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A Comprehensive Review: Process Parameters Impact on Tensile Strength of 3D Printed PLA Parts

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Abstract: *The mechanical strength of the parts developed by 3D printing is an area of study because of the technology's inherent nature, which has led to its emergence as a disruptive technology for fabricating industrial components. The purpose of this study is to examine the effects of various 3D printing parameters on the tensile strength of PLA parts produced using 3D printing. Given their importance to commercial 3D printing, the parameters of nozzle temperature, bed temperature, printing speed, layer thickness, and printing direction have been studied in depth. Three-dimensionally printed specimens made from PLA, the most important material for FDM printing. A key objective of the research is to ascertain whether or not a 3D printing parameter can be used to optimize the investigated mechanical characteristic within a practical budget. Furthermore, trends that may be obvious and major factors in shaping the outcome will be investigated.*

Keywords: 3D Printing, Tensile Strength, Process Parameters, PLA

I. INTRODUCTION

Among the most rapidly and intensively expanding production technologies is additive manufacturing, also known as 3D printing. Several different 3D printing techniques exist, including SLS (Selective Laser Sintering), SLA (Stereolithography), and FDM (Fused Deposition Modeling) (Fused Deposition Modelling)[1]. The 3D printing technology can also print different polymers. Metals, ceramics, composites, concrete, and even biomaterials are just some of the materials that modern printers can produce[2][3]. Most plastics can be printed on FDM-based 3D printers, making them a popular and inexpensive option. The main advantage of 3D printing is that it can be used to make almost any complex shape by building the thing layer by layer[4]. As a result, this technology is highly advantageous from a waste management perspective, as it generates zero or nearly zero waste throughout the process[3]. Several parameters influence 3D printing, but their effects on mechanical properties are frequently unknown[5]. If the item is a prototype or is being made for a purpose other than being physically impacted, this won't be a problem[6]. If the 3D-printed parts will be used in place of an existing component, the impact of the printing settings on the mechanical qualities will be of paramount importance. Recent years have seen an increase in the number of scholarly articles discussing the impact of printing parameters on mechanical qualities, a trend that can be attributed to the widespread adoption of this method in the industry. Most of the articles focus on how they change the tensile or yield strength of a material. However, some papers investigate the effects of printing factors on impact strength. Due to the significant decrease in impact strength caused by the stress collector, these articles primarily focus on notched specimens. Researchers have looked at how infill density, infill pattern, print speed, printing temperature, layer height, and other factors affect impact strength in a variety of ways. Although the extent of the effect varied across parameters, all analyses showed that printing parameters influenced the measured mechanical properties.

While there has been progress in this area, our understanding of how the conditions of the manufacturing process affect the final mechanical performance of these components remains limited. Because of this information gap, this technology is not progressing as quickly as it could be and is not yet available to the public. There is ongoing study into improving the mechanical strength of 3D-printed engineering parts.

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II. THE 3D PRINTING PROCESS

The basic printing procedure for a 3D printer is the same regardless of the type of material it's using[7]. Fig. 1 shows the steps involved in the printing of any part using fused deposition modelling which are starting from creation of CAD model to the cleaning to part.

A. CAD

Make a three-dimensional model in computer-aided design (CAD) software. Using scientific data about specific materials, the software creates virtual simulations of the object's behaviour under specific conditions, which may give you a sense of the structural integrity you can expect in the final product.
Using scientific data about specific materials, the software creates virtual simulations of the object's behavior under specific conditions, which may give you a sense of the structural integrity you can expect in the final product.

B. Conversion to STL

The second step is to "convert to STL," which means changing the CAD file or drawing into the STL format.Standard tessellation language or STL for short.

C. Transfer to AM Machine and STL File Manipulation

The third step involves moving the STL file to the computer that manages the 3D printer and making any necessary modifications. The user can select the paper size and print orientation in that section. The process is analogous to setting up a document for two-sided printing or landscape orientation. The process is analogous to setting up a document for two-sided printing or landscape orientation

D. Machine Setup

Fourth, prepare the machine for the new print job according to the machine's specific instructions. Refilling the printer's polymers, binders, and other consumables is part of this process. A tray can be used as a base, which is also addressed.

E. Build

Fifth, construct: let the machine do its thing; the construction process is largely automated. The typical thickness of a single layer is about 0.1 mm, though this can vary widely. This could take a long time (hours or days) because of the size of the object, the complexity of the machine, and the nature of the materials. Keep an eye on the machine to make sure it's running smoothly.

F. Removal

Take Out: Take the Printed Item Out of the Printer. Take all necessary safety measures to protect yourself, such as wearing gloves when working with potentially hazardous substances or on hot surfaces.

G. Post-Processing

Seventh, the printed object will usually need some additional work after being produced by a 3D printer. The printed item may need to be cleaned, which may involve brushing off any remaining powder or immersing it in water. Due to the curing time needed by some materials, the new print may be fragile at this stage; care should be taken to prevent it from cracking or breaking.

H. Use or Application

Making good use of the newly printed items is the eighth step.

Figure 1: Steps involved in FDM

III. MATERIALS USED IN FUSED DEPOSITION MODELLING (FDM)

After reviewing the various types that are incorporated into 3D printing, the question of what materials are used in these processes, the viability of those materials, the properties they provide, and the processes and applications in which they are used, arises. To that end, the following sections elaborate on the material aspects that are unique to each 3D printing process based on the aforementioned parameters.Some of the thermoplastic materials which are used in fused deposition modelling are ABS (Acrylonitrile Butadiene Styrene), PETG (Polyethylene Terephthalate Glycol), PLA (Polylactic Acid), TPU (Thermoplastic Polyurethane) and PC (Polycarbonate)[5]. FDM has its applications in medical industries, aerospace industries, automotive industries, tooling applications [2].Plant-based polylactic acid (PLA) is a biodegradable material made primarily from plant matter. Limitations in toughness, brittleness, and water sensitivity are apparent. [8].Since PLA has a relatively low melting point, between 150 and 160 degrees Celsius, it is able to be processed with ease, which not only makes it more appealing to people who use 3D printers but also increases its market share. [9].In 2010, PLA, a bioplastic with a lower molecular weight and polymer strength than its predecessor, was the second most consumed bioplastic in the world. [22].A major selling point of PLA filament is its ability to be recycled easily, making it a popular choice among 3D printing filaments. According to the study's findings, since PLA filament is a relatively inexpensive raw material, it should be reused after it has served its purpose in the next 3D printing process.[10].

IV. PROCESS PARAMETERS

The goal of this study is to show that choosing the right process parameters is crucial for printing parts, and that it's crucial to look into the different material properties that are available because they have an impact on component strength. The quality and dimensional stability of the component are also affected.Fig. 2 shows classification of Process Parameters in FDM.

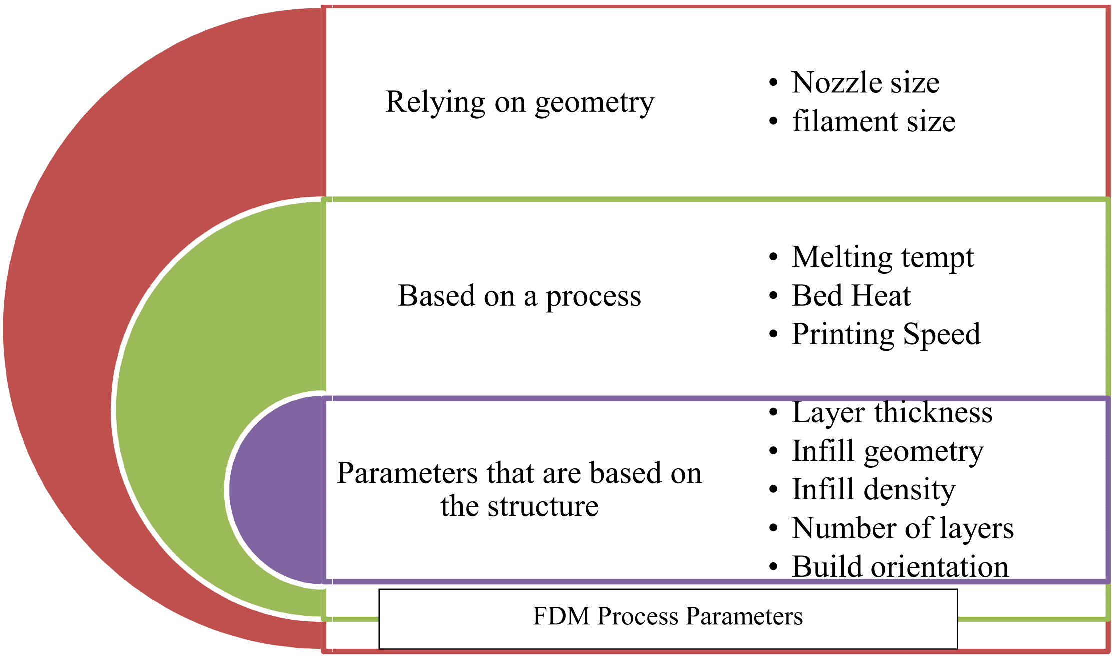

Figure 2: Classification of Process Parameters in FDM

Key process parameters include, Layer thickness is the print bed layer thickness. [11]. The nozzle heats thermoplastic filament before extrusion in FDM. Infill density indicates the percentage of material used to manufacture a product.[12]. The infill pattern creates the FDM printed part's internal structure. [13]. The build platform's X-axis raster angle is where extruded material is deposited. [14].

V. PROCESS PARAMETERS AND MECHANICAL PROPERTIES

Additive manufacturing is widely used in many areas of modern life. It is playing a bigger role in our day-to-day activities. Massive advancements have been made in fields as diverse as medical research and the aerospace industry because to its application. We have been concentrating on making sure the products are of high quality. Tensile strength and process parameters for FDM are shown in Fig.3.

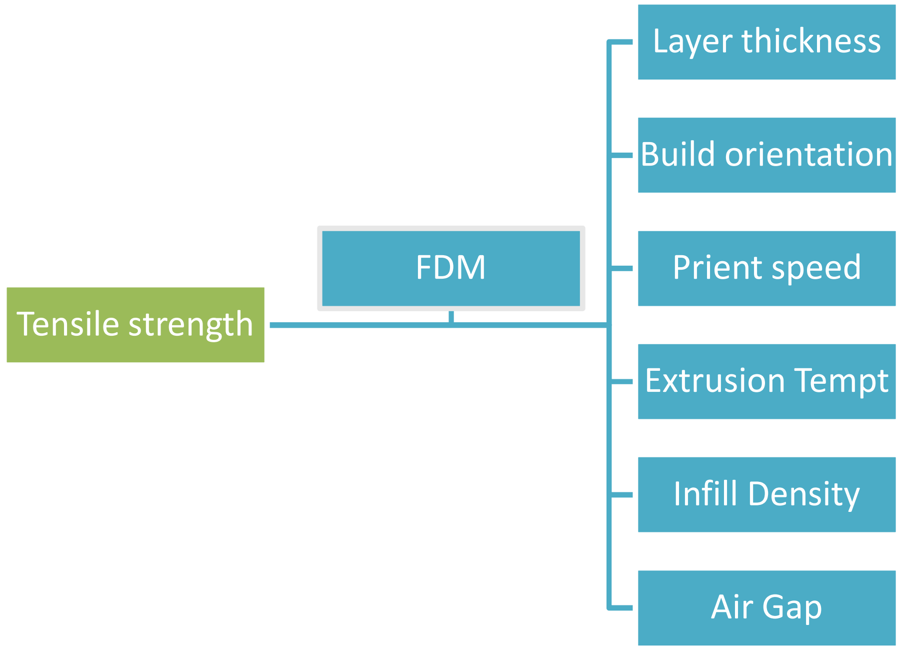

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Figure 3: Process parameters and Tensile strength in FDM

VI. EFFECT OF PROCESS PARAMETERS ON TENSILE STRENGTH

In order to print material of the highest possible quality is required to conduct research on all of the process parameters involved in the printing process. The literature review goes into additional detail regarding a number of significant mechanical properties and how those qualities vary throughout the operation. Some important mechanical properties and their variation with the process are discussed below.

A. Tensile Strength

Tensile strength is an important property for mechanical parts. Researchers have reported the effect on the tensile strength of PLA based specimen with the change in process parameterssuch as build orientation, raster direction angle, and layer height etc., The tensile strength of composites depends on the aspect ratio of fillers[15].Crystalline PLA lattices, The mechanism of the influence of process factors on the sample was investigated at the intended process parameters of printing temperature and printing speed, and the experimental data show that the tensile strength and elastic modulus increase and subsequently drop with increasing printing temperature.[16].When the impact of 3D printing settings on PLA polymer's hardness and tensile strength was evaluated, it was found that the two properties are proportional to one another. [17]**.**FDM printing with PLA filament was perfected by employing a tensile test to find the best settings. All of the possible print settings on FDM machines are taken into account to ensure the greatest possible output. Everything from the extruder's heat to the bed's, as well as the printing's velocity, infill, shell count, and layer height, are all variables here[18]**.**In a series of tensile tests, it was found that the failure load decreased with increasing raster angle. Meanwhile, the breaking force gradually decreases as printing speed rises.[19].The recent studies on the performed-on AM materials to study the effect of process parameters on the tensile properties are shown in Table 1

Table 1: Materials, Standards, Process parameters and Test Performed.

Materials	Standards	Process parameters	Test performed
PLA	ASTM D638 & ASTM D790	layer height print angle ,print speed	Ultimate Tensile strength, and Flexural 3-point bend[15]
PLA	-	printing temperature &Printing speed	Tensile strength [16]
PLA	ASTM D5766	layer thickness,	Tensile strength[20]

		fill density, and feed rate	
PLA, PC, PETG	ISO 527-1:2019 and ISO 178:2019	infill density, layer height ,	tensile strength and flexural strength[21]
PLA	ISO 527-2, ASTM D2240	build orientation, raster direction angle, and layer thickness	tensile strength, hardness[22]
PLA	ASTM D2240	print orientation, filament colors	surface roughness and product hardness[23]
PLA	ASTM D638, type V	raster deposition angle, infill density, nozzle temperature, bed temperature, printing speed, and layer thickness	Surface roughness ,dimensional accuracy, porosity[24]
PLA and PETg	ISO 527–2:2012	Nozzle diameter, printing temperature, Printing speed , print orientation	thermal annealing and salt remelting on the tensile properties[25]
PLA	ASTM D2240	buildorientation, raster direction angle, and layer height.	tensile strength and the hardness [22]
PLA	ASTM D638 and ASTM D790	Build orientation, Raster angel	tensile strength and flexural strength[26]
PLA	ASTM D638	cellular geometry and nozzle diameter	Tensile strength[27]
PLA	ASTM D618	Nozzle diameter, the number of outer shells, extrusion temperature, infill percentage, and pattern.	tensile strength[28]
PLA	ISO 527, ISO 180, and ISO 178	layer thicknesses,occupancy rates and filling structure	tensile strength,bending strength, & impact strength[10]
PLA	ISO 527–1	growing direction, building orientation, layer thickness, specimen thickness, filament color	fracture toughness, tensile strength[20]
PLA	ASTM D638	Chunk slope angle,Chunk overlapping,Number of perimeter shells, Raster orientation,Infill density, Air Gap	Tensile strength [29]
PLA	ASTM D638	raster angles	fracture behavior, tensile tests [19]
PLA	ASTM D638	extruder temperature, bed temperature, layer height, printing speed, travel speed, infill, and shell count	tensile test[18]

VII. CONCLUSION

It can be concluded from the reviewed literature that now a day, with the development and rapid expansion of 3D printing technologies, there is an increasing need for precise knowledge of the parameters of the raw materials used and the limits of their usability. The following areas of uncertainty are recognized as potential targets for improving the tensile qualities of PLA or replacing it with another suitable material.

- PLA is an excellent choice of material for prototypes that require more dimensional accuracy.
- PLA material has the highest negative impacts on water depletion and freshwater ecotoxicity even though it originates from natural resources and is biodegradable. Across the entirety of the product's life cycle, it was discovered that the recycling phase had the most significant affects on the environment..

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- PLA is subject to some limitations, including a sensitivity to water, a lack of toughness, a lack of strength, and brittleness.
- In the future, research may concentrate on engineering applications of polymer base materials such as PETG, TPU, and PC, amongst others, with or without the addition of fibre reinforcement, in order to boost the strength of 3D-printed products.

REFERENCES

[1]. S. Rouf, A. Raina, M. Irfan Ul Haq, N. Naveed, S. Jeganmohan, and A. Farzana Kichloo, "3D printed parts and mechanical properties: Influencing parameters, sustainability aspects, global market scenario, challenges and applications," Advanced Industrial and Engineering Polymer Research, vol. 5, no. 3. KeAi Communications Co., pp. 143–158, Jul. 01, 2022. doi: 10.1016/j.aiepr.2022.02.001.

[2]. I. Gibson and D. Rosen, Additive Manufacturing Technologies.

[3]. P. Bedarf, A. Dutto, M. Zanini, and B. Dillenburger, "Foam 3D printing for construction: A review of applications, materials, and processes," Automation in Construction, vol. 130. Elsevier B.V., Oct. 01, 2021. doi: 10.1016/j.autcon.2021.103861.

[4]. D. Myers, A. Abdel-Wahab, F. Hafeez, N. Kovacev, and K. Essa, "Optimisation of the additive manufacturing parameters of polylactic acid (PLA) cellular structures for biomedical applications," J. Mech. Behav. Biomed. Mater., vol. 136, Dec. 2022, doi: 10.1016/j.jmbbm.2022.105447.

[5]. A. Jandyal, I. Chaturvedi, I. Wazir, A. Raina, and M. I. Ul Haq, "3D printing – A review of processes, materials and applications in industry 4.0," Sustain. Oper. Comput., vol. 3, pp. 33–42, Jan. 2022, doi: 10.1016/j.susoc.2021.09.004.

[6]. M. Chaudhari, B. F. Jogi, and R. S. Pawade, "Comparative Study of Part Characteristics Built Using Additive Manufacturing (FDM)," in Procedia Manufacturing, 2018, vol. 20, pp. 73–78. doi: 10.1016/j.promfg.2018.02.010.

[7]. D. M. D'Addona, S. J. Raykar, D. Singh, and D. Kramar, "Multi Objective Optimization of Fused Deposition Modeling Process Parameters with Desirability Function," in Procedia CIRP, 2021, vol. 99, pp. 707–710. doi: 10.1016/j.procir.2021.03.117.

[8]. M. M. Hanon, A. Ghaly, L. Zsidai, and S. Klébert, "Tribological characteristics of digital light processing (DLP) 3D printed graphene/resin composite: Influence of graphene presence and process settings," Mater. Des., vol. 218, Jun. 2022, doi: 10.1016/j.matdes.2022.110718.

[9]. M. M. Hanon and L. Zsidai, "Comprehending the role of process parameters and filament color on the structure and tribological performance of 3D printed PLA," J. Mater. Res. Technol., vol. 15, pp. 647–660, Nov. 2021, doi: 10.1016/j.jmrt.2021.08.061.

[10]. G. Atakok, M. Kam, and H. B. Koc, "Tensile, three-point bending and impact strength of 3D printed parts using PLA and recycled PLA filaments: A statistical investigation," J. Mater. Res. Technol., vol. 18, pp. 1542–1554, May 2022, doi: 10.1016/j.jmrt.2022.03.013.

[11]. A. Nugroho, R. Ardiansyah, L. Rusita, and I. L. Larasati, "Effect of layer thickness on flexural properties of PLA (PolyLactid Acid) by 3D printing," in Journal of Physics: Conference Series, Nov. 2018, vol. 1130, no. 1. doi: 10.1088/1742-6596/1130/1/012017.

[12]. C. H. Liu and P. T. Hung, "Effect of the infill density on the performance of a 3D-printed compliant finger," Mater. Des., vol. 223, Nov. 2022, doi: 10.1016/j.matdes.2022.111203.

[13]. B. Pernet, J. K. Nagel, and H. Zhang, "Compressive Strength Assessment of 3D Printing Infill Patterns," in Procedia CIRP, 2022, vol. 105, pp. 682–687. doi: 10.1016/j.procir.2022.02.114.

[14]. A. R. Tajik, T. I. Khan, and V. Parezanović, "Raster angle impact on FDM-based additive manufactured fluidic oscillator," Int. J. Thermofluids, vol. 16, Nov. 2022, doi: 10.1016/j.ijft.2022.100230.

[15]. D. Mudakavi, R. B. Sreesha, V. Kumar, and S. M. Adinarayanappa, "A comprehensive experimental investigation on mechanical properties and fracture morphology of particulate composites via material extrusion-based 3D printing," Results Mater., p. 100348, Dec. 2022, doi: 10.1016/j.rinma.2022.100348.

[16]. C. Tang, J. Liu, Y. Yang, Y. Liu, S. Jiang, and W. Hao, "Effect of process parameters on mechanical properties of 3D printed PLA lattice structures," Compos. Part C Open Access, vol. 3, Nov. 2020, doi: 10.1016/j.jcomc.2020.100076.

[17]. M. M. Hanon, J. Dobos, and L. Zsidai, "The influence of 3D printing process parameters on the mechanical performance of PLA polymer and its correlation with hardness," Procedia Manuf., vol. 54, pp. 244–249, 2020, doi: 10.1016/j.promfg.2021.07.038.

[18]. S. Raja et al., "Optimization of 3D Printing Process Parameters of Polylactic Acid Filament Based on the Mechanical Test," Int. J. Chem. Eng., vol. 2022, 2022, doi: 10.1155/2022/5830869.

[19]. M. R. Khosravani, F. Berto, M. R. Ayatollahi, and T. Reinicke, "Characterization of 3D-printed PLA parts with different raster orientations and printing speeds," Sci. Rep., vol. 12, no. 1, Dec. 2022, doi: 10.1038/s41598-022-05005-4.

[20]. L. Marşavina et al., "Effect of the manufacturing parameters on the tensile and fracture properties of FDM 3D-printed PLA specimens," Eng. Fract. Mech., vol. 274, Oct. 2022, doi: 10.1016/j.engfracmech.2022.108766.

[21]. J. Djokikj, O. Tuteski, E. Doncheva, and B. Hadjieva, "Experimental investigation on mechanical properties of FFF parts using different materials," Procedia Struct. Integr., vol. 41, no. C, pp. 670–679, 2022, doi: 10.1016/j.prostr.2022.05.076.

[22]. M. M. Hanon, L. Zsidai, and Q. Ma, "Accuracy investigation of 3D printed PLA with various process parameters and different colors," in Materials Today: Proceedings, 2021, vol. 42, pp. 3089–3096. doi: 10.1016/j.matpr.2020.12.1246.

[23]. M. M. Hanon and L. Zsidai, "Comprehending the role of process parameters and filament color on the structure and tribological performance of 3D printed PLA," J. Mater. Res. Technol., vol. 15, pp. 647–660, 2021, doi: 10.1016/j.jmrt.2021.08.061.

[24]. [24] N. Vidakis, C. David, M. Petousis, D. Sagris, N. Mountakis, and A. Moutsopoulou, "The effect of six key process control parameters on the surface roughness , dimensional accuracy , and porosity in material extrusion 3D printing of polylactic acid : Prediction models and optimization supported by robust design analysis," Adv. Ind. Manuf. Eng., vol. 5, no. November, p. 100104, Nov. 2022, doi: 10.1016/j.aime.2022.100104.

[25]. A. Szust and G. Adamski, "Using thermal annealing and salt remelting to increase tensile properties of 3D FDM prints," Eng. Fail. Anal., vol. 132, Feb. 2022, doi: 10.1016/j.engfailanal.2021.105932.

[26]. Z. Liu, Q. Lei, and S. Xing, "Mechanical characteristics of wood, ceramic, metal and carbon fiber-based PLA composites fabricated by FDM," J. Mater. Res. Technol., vol. 8, no. 5, pp. 3743–3753, Sep. 2019, doi: 10.1016/j.jmrt.2019.06.034.

[27]. J. John, D. Devjani, S. Ali, S. Abdallah, and S. Pervaiz, "Optimization of 3D printed polylactic acid structures with different infill patterns using Taguchi-grey relational analysis," Adv. Ind. Eng. Polym. Res., 2022, doi: 10.1016/j.aiepr.2022.06.002.

[28]. L. Le, M. A. Rabsatt, H. Eisazadeh, and M. Torabizadeh, "Reducing print time while minimizing loss in mechanical properties in consumer FDM parts," Int. J. Light. Mater. Manuf., vol. 5, no. 2, pp. 197–212, Jun. 2022, doi: 10.1016/j.ijlmm.2022.01.003.

[29]. L. Poudel, Z. Sha, and W. Zhou, "Mechanical strength of chunk-based printed parts for cooperative 3D printing," 2018, vol. 26, pp. 962–972. doi: 10.1016/j.promfg.2018.07.123.