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Abhay Mishra[1], Rajeev Kumar[1], Anuj Kumar Sharma[2]

[1]Department of Mechanical Engineering, Institute of Engineering & Technology, Lucknow, India
[2]Department of Mechatronics, Centre for Advanced Studies, Lucknow, India

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RECOVERY BEHAVIOUR OF SMALL LOAD BEARING STRUCTURES OF IRON-PLA MATERIAL FABRICATED BY FDM TECHNOLOGY

Abhay Mishra[1*], Rajeev Kumar[1], Anuj Kumar Sharma[2]

[1]*Department of Mechanical Engineering, Institute of Engineering & Technology, Lucknow, India*
[2]*Department of Mechatronics, Centre for Advanced Studies, Lucknow, India*

Corresponding author: abhaymishra78933@gmail.com

Abstract: *3D printing has become a state-of-the-art manufacturing technique that goes beyond its original use in prototyping to create working assemblies. This work centers on the development and production of compact load-bearing structures utilizing FDM technology. We have used a commercially available fused deposition modeling (FDM) printer and Iron-PLA material. Thus, the effect of process parameters on the flexural strength and bending angle of Iron-PLA material are determined on the same. The fabricated samples, which were printed with a 100% infill density were measured and tested in accordance with ASTM D790, therefore the results were compared to the original 3D CAD model. The CT3 Texture Analyzer was utilized to perform the three-point bending test. The device is outfitted with a calibrated load cell that can measure forces up to 500 N with a precision of 0.5%. After which, their mechanical qualities were assessed on the basis of the flexural test performed. The results are examined on both the experimental and theoretical methods.*

Keywords: *Bearing structure, Flexural tests, Mechanical analyze, Iron-PLA, 3D printing*

INTRODUCTION

3D printing, also known as additive manufacturing (AM), enables the production of complex three-dimensional objects by depositing material layer by layer based on a digital model. This technique entails systematic application of substances, such as liquids or powders, to build the intended form. A key advantage of 3D printing is its capacity to manufacture intricate patterns using a variety of materials directly from computer-aided design (CAD) models. Currently, there are several prominent 3D printing technologies in use, such as Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Stereo lithography (SLA), among others. Continual research is actively broadening and improving these techniques.[1] 3D printing provides notable benefits in comparison to conventional manufacturing techniques, such as the capacity to personalize things and manufacture small quantities in a cost-efficient manner. It is frequently employed to produce prototypes at the design stage, greatly decreasing the time from idea generation to the actualization of the final product. The uses of 3D printing are wide-ranging, including industrial parts, 3D printed electronics, structural elements, medical devices, and the emerging field of bio-printing functionalized tissues. Furthermore, it has been employed to produce final goods and replacement components.[2,3]

Recent progress has been made in the field of multi-material printing, enabling the creation of intricate things that possess diverse material characteristics. Although there have been significant breakthroughs, 3D printing is still a developing technology. Current research is mostly focused on improving the mechanical qualities of the final items.[4] Polylactic acid (PLA), or polylactide, is a frequently utilized polymer in Fused Deposition Modeling (FDM) 3D printing. PLA, classified as a bioplastic, is a biodegradable polymer that is generated from plant starch.

This means that it is both ecologically friendly and biocompatible. PLA is widely used in health and industry as a cost-effective and advantageous substitute for traditional polymers. PLA offers several advantages, including as its positive impact on the environment, compatibility with living organisms, simplicity in manufacturing, and energy efficiency in the production process. PLA is utilized in the medical industry for the production of scaffolds, sutures, and drug delivery systems. Furthermore, it functions as a biodegradable substance for the purpose of packaging and consumer products, including bags, food containers, and disposable dinnerware.[5]Nevertheless, PLA is subject to specific constraints, such as inadequate mechanical robustness, sluggish breakdown rates, and hydrophilic characteristics that result in attraction and retention of moisture. Consequently, current research endeavors to enhance and customize the mechanical characteristics of PLA-based products in order to more effectively fulfill specific application demands.[6]Ongoing studies are being conducted to investigate the influence of infill qualities on the flexural rigidity of frame structures created by FDM-based 3D printing. Notable results suggest that changes in the order of material deposition can significantly impact the mechanical properties of the printed objects. Both the speed at which printing occurs and the time between the deposition of neighboring layers have been demonstrated to impact both the flexural strength and tensile. The selection of infill pattern also has a pivotal impact on determining the mechanical properties of the material.[7,8]The flexural test is a simple and efficient method for evaluating the flexural strength of structural elements. It allows for easy preparation of test samples. More precisely, the layer thickness used in the 3D printing process has a notable impact on the flexural strength of PLA. Modifications to the printing temperature and subsequent heat treatment can be employed to alter the mechanical characteristics of the end product. Empirical investigations have shown that changes in layer thickness and filament diameter have a substantial impact on the flexural strength of PLA, whereas the printing speed does not seem to have a major influence.[9,10]Iron-filled PLA (Polylactic Acid) is a 3D printing filament that combines the qualities of PLA with iron powder, creating a magnetic substance that may be utilized in applications that need a metallic appearance or feel.[11] They make pieces with a metallic shine. They exhibit ferromagnetic qualities (iron and other magnetic elements are drawn to items created with magnetic iron 3D printing filaments).[12] They have strength and qualities (mechanical, thermal, electrical, chemical, biodegradability, and recyclability) that are more comparable to the original thermoplastic matrix material than to the additional metal. They have a density that is about 1.5 times greater than the underlying polymer filament material.[13] Metal powder particles are abrasive, causing the printer extrusion nozzle to wear faster than plastic filament. The increased density of the filament owing to the iron particles reduces its bridging and support capabilities. Magnetic iron filaments are most often used in 3D printing to create parts with realistic metallic lusters, such as sculptures, jewellery, decorations, props, and reproductions. In addition to ornamental and decorative elements, items printed with these filaments are increasingly being used in sensors and actuators, tiny motors, and computer storage devices.[14,15]

This study investigates the process of creating and constructing miniature structures capable of supporting weight utilizing FDM 3D printing technology using Iron-PLA filament. The research encompasses a comprehensive examination of the printing parameters and printer settings employed during the production process. The three-point bending test was used to assess the mechanical properties of the produced components. The study analyzes the process parameters and the accompanying results, offering insights into the structural performance of the printed pieces.

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METHODOLOGY

A specimen made of Iron-PLA was created via FDM 3D printing, with a normal black filament with a diameter of 1.75 mm. The specimen, configured as a beam, possesses measurements of 125 mm in length, 12.70 mm in breadth, and 3.2 mm in thickness. Figure 1 shows the geometry of the sample, whereas Figure 2 illustrates the printed Iron-PLA specimen.

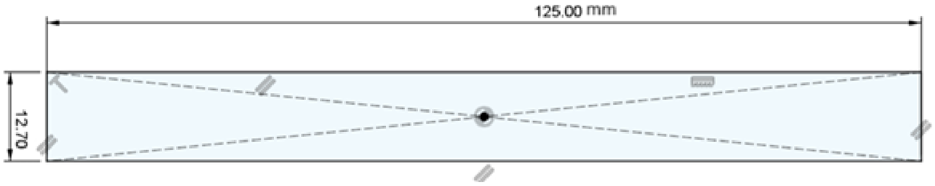

Fig.1. Flexural test sample (ASTM D790)

Fig.2. Printed Specimen for flexural test of Iron-PLA material.

The samples in this study were produced using a Creality Ender 3D FDM printer that has a 0.4 mm nozzle. The printer maker provided the standard Iron-PLA filament, which was utilized to evaluate its suitability for constructing modest load-bearing structures. The printer functioned using the typical default settings, which included a layer height of 0.1 mmand100% infill density. The printing speed was configured to operate at a rate of 60 mm/sec, resulting in an expected duration of 1 hour for the printing process. Additionally, the material consumption was anticipated to be around 12 grams.

Table 1 contains comprehensive printing settings.

The layer height represents the thickness of each individual layer that is deposited during the 3D printing process, while the shell thickness refers to the thickness of the outermost layers. The printer's nozzle initially outlines the outer surface and subsequently fills the interior with successive layers. Regardless of the specified infill density, the first and final layers are printed as solid, so their thickness is referred to as the bottom-top thickness. The density of infill measures how completely the inside of a printed item is filled with material. How quickly the printing head travel in a straight line is called the print speed. Bed temperature is the heated surface of the build plate that prevents warping and ensures sufficient adhesion; printing temperature is the nozzle's temperature while extruding material. A raft was employed as a supportive framework to assist the effortless extraction of the ultimate printed specimen from the build plate.

Table1. Printing parameters for the Creality Ender 3D printer using Iron-PLA filament

Quality	
Shell thickness	0.8mm
Layer height	0.1mm
Enable retraction	Yes

Wall Count	4
Fill	
Infill density	100%
Top thickness/Bottom	0.6mm
Temperature andPrint speed	
Printing temperature	230°C
Print speed	60mm/s
Bed temperature	80°C
Support	
Platform adhesion type	Raft
Support type	None
Filament	
Flow	100%
Diameter	1.75mm

One kind of three-dimensional printing called fused deposition modeling (FDM) uses a thermoplastic filament that runs continuously. A heated extruder head melts the filament before placing it onto a pre-heated construction plate; this process is called printing. The printer head, under computer control, advances horizontally and intermittently lowers vertically to form fresh layers. The speed of the extruder head can be adjusted to govern the initiation and cessation of material deposition. The Creality Ender 3 is a 3D printer that employs a conventional filament diameter of 1.75 mm. Ultimaker Cura, the printer's software, establishes a collection of printing parameters. A stepper motor propels the filament through a nozzle with a diameter of 0.4 mm, while the nozzle is heated to a predetermined temperature in order to liquefy the filament. The process of creating the 3D model starts in specialized software for 3D modeling, from which it is then saved as a file with the .stl extension. Subsequently, this file is imported into the software of the printer, in which it is sliced and laid out with respect to the construction base. The selection of printing parameters, such as infill density, printing speed, layer height, wall count, shell thickness, and the decision to use support structures or a raft, is determined by the material's characteristics and the desired results. Once all settings are configured, a G-code file is created and transmitted to the printer, which then carries out the process of printing the physical model.

The CT3 Texture Analyzer was utilized to perform the three-point bending test. The device is outfitted with a calibrated load cell that can measure forces up to 500 N with a precision of 0.5%. Figure 3 presents a diagram illustrating the test arrangement.

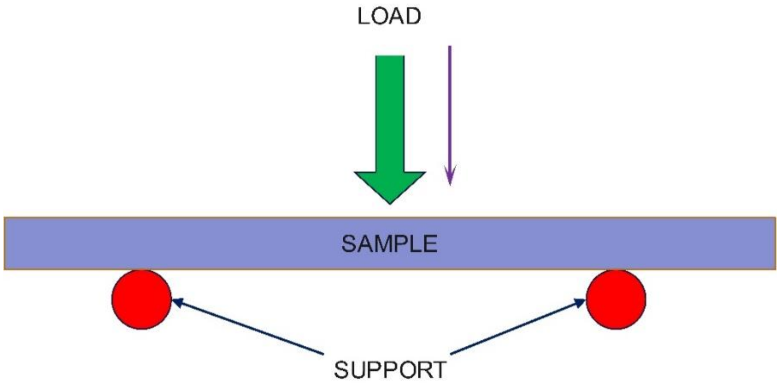

Fig.3. Schematic of the flexural test

The test parameters were continuously monitored in real time using the instrument's integrated software. This software tracks the impact of the load on displacement throughout the whole period of the test. The data was collected in real-time using the frequency sampling configuration that was created at the beginning of the test. The gathered data enabled the computation of strain, stress, and strain rate. For testing purposes, the sample was placed on two roller bearings, as shown in Figure 3. The indenter exhibited a velocity of 0.1 mm/s during both the withdrawal and compression stages. The compression process was stopped, and the indenter was withdrawn after reaching the desired displacement. The threshold displacement, measured from the horizontal baseline, was established at 17.3 mm, marking the conclusion of the test. The study aims to analyze the correlations between load and displacement, as well as load and bending angle.

RESULTS AND DISCUSSION

The left image in Figure 4 depicts the sample at the precise moment that it reaches its maximum bending angle during the test. The state of the sample following the test is illustrated in Figure 4 (right image). After the flexural test was finished, the sample somewhat regained its former shape but still showed visible distortion. This suggests that the applied force on the material surpassed its elastic limit. The ultimate deflection angle, following the material's relaxation, was documented at 12°, as depicted in Figure 5.

Fig.4. Samples before and after relaxing (left) and their maximum bending (right)

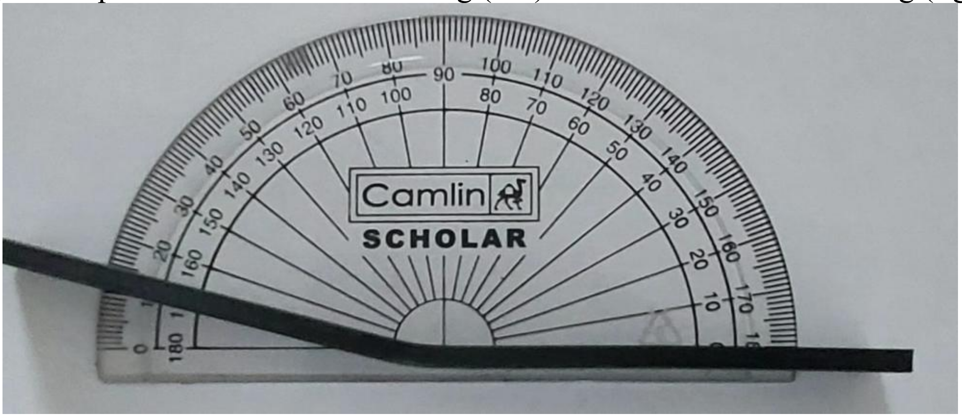

Fig.5. Angle of deflection after the relaxing of the sample

The threshold displacement of 17.3 mm, determined during the test, corresponds to a maximum compressive load of 30 N, as depicted in Figure 6. The diagram in Figure 6 was obtained by applying the bending angle calculation formula presented in reference[16]. At the peak load of 30 N, the deflection angle measured is 20°. After the indenter was removed, the compressive force was gradually lowered. However, the sample still showed bending and reached a maximum bending angle of 32° at a load of 25 N, as shown in Figure 7. After reaching this point, the sample stopped bending any further and started returning to its previous shape. The material's elastic limit was surpassed at around 24 N, resulting in a bending angle of roughly 12.5°.

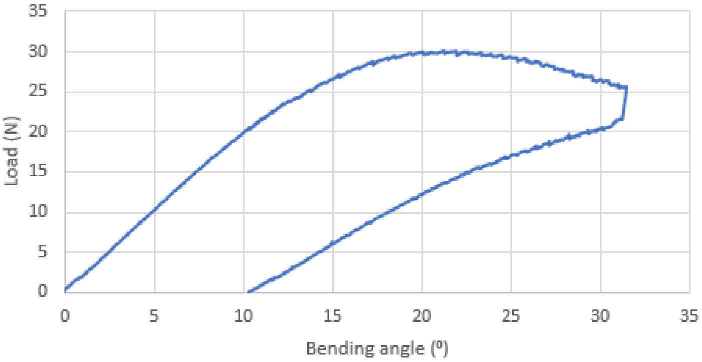

Fig.6. The relationship between the bending angle and the compressive load was determined during a flexural.

The bending angle was computed using the equation presented in reference[16].Based on the illustration in Figure 6, the sample ultimately reached a final bending angle of approximately 10.5°. Experimental observations revealed that the bending angle reached around 12° when the sample was taken out of the test equipment and given time to relax, as depicted in Figure 5. The difference between the calculated final bending angle (Figure 6) and the observed value from the experiment (Figure 5) is roughly 1.5°. Larour et al.[16] observed that different methodologies used to calculate bending angles can produce varying outcomes, emphasizing the necessity for experimental confirmation. Nevertheless, the values exhibit a reasonable level of consistency despite the minor discrepancy.

Figure 7 depicts the relationship between the flexural strength of the PLA sample and the deflection of the sample during the three-point bending test. The highest recorded flexural stress was 270 MPa, occurring at a deflection of 12.5 mm. The first little failures in the sample were noticed after it deflected by about 6.5 mm, which corresponds to a flexural stress of 215 MPa. The flexural strength of the Iron-PLA sample was measured to be 215 MPa.

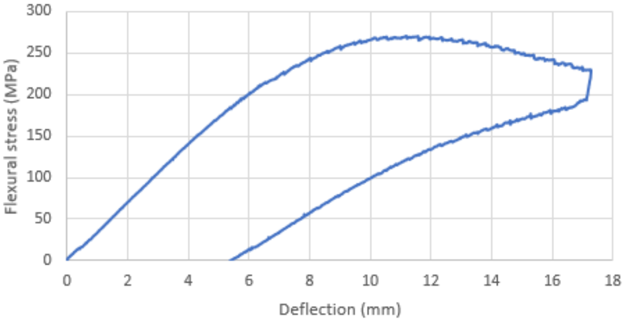

Fig.7. The flexural strength of an Iron-PLA sample is measured during flexural test, with the sample deflection being the independent variable.

The results of this investigation align with the conclusions published by other studies[17]. In their study, reported a decrease in flexural strength for 3D-printed layers at a thickness of 0.2 mm, with values measuring at 68 MPa. Their findings also emphasized a notable decrease in Iron-PLA flexural stress as layer height increased. Conversely, the layer height employed in our investigation was 0.1 mm, which is anticipated to result in increased flexural strength, as demonstrated in Figure 7. The PLA samples in the study had a 40% infill density, and the flexural test was performed using an indenter speed of 0.2 mm/s. For our study, we utilized samples that were printed with a 100% infill density and subjected to testing using an indenter speed of 0.1 mm/s. The variations in printing parameters were responsible for the increased flexural strength reported in our samples.

CONCLUSIONS

The Iron-PLA beam was effectively produced utilizing FDM 3D printing with a layer thickness of 0.1 mm, exhibiting good mechanical properties during three-point bending tests. The samples, which were printed with a 100% infill density, demonstrated a flexural strength of 215 MPa. The material's elastic limit was surpassed at around 24 N, resulting in a bending angle of roughly 12.5°. Following the relaxation of the material and the completion of testing, the beam's final bending angle was observed to be 12°. The experimental results corroborated the numerical predictions of the final bending angle. The researchers discovered that the density of the infill material used in 3D printing had a substantial influence on the mechanical characteristics of the printed samples. Subsequent investigations will prioritize the alteration of this parameter in order to gain a deeper comprehension of its impacts and to refine the 3D printing parameters for superior mechanical functionality of the product.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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