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Investigation on Tensile Properties of Redwood PLA Using FDM Process

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Abstract

Fused Deposition Modeling (FDM) is an additive manufacturing technique employed to construct comprehensive 3-dimensional models using a variety of materials, catering to diverse applications. This study explores the fabrication of REDWOOD polylactic acid using (FDM) additive manufacturing processes. REDWOOD PLA, recognized for its biodegradability and renewable sourcing, holds promise as an eco-friendly material for 3D printing applications. The research investigates the tensile properties of REDWOOD polylactic acid (PLA) fabricated through Fused Deposition Modeling (FDM), emphasizing the impact of process variables. The parameters examined include printing speed (40, 50, and 60 mm/s), raster angle (0°, 45°, and 90°), layer thickness (0.1, 0.2, and 0.3 mm) and infill density (60%, 80%, and 100%). Through adherence to ASTM D368 standards, a total of 27 samples are produced and analyzed. The findings obtained from tests were analyzed and compared. Through systematic experimentation, it was found that specimens with printing speed of 60 mm/s, raster angle at 45°, a layer thickness of 0.1 mm, and an infill density of 80% exhibited the highest tensile strength [UTS-31.127 MPa]. Results reveal optimal printing conditions for achieving high tensile strength, providing valuable insights into the manufacturing of REDWOOD PLA via FDM. This research contributes to the advancement of sustainable additive manufacturing materials and informs future endeavors aimed at optimizing process parameters for enhanced mechanical performance.

Keywords: FDM, REDWOOD PLA, tensile strength, UTS, infill density

INTRODUCTION

3D printing, or additive manufacturing, has transformed the manufacturing sector by allowing quick creation of intricate designs, bespoke parts, and small-scale production at lower expenses. Among the various 3D printing technologies, Fused Deposition Modeling (FDM) has become a widely favored technique. This technique functions by pushing a thermoplastic filament through a heated nozzle, layering material to form a three-dimensional object. The popularity of FDM stems from its affordability, straight forwardness, and the variety of materials compatible with the process. Polylactic Acid (PLA) is frequently utilized in Fused Deposition Modeling (FDM) thanks to its biodegradability, user-friendliness, and decent mechanical characteristics [1]. Sourced from renewable materials such as sugarcane or corn starch, PLA offers an eco-friendly substitute to conventional petroleum-based plastics. Its low melting point and minimal warping render it ideal for numerous applications, including prototyping and functional components. Despite this, the inherent mechanical properties and aesthetics of standard PLA can be limiting, prompting the creation of composite materials like Redwood PLA [2].

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Redwood PLA is a composite filament that combines PLA with wood fibers, creating a material that offers both the beneficial properties of PLA and the unique characteristics of wood. This blend results in a filament that not only has the mechanical benefits of PLA but also exhibits a wood-like appearance and texture, which is highly desirable for certain applications. The addition of wood fibers can also potentially improve the material's properties, such as tensile strength and stiffness, making Redwood PLA a compelling option for both aesthetic and functional components. The use of Redwood PLA in FDM presents several advantages. Firstly, the wood fibers give the printed objects a natural, wood-like finish that is appealing for decorative items, architectural models, and artistic pieces [3]. Secondly, the composite material can provide enhanced mechanical properties compared to standard PLA, potentially making it suitable for a wider range of structural applications. Additionally, the biodegradable nature of both PLA and the wood fibers aligns with the increasing demand for sustainable and eco-friendly materials in manufacturing. This paper aims to explore the tensile properties of Redwood PLA when manufactured using FDM technology. By examining the tensile strength, elasticity, and failure behavior of Redwood PLA, this research aims to offer a thorough understanding of the material's capabilities and limitations. Grasping these characteristics is essential for assessing the appropriateness of Redwood PLA for different uses and for fine-tuning the FDM process parameters to attain optimal performance [4]. This study will contribute to the broader knowledge of composite materials in additive manufacturing and help identify new opportunities for the use of Redwood PLA in both consumer and industrial markets. This study seeks to expand the overall knowledge of composite materials in additive manufacturing and identify new potential applications for Redwood PLA in consumer and industrial markets [5].

MATERIALS AND METHODS

Material

In this study, redwood PLA filament was produced by Flashforge 3D Technology Co. Ltd, as shown in Figure 1. The filament is composed of PLA and 20% recycled redwood particles. It prints similarly to standard PLA, offering a beautiful redwood color and texture, with the printed object even having a wood-like scent. The filament used in this research has a diameter of 1.75 mm, and the average size of the redwood particles is approximately 200 µm [6].

Fabrication of Samples By FDM

In the FDM process, the 3D CAD model of the specimen is converted into an STL file, which is used to create sliced layers for printing. A filament is fed through the extrusion head, heated to a semi-liquid state, and then extruded through a nozzle onto the build platform [7]. Each layer is formed horizontally, and the nozzle is lifted vertically to print the next layer, repeating until the component is fully printed. Afterward, the component is cleaned and prepared for further analysis or use.

Figure 1. Redwood PLA filament.

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The Creality Ender 3 V3 SE 3D Printer is used for this FDM process (Fig. 2). Its specifications include a build volume of 220x220x250 mm, a build speed of up to 180 mm/s, a layer thickness ranging from 0.1 to 0.4 mm, a nozzle diameter of 0.4 mm, and a maximum extruder temperature of 255 °C. Specimens were prepared with a constant nozzle temperature of 200 °C [8]. The specific process parameters are outlined in Table 1. The selected process parameters influencing the output characteristics [9].

Table 1. Parameters and variable levels.

Parameters	Units	Variable levels		
Printing Speeds	mm/s	40	50	60
Raster Angle	Deg	0	45	90
Infill density	%	60	80	100
Layer Thickness	mm	0.1	0.2	0.3

Measurement of Tensile Properties

A tensile test was conducted on 27 samples with process parameters including a layer thickness of 0.1, 0.2& 0.3 mm, printing speeds of 40, 50, and 60 mm/s, orientations of 0, 45, and 90 degrees, and infill densities of 60%, 80%, and 100%, following ASTM D368 standards, using flat specimens with a width of 19 mm and a thickness of 7 mm in Figure.2. A series of tensile tests were conducted on 27 samples (Figure 3- 4) using Universal Testing Machines (UTM) [10]. Each sample underwent meticulous preparation to ensure consistency in testing conditions. The UTM machines applied a uniaxial force to each specimen, gradually increasing the load until failure occurred. Throughout the testing process, various parameters such as tensile strength, yield strength, and elongation at break were recorded.

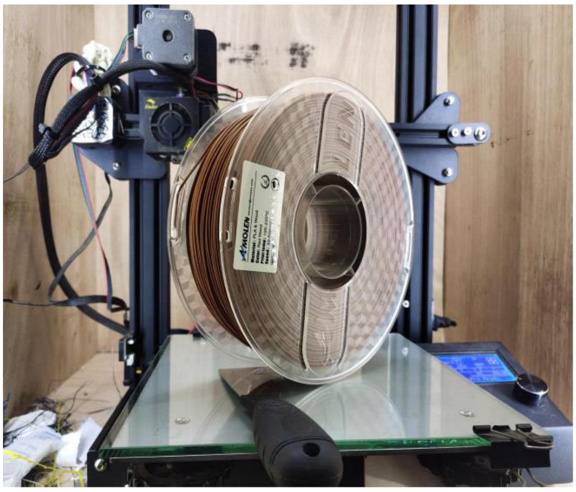

Figure 2. Creality ender 3 V3 SE 3D printer.

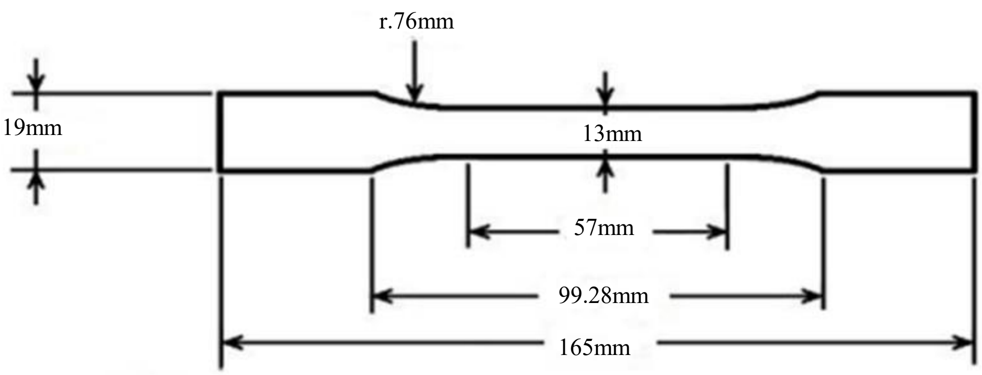

Figure 3. Schematic representation of tensile specimen.

Figure 4. Specimens after tensile testing.

Table 2. Experimental Observations.

S. N.	Layer thickness(mm)	Printing speed(mm/s)	Raster angle(degree)	Infill density(%)	% of elongation	UTS[N/mm^2]
1	0.2 mm	50	0	100	9.540	29.352
2	0.2 mm	60	45	60	9.960	20.836
3	0.1 mm	50	0	80	10.680	22.847
4	0.3 mm	50	45	60	10.330	20.836
5	0.2 mm	40	45	100	6.000	30.597
6	0.2 mm	60	0	80	10.330	23.161
7	0.3 mm	50	45	100	7.610	30.215
8	0.1 mm	60	45	80	10.490	31.127
9	0.2 mm	50	45	80	5.000	22.808
10	0.2 mm	50	45	80	3.810	19.267
11	0.2 mm	50	90	60	5.560	16.628
12	0.1 mm	40	45	80	4.090	18.433
13	0.2 mm	60	45	100	5.120	30.745
14	0.2 mm	40	0	80	5.120	21.219
15	0.2 mm	60	90	80	7.160	22.985
16	0.2 mm	50	45	80	5.960	14.905
17	0.2 mm	40	45	60	5.260	17.844
18	0.3 mm	60	45	80	5.020	24.319
19	0.2 mm	50	0	60	5.250	18.021
20	0.1 mm	50	90	80	4.470	18.021
21	0.3 mm	40	45	80	4.110	18.688
22	0.1 mm	50	45	100	5.440	28.920
23	0.2 mm	40	90	80	5.600	18.639
24	0.1 mm	50	45	60	5.020	13.763
25	0.2 mm	50	90	100	4.740	25.388
26	0.3 mm	50	0	80	6.040	19.218
27	0.3 mm	50	90	80	6.230	18.472

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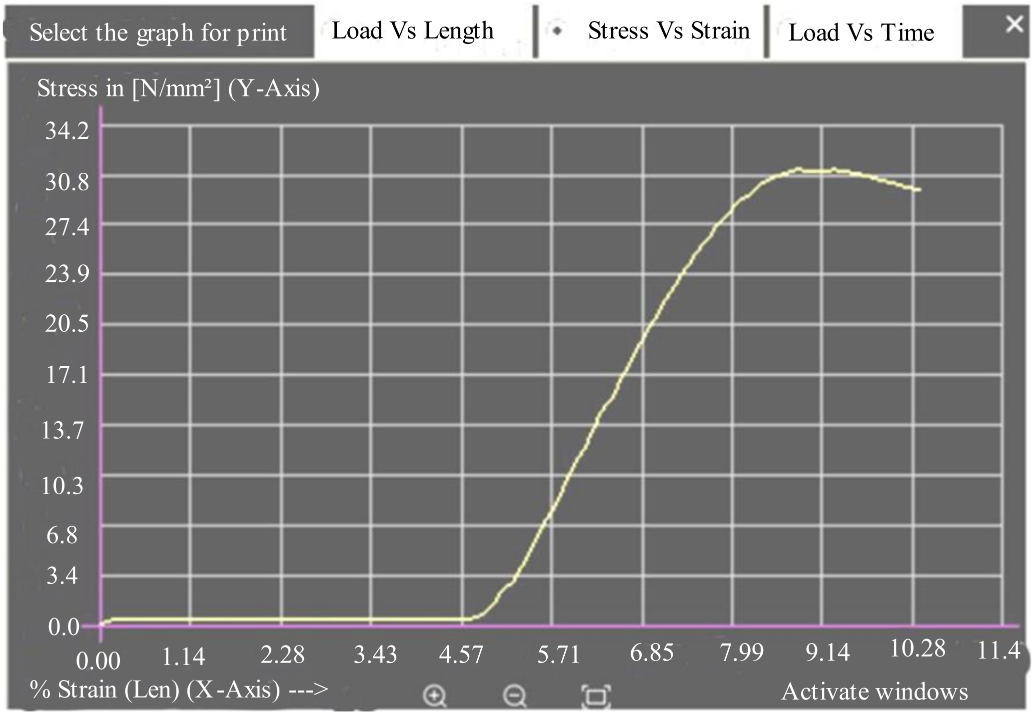

Figure 5. Stress Vs strain curve for sample 8.

RESULTS AND DISCUSSIONS

Design Expert-16 was used for experimental planning and evaluating the strength of Redwood PLA composites. Multiple process parameters-including printing speed, raster angle, layer thickness, and infill density-are detailed with their respective values in Table 1. A Box-Behnken design with four factors and three center points, resulting in 27 runs, was employed to structure the experimental setup [11]. The corresponding outputs for each set of inputs are shown in Table 2.The raster angle refers to the orientation of the individual strands or tracks of material laid down during the 3D printing process. In this context, angles of 0, 45, and 90 degrees denote the directions in which these strands are arranged:0 degrees: The strands are oriented horizontally, 45 degrees: The strands are oriented diagonally at a 45-degree angle.90 degrees: The strands are oriented vertically.Infill density denotes the amount of material utilized to fill the interior of a printed object. It is usually expressed as a percentage, with higher percentages indicating more material and thus a denser, stronger object: 100% infill density: The object is completely solid, with no gaps or voids inside [12]. This provides the maximum strength and rigidity but also uses the most material and takes the longest to print: 80% infill density: The object is mostly solid with small gaps inside [13]. This offers a balance between strength and material usage, making it strong while still saving some material and print time: 60% infill density: The object has a more noticeable pattern of gaps inside. While still providing reasonable strength, it uses less material and prints faster than higher densities [14]. The stress vs strain curve for sample 8 as shown in Figure 5, indicated that ultimate tensile strength value and its elongation.

CONCLUSION

Redwood PLA composites were manufactured via FDM, with an investigation into their tensile properties involving the adjustment of different process parameters. The study yielded the following findings:

- Tensile strengths range between approximately 13.76 N/mm² to 31.13 N/mm², showcasing the impact of parameter variations on material performance.
- *Sample 8 (printing speed*: 60 mm/s, Raster Angle: 45 degree, Layer Thickness: 0.1 mm, Infill Density: 80%) shows a high tensile strength of 31.13 N/mm² and a decent percent elongation of 10.49%, making it a strong candidate if high strength is a priority.

- *Sample 1 (printing speed*: 50mm/s, Raster Angle: 0 degree, Layer Thickness: 0.2 mm, Infill Density: 100%) also exhibits high tensile strength (29.35 N/mm²) and moderate percent elongation (9.54%), indicating robust performance.
- *Sample 13 (printing speed*: 60 mm/s, Raster Angle: 45 degree, Layer Thickness: 0.2 mm, Infill Density: 100%) shows good strength (30.74 N/mm²) and reasonable percent elongation (5.12%), striking a balance between strength and flexibility.

Declaration of Interest

The authors declare no conflicts of interest regarding the research presented in this article. This work was conducted impartially, and there are no financial, personal, or professional affiliations that could be perceived as influencing the research outcome. The authors affirm their commitment to maintaining the highest standards of integrity and transparency in reporting their findings.

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