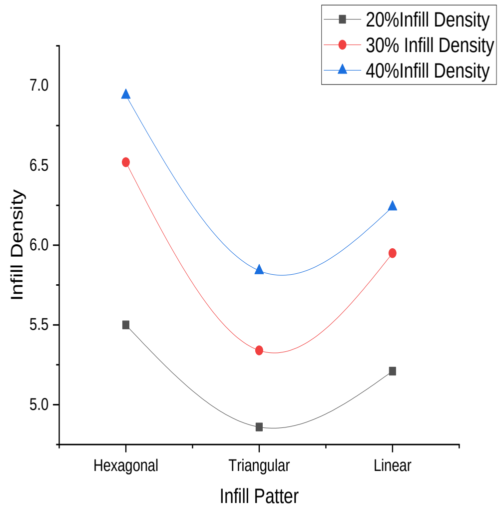
TABLE 3. Compressive strength

	Infill Density		
Infill Pattern	**20%**	**30%**	**40%**
Hexagonal	5.5	6.52	6.94
Triangular	4.86	5.34	5.84
Linear	5.21	5.95	6.24

All the values presented above are in Kilo-Newtons.

To visualize the distribution of above data following graph.1is plotted:



Graph.1. Relation between Infill density, infill pattern for compressive Strength

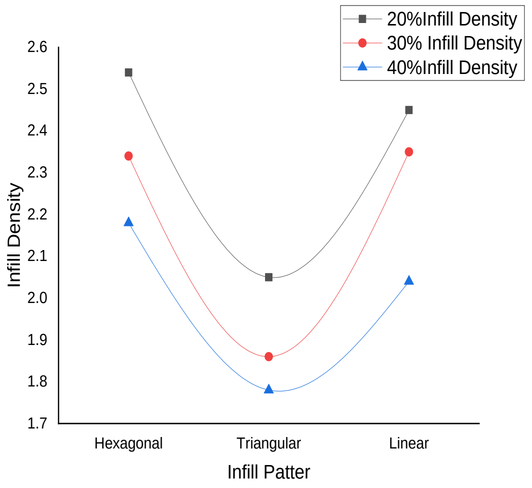
2) Strength to Weight Ratio

Strength to weight ratio is an important consideration when speaking of infill percentages. The following data has been observedin the present experiment:

TABLE 4. Strength to Weight Ratio

	Infill Density		
Infill Pattern	**20%**	**30%**	**40%**
Hexagonal	2.54	2.34	2.18
Triangular	2.05	1.86	1.78
Linear	2.45	2.35	2.04

To visualize above data following graph 2. has been generated:



Graph.2. Relation between Infill density, infill pattern for Strength to Weight Ratio

3) Young's Modulus

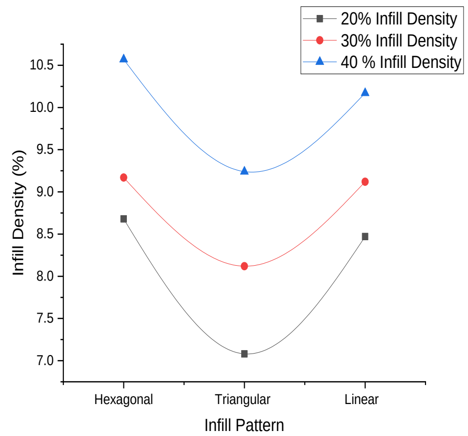
The test data obtained is used to calculate the young's modulus. The results have been shown below:

TABLE 5. Young's Modulus

	Infill Density		
Infill Pattern	**20%**	**30%**	**40%**
Hexagonal	8.68	9.17	10.57
Triangular	7.08	8.12	9.24
Linear	8.47	9.12	10.17

All the values presented above are in kN/mm^2

When the above data is plotted following graph 3 has been generated.



Graph.3. Relation between Infill density, infill pattern for Young's Modulus

3) Conclusions

- The maximum yield load was 6.94 kN for a hexagonal design with 40% infill, whereas the minimum yield load was 4.86 kN for a triangular pattern with 20% infill.
- Although the solid specimen yielded at a lower load than the hexagonal with 30%, the load required for further deformation increased after the yield point owing to solid infill, whereas it decreased in all other situations.
- With the exception of solid infill condition, the stress strain study revealed that all infill % and infill patterns combinations display a graph that is quite similar.

- In a hexagonal pattern with 20% infill, the maximum strength to weight ratio was 2.54, while the minimum strength to weight ratio was 1.78 in a specimen with 40% infill.
- The greatest Young's Modulus recorded in the case of a hexagonal pattern with 40% infill was 10.57kN/mm ^{2}, while the minimum Young's Modulus observed in the case of a triangular infill pattern with 20% infill was 7.08 kN/mm^{2}.

REFERENCES:

[1] Yong-Jin Yoon, Seung Ki Moon, and Jihong Hwang, 3D printing as an efficient way for comparative study of biomimetic structures - trabecular bone and honeycomb, Journal of Mechanical Science and Technology 28 (11) (2014) 4635~4640

[2] Antreas Kantaros & Nikoleta Chatzidai& Dimitris Karalekas1, 3D printing-assisted design of scaffold structures, Springer-Verlag London 2015

[3] Bharat Bhushan, Matt Caspers, An overview of additive manufacturing (3D printing) for micro fabrication, Springer-Verlag Berlin Heidelberg 2017

[4] Seung Ki Moon, Yu En Tan, Jihong Hwang, and Yong-Jin Yoon, Application of 3D Printing Technology for Designing Light -weight UnmannedAerial Vehicle Wing Structure, International Journal Of Precision Engineering And Manufacturing-Green Technology Vol. 1, No. 3, pp. 223-228

[5] Masato Makino, Kodai Suzuki, Kyuichiro Takamatsu, AtsukiShiratori, Azusa Saito, Kazuyuki Sakai, and Hidemitsu Furukawa, 3Dprintingofpolicewhistles for STEM education, Springer-Verlag Berlin Heidelberg 2017

[6] Matthew A.Perras, Daniel Vogle, CompressiveandTensileBehaviorof3D-Printedand Natural Sandstones, SpringerNatureB.V.2018

[7] Zengguang Liu & Yanqing Wang & Beicheng Wu & Chunzhi Cui & Yu Guo& Cheng Yan , A critical review of fused deposition modelling 3D printing technology in manufacturing polylactic acid parts , Springer-Verlag London Ltd., part of Springer Nature 2019

[8] Yuki Nakagawa & Ken-ichiro Mori& Tomoyoshi Maeno, 3D printing of carbon fibre-reinforced plastic parts, Springer-Verlag London 2017

[9] Ali Nadernezhad & Serkan Unal & Navid Khani& Bahattin Koc, Material extrusion -based additive manufacturing of structurally controlled poly(lactic acid)/carbon nanotube nanocomposites, Springer-Verlag London Ltd., part of Springer Nature 2019

[10] Md. Hazrat. Ali & Nazim Mir-Nasiri & Wai Lun Ko, Multi-nozzle extrusion system for 3D printer and its control mechanism , Int J AdvManufT echnol (2016) 86:999–1010

[11] Dawei Li & Ning Dai & Xiaotong Jiang& Xiaosheng Chen, Interior structural optimization based on the density -variable shape modelling of 3Dprinted objects, Springer-Verlag London 2015

[12] Taeseok Lee, Jusung Lee, Kunwoo Lee, Extended block based infill generation, Springer-Verlag London 2017

[13] G. Domínguez-Rodríguez & J. J. Ku-Herrera& A. Hernández-Pérez, An assessment of the effect of printing orientation, density, and fillerpatternonthe compressive performance of 3D printed ABS structures by fuse deposition, Springer-Verlag London Ltd., part of Springer Nature 2017

[14] V. Vega, J. Clements, T. Lam, A. Abad, B. Fritz, N. Ula, and O.S. Es-Sai , The Effect of Layer Orientation on the Mechanical PropertiesandMicrostructure of a Polymer (Submitted June 15, 2010 JMEPEG (2011) 20:978 –988 ASM International DOI: 10.1007/s11665-010-9740-z 1059-9495

[15] Wenzheng Wu ,Peng Geng ,Guiwei Li ,DiZhao ,Haibo Zhang and JiZhao , Influence of Layer Thickness and Raster Angle on the MechanicalPropertiesof 3D-Printed PEEK and a Comparative Mechanical Study between PEEK and ABS, Materials 2015, 8, 5 834-5846; doi:10.3390/ma8095271

[16] Nadir Ayrilmis & Mirko Kariz & Jin Heon Kwon & Manja Kitek Kuzman, Effect of printing layer thickness on water absorption and mechanical properties of 3D-printed wood/PLA composite materials, Springer-Verlag London Ltd., part of Springer Nature 2019

[17] A. Imeri & I. Fidan & M. Allen & D. A Wilson& S. Canfield, Fatigue analysis of the fibre reinforced additively manufactured objects, Springer-Verlag London Ltd., part of Springer Nature 2018

[18] Dhruv Mahesh Kumar Patel, Effects of Infill Patterns on Time, Surface Roughness and Tensile Strength in 3D Printing, 2017 IJEDR | Volume5,Issue3|ISSN: 2321-9939

[19] Shilpesh R. Rajpurohit& Harshit K. Dave, Analysis of tensile strength of a fused filament fabricated PLA part using an open-source 3D printer,Springer- Verlag London Ltd., part of Springer Nature 2018

[20] Ognjan Lužanin, Dejan Movrin, Miroslav Planča, Effect Of Layer Thickness, Deposition Angle, And Infill On Maximum Flexural Force In Fdm -Built Specimens , Journal for Technology of Plasticity, Vol. 39 (2014), Number 1

[21] K. G. Jaya Christiyan, U. Chandrasekhar, K. Venkateswarlu, Flexural Properties of PLA Components under Various Test Condition Manufacturedby3D Printer, the Institution of Engineers (India) 2016.

[22] Vishwjeet Ambade, M. Nimbhorkar, Journal of Emerging Technologies and Innovative Research 7, 7-13 (2020).

[23]. Torres, J., Cotelo, J., Karl, J., Gordon, A. P. Mechanical property optimization of FDM PLA in shear with multiple objectives. JOM 2015, 67, 1183–1193; https://doi.org/10.1007/s11837-015-1367-y.

[24]. Hanon, M. M., Marczis, R., Zsidai, L. Anisotropy evaluation of different raster directions, spatial orientations, and fill percentage of 3D printed PETG tensile test specimens. Key Eng. Mater. 2019, 821, 167–173; https://doi.org/10.4028/www.scientific.net/kem.821.167.

[25]. Peng, A., Xiao, X., Yue, R. Process parameter optimization for fused deposition modeling using response surface methodology combined with fuzzy inference system. Int. J. Adv. Manuf. Technol. 2014, 73, 87–100; https://doi.org/10.1007/s00170-014-5796-5.

[26]. Hanon, M. M., Zsidai, L., Ma, Q. Accuracy investigation of 3D printed PLA with various process parameters and different colors. Mater. Today Proc. 2021, 42, 3089–3096; https://doi.org/10.1016/j.matpr.2020.12.1246.

[27]. Vijayaraghavan, V., Garg, A., Lam, J. S. L., Panda, B., Mahapatra, S. S. Process characterisation of 3D-printed FDM components using improved evolutionary computational approach. Int. J. Adv. Manuf. Technol. 2015, 78, 781–793; https://doi.org/10.1007/s00170-014-6679-5.

[28]. Alaimo, G., Marconi, S., Costato, L., Auricchio, F. Influence of meso-structure and chemical composition on FDM 3D-printed parts. Compos. B Eng. 2017, 113, 371–380; https://doi.org/10.1016/j.compositesb.2017.01.019.

[29]. Hanon, M. M., Marczis, R., Zsidai, L. Impact of 3D-printing structure on the tribological properties of polymers. Ind. Lubric. Tribol. 2020, 72, 811–818; https://doi.org/10.1108/ilt-05-2019-0189.

[30]. Sood, A. K., Ohdar, R. K., Mahapatra, S. S. Parametric appraisal of mechanical property of fused deposition modelling processed parts. Mater. Des. 2010, 31, 287–295; https://doi.org/10.1016/j.matdes.2009.06.016.

[31]. Hanon, M. M., Marczis, R., Zsidai, L. Influence of the 3D printing process settings on tensile strength of PLA and HT-PLA. Period. Polytech. – Mech. Eng. 2020, 65, 38–46; https://doi.org/10.3311/ppme.13683.

[32]. Fatimatuzahraa, A. W., Farahaina, B., Yusoff, W. A. The effect of employing different raster orientations on the mechanical properties and microstructure of fused deposition modeling parts. In 2011 IEEE Symposium on Business, Engineering and Industrial Applications (ISBEIA); IEEE: Langkawi, Malaysia, 2011; pp. 22–27.10.1109/ISBEIA.2011.6088811

[33]. Durgun, I., Ertan, R. Experimental investigation of FDM process for improvement of mechanical properties and production cost. Rapid Prototyp. J. 2014, 20, 228–235; https://doi.org/10.1108/rpj-10-2012-0091.

[34]. Li, H., Wang, T., Sun, J., Yu, Z. The effect of process parameters in fused deposition modelling on bonding degree and mechanical properties. Rapid Prototyp. J. 2018, 24, 80–92; https://doi.org/10.1108/rpj-06-2016-0090.

[35]. Sood, A. K., Ohdar, R. K., Mahapatra, S. S. Experimental investigation and empirical modelling of FDM process for compressive strength improvement. J. Adv. Res. 2012, 3, 81–90; https://doi.org/10.1016/j.jare.2011.05.001.

[36]. Baich, L., Manogharan, G., Marie, H. Study of infill print design on production cost-time of 3D printed ABS parts. Int. J. Rapid Manuf. 2015, 5, 308; https://doi.org/10.1504/ijrapidm.2015.074809.

[37]. Onwubolu, G. C., Rayegani, F. Characterization and optimization of mechanical properties of ABS parts manufactured by the fused deposition modelling process. Int. J. Manuf. Eng. 2014, 2014, 1–13; https://doi.org/10.1155/2014/598531.

[38]. Attaran, M. The rise of 3-D printing: the advantages of additive manufacturing over traditional manufacturing. Bus. Horiz. 2017, 60, 677-688; https://doi.org/10.1016/j.bushor.2017.05.011.

[39]. Ziemian, C., Sharma, M., Ziemi, S. Anisotropic mechanical properties of ABS parts fabricated by fused deposition modelling. In Mechanical Engineering; InTech: Rijeka, Croatia, 2012.10.5772/34233

ISSN PRINT 2319 1775 Online 2320 7876
  UGC CARE Listed (Group -I) Journal Volume 11, Spl Iss 3, 2022

[40]. Ziemian, S., Okwara, M., Ziemian, C. W. Tensile and fatigue behavior of layered acrylonitrile butadiene styrene. Rapid Prototyp. J. 2015, 21, 270–278; https://doi.org/10.1108/rpj-09-2013-0086.

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