



Sustainable Innovation in 3D Printing: Biodegradable PLA Composites Reinforced with Wood Waste

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Abstract— This piece of research aims to develop sustainable and novel bio composites for 3D printing based on a biodegradable polymer, polylactic acid (PLA) reinforced with wood waste, to address challenges in additive manufacturing such as enhancing material performance, reducing production costs and overall environmental impact. The mechanical characteristics of PLA (polylactic acid) and Wood + PLA composite specimens that were 3D printed using a Creality Ender 3 FDM printer at infill densities of 25%, 35%, and 45% were examined. Standardized equipment such as a 50 kN computerized universal testing machine, a 6-tonne conventional universal testing machine, a computerized impact tester (0–100 J range), and a Shore D Durometer were used to test the specimens for tensile strength, compression strength, impact resistance, and hardness. According to tensile tests, PLA demonstrated constant strength at 35% and 45% infill, however Wood + PLA only performed at its best at 35% infill, with a notable decline at 45% infill. Both materials maintained high stiffness in compression tests, with PLA showing better stress resistance. According to impact testing, PLA absorbed more energy than Wood + PLA, which was more brittle because of the wood particles. Comparing PLA to Wood + PLA, hardness tests verified that PLA had greater surface resistance. The findings demonstrate how material composition and infill density affect mechanical performance, with PLA having a higher edge over Wood + PLA in the majority of tests. Nevertheless, Wood + PLA composites have special qualities that make them appropriate for stiff, lightweight applications. In order to improve the mechanical properties of the Wood + PLA composite, future research should concentrate on optimizing the particle dispersion and investigating various wood-to-PLA ratios.

The study also shows how low cost and sustainable PLA-based composites produced with natural resources can be used in Additive Manufacturing technology replacing common materials.

Refined products with basic raw materials effectively reduce part costs without compromising part characteristics or performance. It also reduces its carbon footprint, becoming more sustainable. There are important advantages when applying these materials in areas requiring good mechanical properties considering their readiness of end-life cycle using composting or even recycling after grinding and processing back into filament form, meaning nothing goes wasted all over life cycle.

Keywords—3D printing, Sustainable materials, Wood waste, PLA composites

Introduction

With the advancement of technology in recent years, additive manufacturing (AM), has found widespread use in everyday life. One of the rapid prototyping techniques, 3D printers are employed in both industry and research and academic pursuits.

Using a data file created from geometry data with basic or complicated geometry, 3D production is a computer-aided method of production. Layer by layer, the components will be created using various connecting principles in accordance with conventional techniques from the generated data file.

Instead of using conventional production methods and stereotypical manufacturing, additive manufacturing (AM) uses 3D model data to manufacture items by depositing materials layer by layer.

This domain has rapidly expanded and changed a variety of industries, including the healthcare and automotive sectors.

When compared to conventional manufacturing methods, this technology delivers previously unheard-of levels of customisation, material efficiency, and waste reduction. However, there are questions over sustainability due to the effects of 3D printing on the environment, especially the use of petroleum-based polymers. An important step toward more environmentally friendly additive manufacturing solutions has been made with the creation of biodegradable materials like polylactic acid (PLA) and creative reinforcements like wood waste. The potential of biodegradable PLA composites combined with wood waste as a sustainable 3D printing breakthrough is examined in this research.

I. 3D PRINTING

A. The need for sustainable materials in 3D printing

The market for 3D printing has grown rapidly worldwide, and its uses are becoming more widespread across industries. Notwithstanding its many benefits, the sector faces serious environmental challenges because to its reliance on synthetic polymers like polyethylene terephthalate glycol (PETG) and acrylonitrile butadiene styrene (ABS). If not disposed of properly, these materials are non-biodegradable and cause long-term contamination. Furthermore, energy-intensive procedures that contribute to greenhouse gas emissions include the mining and manufacturing of petroleum-based polymers. On the other hand, PLA provides a biodegradable substitute made from renewable resources like sugarcane or maize starch. Lactic acid, a naturally occurring substance with little environmental impact, is produced as it breaks down. Despite its widespread use, PLA's applicability in demanding conditions are limited by its intrinsic brittleness and inferior mechanical qualities when compared to synthetic polymers. Because of this restriction, scientists and engineers are investigating composite materials, in which PLA is strengthened with additives to improve performance while preserving biodegradability, maintaining the veracity of the specifications.

B. Wood waste as a reinforcement material

Wood waste, a plentiful byproduct of the furniture and forestry sectors, offers a strong chance to increase PLA composites' sustainability. By repurposing a resource that would otherwise be discarded, the integration of wood waste into PLA is consistent with the circular economy's tenets. The PLA-wood composites that are produced have better mechanical qualities, such as increased elasticity and tensile strength. Additionally, the organic beauty of wood particles gives 3D-printed goods a distinctive look and feel that increases their marketability. Using wood waste as a reinforcing element lowers the composite's overall carbon footprint from an environmental standpoint. When compared to synthetic alternatives, the energy required to produce wood-based fillers is far lower. Furthermore, wood waste's biodegradability guarantees that the composite material will continue to be ecologically favourable for the duration of its existence. According to recent research, PLA-wood composites are a good substitute for traditional polymers in 3D printing because they maintain high levels of biodegradability even when wood particles are added.

C. Future scope

PLA-wood composites are a potential option for environmentally friendly 3D printing, but in order to maximize their scalability and performance, a number of issues need to be resolved. The even distribution of wood particles throughout the PLA matrix is a critical factor. Inconsistent mechanical characteristics and flaws in the printed goods can result from poor dispersion. To address this problem, surface treatments for

wood particles and sophisticated compounding processes are being investigated.

Finding a balance between mechanical performance and biodegradability is another difficulty. Even though PLA benefits from wood waste in some ways, more study is required to increase its moisture resistance and thermal stability to satisfy the demands of many applications. To provide standardized formulations and processing methods, cooperation between material scientists, engineers, and industry stakeholders will be crucial. A creative and sustainable 3D printing solution is provided by the incorporation of wood waste into biodegradable PLA composites. This strategy has the potential to transform the additive manufacturing sector and advance global sustainability objectives by tackling the technical and financial obstacles. PLA-wood composites stand out as a shining example of responsible innovation, opening the door to a more environmentally friendly industrial future as the need for eco-friendly materials keeps growing.

II. LITERATURE SURVEY

For the purpose of analysing mechanical behaviour, Barnasree, Kumar, and Bhowmik et al. [1] investigated wood dust particle reinforcement in epoxy-based composite. The particle of sun-dried wood dust was utilized as reinforcement, and the resin was LY 556 epoxy. The study utilized six different percentages of filler particles. UTM was used for the tensile and flexural tests, and the ASTM Standard was used to determine the sample size. Using GRA, many design parameters were optimized, such as filler content and loading speed with tensile and flexural strength. One benefit of optimization by GRA is the ability to choose the best and worst solutions. According to GRG, test run number three is the least significant and test run number thirteen is the most appropriate.

Sundi wood dust particle reinforced composite materials were fabricated and experimented by Kumar, Sahoo, and Bhowmik et al. [2]. Sundi wood dust particle reinforced epoxy composite was treated at seven different filler weight percentages in this experiment. To examine the mechanical behaviour of composites, tensile and flexural tests were conducted at three distinct rates. With a filler weight of 10% and 15%, respectively, and a speed of 1 mm/min, the maximum load, tensile stress and strain, and flexural stress and strain values are recorded at maximum and minimum at 10% filler weight with a speed of 2mm/min and at 0% filler weight with a speed of 1mm/min respectively. At 10% filler weight with a speed of 1mm/min and 2mm/min best mechanical properties are observed.

In order to create multilayer bamboo epoxy-based composite laminates, Verma and Chariar et al. [3] conducted research on dry bamboo culms using epoxy resin. The manufactured composite material's tensile, flexural, and screw-holding capacities were assessed. As recommended by ASTM standards, the mode of failure was determined at the macroscopic level, and the mechanism was investigated at the microscopic level using SEM examination of cracked surfaces under various test conditions. Because the lamina configuration has an impact on mechanical qualities, a variety of parameters may be used to determine the use of bamboo laminates. The mechanical characteristics of the layered laminate bamboo composites (LLBCs) that were studied are comparable to those of teak wood. The ability to increase volume in any shape and in any direction by increasing the number of layers allows the thickness and shape of the composite to be tailored during fabrication to meet specific requirements. This makes LLBCs suitable for use as building and general-purpose materials, such

as furniture, beams, and columns, according to a comparative cost and mechanical properties analysis of LLBCs with teak wood timber. The economics of rural residents may benefit from the increased use of bamboo and technology in the production of LLBCs. Using epoxy resin, dry bamboo culms were processed into a thin lamina and then cold pressed. As the lamina angle increased, the LLBCs' tensile and compressive qualities decreased.

A study by Cerqueira, Baptistab, Mulinari, et al. [4] examined the production of composite materials using natural fibers serving as reinforcing fibers. He assessed how a chemical changes affected the mechanical properties of composites made of polypropylene reinforced with sugarcane bagasse fiber. After treating the fibers with a 10% sulfuric acid solution, they were delignified using a 1% NaOH solution. The impact, flexural (3-point bending), and tensile tests of the manufactured composites were examined. SEM (secondary electron mode) was used to analyze the fractures. Composite samples' results are comparable to those of pure polymers. This study shown cellulose based chemically modified from sugarcane bagasse has better property than chemically untreated fibre particle reinforced composites.

The erosion wear process of a nonlinear issue with operational variables was analyzed by Rout and Sahoo et al. [5]. Numerous limitations, such as impact velocity, impingement angle, material, erodent size, etc., affect how a material wears. Experiment with materials that have a combination of these properties to have the lowest rate of erosion. Waste granite powder was being considered as a filler for the reinforced epoxy composite's jute fiber. It was determined that low-cost natural fiber reinforced composite may be made from industrial waste, such as granite powder. Additionally, the composite samples' resistance to erosion was improved by the chemical treatment of the fiber and filler.

Shankar and Rao et al. [6] investigated the tensile characteristics of hybrid composites made of epoxy reinforced with glass and bamboo. Analysis of bamboo fiber properties following alkali treatment. The results of his research show that hybrid composites have better tensile qualities than alkali-treated bamboo fiber reinforced composites, regardless of the amount of glass fiber.

The mechanical characteristics of hybrid composites reinforced with palm-Kevlar fibers were examined by Mosawi et al. [7]. Hardness, flexural strength, tensile strength, and impact strength were all examined. Fibers in varying percentages (10%, 20%, 30%, 40%, 50%, 60%, 70%, & 80%) combined with epoxy resin (LY 556). During testing, it was shown that the mechanical qualities of hybrid composites increased with 50% Kevlar and 50% Palm fibers, respectively. However, at 70–80%, the mechanical properties decreased because of the decreased wettability between the fibers and resin.

The production of high-performance materials from natural resources was the subject of research by Faruk, Bledzki, Peter, and Sainet al. [8]. The characteristics of biobased composite materials vary depending on a number of factors, including fiber type, processing techniques, method modification, etc. This article provides a thorough review of the widely used biopolymers and natural fibers. The full characteristics of the natural fiber utilized for biocomposites' reinforcement, including its source and category configuration having 130 properties were also examined.

Sarkia, Hassana, Aigbodiona, and Ogheneveta et al. [9] investigated the mechanical behavior and morphology of filler reinforced with coconut shell particles using epoxy-based

composites. The epoxy polymer matrix used to create the coconut shell-filled composites had up to 30% coconut shell fillers. Scanning electron microscopy (SEM) of composite surfaces revealed strong interfacial contact between the epoxy matrix and coconut shell particles. Following testing, it was found that the tensile strength and modulus values rose in proportion to the amount of coconut shell particles present. When compared to pure epoxy resin, the impact strength was somewhat reduced.

According to Faut Kartal and Arslan Kaptan, [10] in order to improve the mechanical performance and sustainability of 3D-printed components, the study explores the addition of waste beech sawdust (WBS) to polylactic acid (PLA) composites for use in additive manufacturing. Through a single-screw extrusion method, WBS, a byproduct of industrial lumber processing, was utilized in different concentrations (0–20%) to create PLA composite filaments, which were then used in fused filament fabrication (FFF). In addition to thermal stability and microstructural examination, mechanical attributes such as tensile, flexural, and impact strengths were assessed. The findings showed that adding WBS improved the PLA composites' stiffness and hardness, with 5–10% WBS content exhibiting the best mechanical performance. By recycling waste materials and lessening the environmental effect of disposing of industrial leftovers, using WBS as a reinforcement material supports sustainable development goals. Additionally, this method gives the possibility of using fewer non-renewable resources in the production of composites.

In a study by Brailson Mansingh Bright and et.al., [11] altering the weight percentage (wt%) of the reinforcement and by annealing process, it has proven possible to improve the mechanical and thermal properties of 3D printed polylactic acid (PLA) composites reinforced with coir fiber powder (CFP). CFP/PLA composite filaments were created with CFP contents of 0.1, 0.3, and 0.5 weight percent. Test specimens for CFP/PLA were printed using these filaments. After being annealed in a hot air oven for 120 minutes at 90°C, the specimens were allowed to cool to room temperature. These specimens underwent mechanical, morphological, crystallographic, and thermal characterizations. When printed composite specimens with 0.5 weight percent CFP as reinforcing material were used, the tensile and flexural strengths of neat PLA were found to be 49.7 and 82.4 MPa, respectively, which dropped by 6.4% and 8.13%. Conversely, the CFP/PLA composite specimen that had been annealed and had 0.1 weight percent CFP as reinforcement showed greater tensile and flexural strength. In particular, its highest tensile strength was 56.4 MPa, and its maximum flexural strength was 92.9 MPa. These values are 13.5% and 12.7% higher than those of pure PLA, respectively. Compared to the unannealed CFP/PLA composite specimen with the same weight percentage of CFP reinforcement, these strengths are 15.5% and 16.7% higher, respectively. By improving the crystallinity index (63%) and crystalline size (6.7 nm), the annealing method raised the crystallinity of composites. Composites are appropriate for use in food and medical packaging due to their excellent thermal stability.

Nasir, Tufan and Mehmat [12] in their investigation state that PLA composites supplemented with variable percentages of waste pine sawdust were examined for their mechanical, thermal, and morphological characteristics. Test samples were created using a 3D printer in accordance with the mechanical test standards in order to ascertain the mechanical characteristics of the acquired filaments. With no issues, the filaments made from blends that included the maximum amount of wood sawdust (20%) could be printed using a 3D printer. The addition of wood sawdust to the clean PLA polymer resulted in a drop in the composites' tensile strength values. However, the

inclusion of wood sawdust was shown to greatly boost the flexural strength values of the wood sawdust/PLA composites. It was determined that leftover pine sawdust may be compatibly extruded with PLA polymer and is a suitable reinforcing material for the creation of composite filament for 3D printing applications. Sawdust can therefore be utilized as a waste resource with additional value to produce premium 3D polymeric materials.

Danquah et al. [13] offer a thorough analysis of wood fiber reinforced polylactic acid (PLA) composites in this research. The characteristics of PLA and wood fibers, as well as the difficulties in fusing them to produce a composite material, are covered by the authors. Additionally, they go over several methods of processing wood-PLA composites and how processing variables affect the final composite's characteristics. The authors explore the variables influencing the mechanical, thermal, and water absorption characteristics of wood-PLA composites and provide an overview of the literature in this area. Additionally, the literature on wood-PLA composites' sustainability and biodegradability and contrast their performance with that of other natural fiber reinforced composites is examined.

Chen et al. [14] investigates and analyses composites made of polylactic acid (PLA) reinforced with wood and other natural fibers. The authors study the characteristics of PLA and natural fibers such cellulose, lignin, and hemicellulose as well as the possibility of reinforcing PLA composites with natural fibers. Additionally, various techniques for processing PLA-based composites and how processing affects the final materials' characteristics are studied. The uses of PLA-based composites reinforced with natural fibers and their performance with that of other composite material types is analyzed. They come to the conclusion that PLA-based composites reinforced with natural fibers have a very high usage in a variety of industries, including the construction, automotive, and packaging sectors due to their biodegradable and renewable properties.

A comparison of polypropylene (PP) and polylactic acid (PLA)/wood flour composites is presented in this paper by Marcovich et al. [15]. The characteristics of PLA, PP, and wood flour are covered by the writers, along with the possibility of employing wood flour as a reinforcing filler in these materials. Additionally, they investigate various processing methods that are employed to create these composites as well as how processing circumstances affect the final materials' characteristics. Further, the uses of PLA/wood flour composites and their performance with that of PP/wood flour composites are examined. According to their findings, PLA/wood flour composites provide the benefit of being renewable and biodegradable, but they also exhibit mechanical qualities that are comparable to or marginally inferior to those of PP/wood flour composites.

III. LITERATURE GAP AND OBJECTIVES

Wood plastic composite (WPC) may be molded into nearly any size or shape, even arched or bending shapes, because it is made from a substance that begins as a paste. WPC can be colored or dyed to fit practically any design scheme, demonstrating its inherent versatility. Considering the lengthy history of natural lumber as a building material, WPCs are still relatively new. However, one of the most important and promising engineered wood products to date is wood-plastic composites (WPCs), which have been widely used in the building construction, transportation, landscape, and municipal engineering sectors. It has been used to gradually replace traditional composites made of wood. Advanced composite

materials have a very promising future. The use of these materials will rise significantly across a wide range of business sectors, including aerospace and defense. Over time, the materials utilized in practically every industry will be dominated by these exceptionally strong, lightweight materials. The 3D printed components which use WPC as a material will result as heat and stress resistant, reduce thermal contraction and boost tensile strength.

From the literature review there are considerable gaps which are identified. One of the major gap with the widely used feedstock materials in the FDM process, acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA), is the lack of understanding regarding how the mechanical characteristics of PLA, such as strength, flexibility, and heat resistance, impact the sustainability, functionality, and durability of printed components. In order to address these issues, the following are the objectives of this piece of research.

- To fabricate and evaluate a composite material suitable for usage as feedstock in FDM 3D printers.
- To evaluate the properties of specimens fabricated with wood reinforced with polylactic acid (PLA) composite material.

IV. METHODOLOGY

The methodology involves the following steps.

1. Study of the conventional PLA Filament
2. Study of the available Wood PLA Filament
3. Description of Extrusion compounding of Wood PLA Filament Material.

A. PLA Filament

One of the most popular materials for 3D printing is polylactic acid (PLA). Made from renewable resources like cornstarch or sugarcane, it is a material that is both biodegradable and compostable. PLA creates prints of excellent quality with a glossy finish and is simple to print on. Because of its price and ease of use, it is also a popular resource for novices. PLA has the advantage of having a low warping propensity, which reduces the likelihood that the printed item may warp or distort while being printed. It is also easier to work with and less likely to clog the nozzle because it has a lower printing temperature than other materials.

PLA can be printed with unique finishes, such metallic or translucent ones, and comes in a variety of colours. Because of this, it's a common option for aesthetically pleasing or decorative prints. Despite its many benefits, PLA is not as robust or long-lasting as other materials like nylon or ABS. Applications where great strength and impact resistance are not necessary are best suited for PLA. It is frequently used in making of toys, models, and home goods. Furthermore, PLA's resilience to temperature has certain limitations. It is not appropriate for applications requiring high-temperature resistance since it softens and deforms at temperatures exceeding 60°C. In general, PLA is a popular and adaptable filament material for 3D printing.

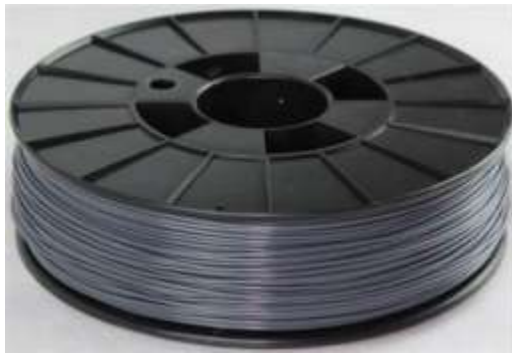


Figure 1. 3D PLA Filament Coil

B. Wood Reinforced PLA

One kind of filament material utilized in 3D printing is wood reinforced PLA filament, sometimes referred to as wood filament or wood-infused filament. In order to produce a filament with a wood-like feel and look, PLA is combined with wood particles, usually sawdust or wood flour. The natural look and feel of wood-reinforced PLA filament is one of its key benefits. To provide a more genuine wood finish, the filament's wood particles can be sanded and stained to create a distinctive wood grain pattern and texture. This makes it a popular option for furniture, décor, and artwork—applications where a rustic or natural look is sought. Nevertheless, wood reinforced PLA filament is composed of renewable resources and can be composted at the end of its useful life, it is environmentally benign and biodegradable. Because it has characteristics with PLA filament and can be printed on most 3D printers with typical settings, it is also simple to use. PLA filament bonded with wood, however, has several drawbacks. It may be more likely to distort or crack during printing and is not as robust or long-lasting as other materials like nylon or ABS. Additionally, it is not appropriate for applications requiring high-temperature resistance because it has a lower temperature resistance than other materials.



Figure 2. Wood PLA Composite Filament

C. Extrusion Compounding

Though there is considerable research carried out on Wood reinforced PLA, there is a huge scope for further research by altering the percentage of wood quantity, type of dispersion, shape and size of reinforcements, etc. Hence an effort is made to compound a unique wood reinforced PLA material for 3D printing of specimens. The specimens are further validated by testing for mechanical characterization.

The following is the data of the Wood PLA Composite Filament which is obtained as a result of extrusion compounding.

1. Composition of the material: 50% Wood + 50% PLA
2. Quality of the material: Premium
3. Net weight: 1 Kg
4. Nature of the material: Organic Material
5. Strength of the material: 30 to 60 MPa
6. Melting temperature: 210-240°C
7. Heat resistance: 60-70°C
8. Impact strength: 37 MPa
9. Flexural strength: 59.6 MPa occurred at 0.5 mm layer thickness
10. PLA material: Grade 2110 Bio-PLA
11. Heat deflection: HDT is a measure of resistance to distortion as the temperature increases.
12. Extruded temperature: 210-240°C
13. Minimum wall thickness: 0.3 mm
14. Chemical composition: It is a type of polyester made from fermented plant starch from corn, cassava, maize, sugarcane or sugar beet pulp.

D. Fabrication of Testing Specimen

The Wood PLA Composite Filament is used to fabricate the specimen as per ASTM D638 standards. The fabrication of the testing specimen is carried out on a Creality Ender 3 3D printer. The specifications of the machine are as follows:

Bed size - x: 220, y:220, z:250 mm
 Materials: PLA, ABS, WOOD, TPU
 Printing precision: 0.1mm
 Printing speed: <180mm/s (normal -60mm/s)
 Layer thickness: 100 - 400 Microns
 Closed print chamber: No, an open structure
 Feeder system: Direct
 Extruder: Single
 Print bed details: Heated bed



Figure 3. Creality Ender 3

The specimens are prepared using two materials.

1. PLA specimen
2. Wood + PLA composite specimen

The PLA and Wood + PLA Composite specimens used for mechanical characterization is usually a standardized test sample intended to assess the mechanical characteristics of the material, which includes tensile test, compression test, impact test and hardness. Standardized dimensions, as per ISO 527-2 or ASTM D638, are followed in the preparation of the specimen. The shape of the specimen is of dumb bell type, having broader ends for gripping and a small gauge piece in the middle. The gauge section's typical length is 50 mm, a width of 26 mm. overall length of 165 mm and a thickness of 3mm as shown in Figure 5 & 6. The compression specimens are prepared as per ASTM D695 standard for a cylindrical cross-section. These cylindrical specimens are 12.7 mm in diameter and 25.4 mm in height as shown in Figure 7 & 8.

The specimen is prepared through a Fused Deposition Modelling (FDM) process using Creativ Ender 3 machine. The specimen has a layer height of 0.2 mm, three infill densities of 25 %, 35 % and 45 % and has a flat on the build plate print orientation. Hence reproducibility and comparability of results across various investigations and testing conditions are guaranteed by this standardized specimen. The below pictures show both PLA specimens and Wood + PLA composite specimens at different infill densities as mentioned above.



Figure 4. PLA Tensile Specimen



Figure 5. Wood + PLA composite Tensile specimen

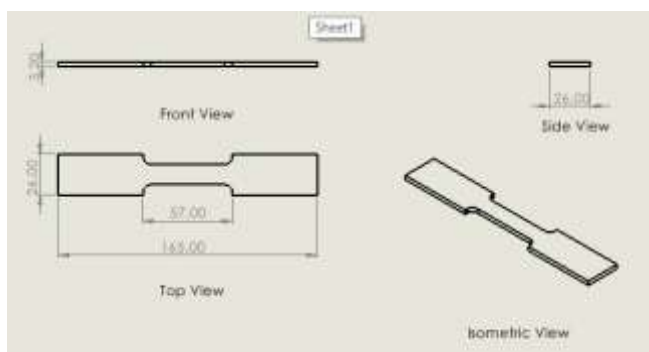


Figure 6 . Specimen dimensions as per ASTM D638 standards



Figure 7. Compression Specimens

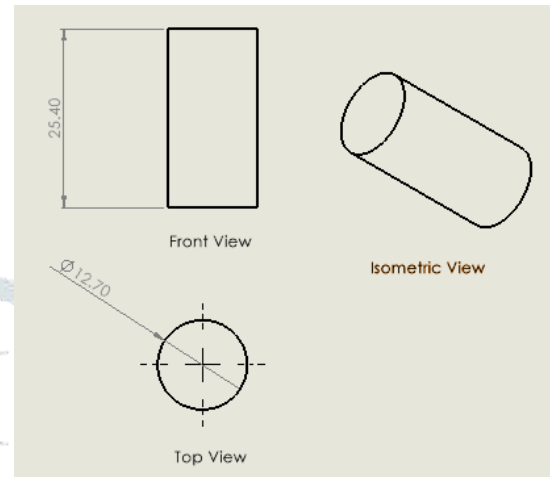


Figure 8. Specimen dimensions as per ASTM D695 standards

E. Testing Machines to test Tensile, Compression, Impact strengths and Hardness of the specimens.

1. Computerized Universal Testing Machine

The tensile test is carried out on a Computerised Universal Testing Machine of a capacity of 50KN having a maximum load at wear track of 30 N. Both PLA specimens and Wood + PLA composite specimens are tested for tensile strength at different infill densities using the Computerised UTM.



Figure 9 . Computerised UTM

2. Universal Testing Machine for Compression Test

The compression test is carried out on a conventional UTM having a capacity of 60 Tonnes. This is a versatile and reliable machine for assessing the mechanical characteristics of materials, including wood-PLA (polylactic acid) composite

specimens. The machine can test composite materials with different compositions and densities because of its high load capacity of 60 tonnes, which guarantees that it can handle large or dense specimens.



Figure 10 . Compression Testing

3. Computerized Impact Tester

The Impact test is accomplished on a computerised Impact Tester, whose impact energy ranges from 0 to 25 Joules and has a release angle of pendulum of 150 degrees. This is a sophisticated testing machine for determining the impact energy or toughness of materials, including PLA (polylactic acid) and Wood-PLA composite specimens. Usually, it uses a pendulum-based technique in which a weighted pendulum hits a specimen with a notch, breaking it.



Figure 11. Computerised Impact Tester

4. Shore D Durometer to measure hardness

The hardness of rigid and semi-rigid materials, including hard rubber, thermosetting resins, and hard plastics, can be measured with a Shore D Durometer. The Shore A scale is utilized for softer materials, such as flexible plastics and elastomers, while the Shore D scale is specifically made for tougher materials. A spring-loaded indenter in the durometer exerts a certain force on the surface of the material. On the Shore D scale, the indenter's depth of penetration into the material is measured and translated into a hardness rating. With 0 denoting least hardness (deep penetration) and 100 denoting maximal hardness (no penetration), the scale runs from 0 to 100.



Figure 12. Hardness Tester (Shore D Durometer)

F. Testing and Analysis – Tensile Test

1. Material: PLA (Infill Density = 25%)

Temperature: 30°C
Area: 45 sq-mm
Gauge Length: 60 mm
Width: 15 mm
Thickness: 3 mm
Maximum Load: 0.6 KN

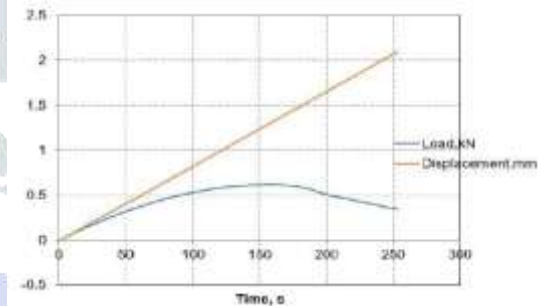


Figure 13. Graph 1

2. Material: Wood + PLA (Infill Density = 25%)

Temperature: 30°C
Area: 45 sq-mm
Gauge Length: 60 mm
Width: 15 mm
Thickness: 3 mm
Maximum Load: 0.25 KN

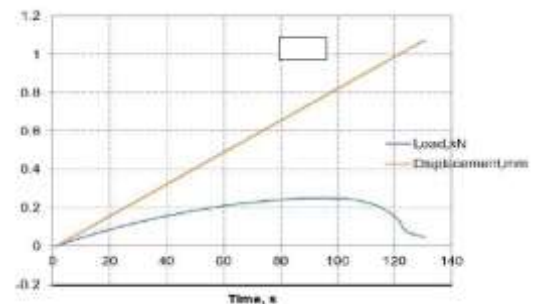


Figure 14. Graph 2

3. Material: PLA (Infill Density = 35%)

Temperature: 30°C
Area: 45 sq-mm
Gauge Length: 60 mm
Width: 15 mm
Thickness: 3 mm
Maximum Load: 0.65 KN

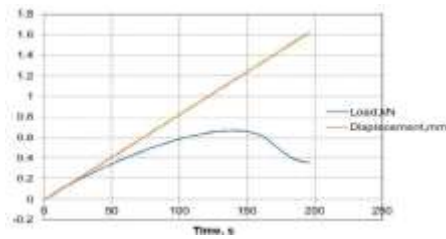


Figure 15. Graph 3

4. Material: Wood + PLA (Infill Density = 35%)
 Temperature: 30°C
 Area: 45 sq-mm
 Gauge Length: 60 mm
 Width: 15 mm
 Thickness: 3 mm
 Maximum Load: 0.65 KN

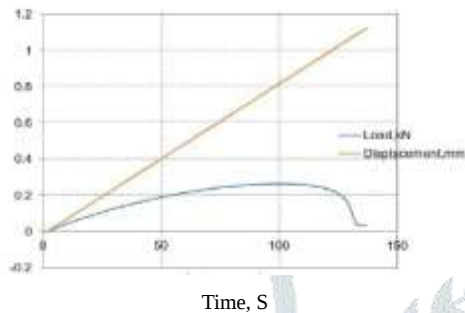


Figure 16. Graph 4

5. Material: PLA (Infill Density = 45%)

Temperature: 30°C
 Area: 45 sq-mm
 Gauge Length: 60 mm
 Width: 15 mm
 Thickness: 3 mm
 Maximum Load: 0.65 KN

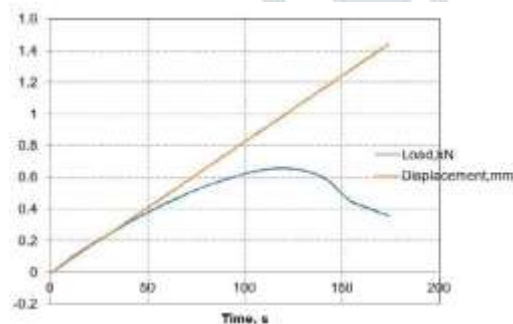


Figure 17. Graph 5

6. Material: Wood + PLA (Infill Density = 45%)

Temperature: 30°C
 Area: 45 sq-mm
 Gauge Length: 60 mm
 Width: 15 mm
 Thickness: 3 mm
 Maximum Load: 0.25 KN

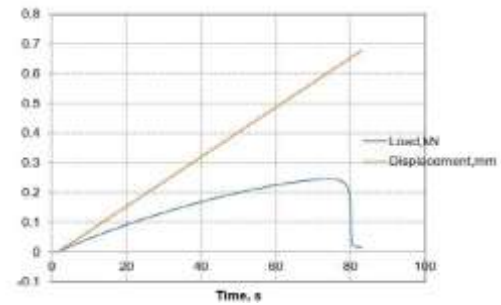


Figure 18. Graph 6

G. Testing and Analysis – Compression Test

1. Material : PLA

Initial Length, $L_i = 30$ mm
 Diameter, $D_i = 9$ mm
 Original Area, $A_o = 63.617$ sq.m
 Maximum Load, $F_{max} = 4.8 \times 10^3$ N
 Final Length, $L_f = 24$ mm
 Deformation, $\Delta L = 1.18 \times 10^{-8}$ mm
 Stress, $\sigma = 1.186$ N/mm²
 Strain, $\varepsilon = 3.93 \times 10^{-10}$
 Youngs Modulus, $E = 3.017 \times 10^9$ N/mm²

Table 1. PLA compression test result

S.No	Load F (N)	Deformation ΔL (mm)	Stress σ (mm)	Strain ε	Youngs modulus E (N/mm ²)
1	4.8×10^3	1.18×10^{-8}	1.186	3.93×10^{-10}	1.91×10^{11}
2	4.8×10^3	1.18×10^{-8}	1.186	3.93×10^{-10}	1.91×10^{11}

2. Material: Wood + PLA

Initial Length, $L_i = 30$ mm
 Diameter, $D_i = 9$ mm
 Original Area, $A_o = 63.617$ sq.m
 Maximum Load, $F_{max1} = 3.2 \times 10^3$ N
 Maximum Load, $F_{max2} = 4 \times 10^3$ N
 Final Length, $L_{f1} = 16$ mm
 Final Length, $L_{f2} = 19$ mm
 Deformation, $\Delta L_1 = 4.74 \times 10^{-12}$ mm
 Deformation, $\Delta L_1 = 5.93 \times 10^{-12}$ mm
 Stress, $\sigma_1 = 0.79$ N/mm²
 Stress, $\sigma_2 = 0.98$ N/mm²
 Strain, $\varepsilon = 1.58 \times 10^{-13}$
 Youngs Modulus, $E = 3.017 \times 10^9$ N/mm²

Table 2. Wood + PLA compression test result

S.No	Load F (N)	Deformation ΔL (mm)	Stress σ (mm)	Strain ε	Youngs modulus E (N/mm ²)
1	3.2×10^3	4.74×10^{-12}	0.79	1.58×10^{-13}	5×10^{12}
2	4×10^3	5.93×10^{-12}	0.98	1.97×10^{-13}	4.97×10^{12}

H. Testing and Analysis – Impact Test

Impact Energy – 0 to 25 Joules

Release angle of pendulum – 150 degrees

Table 3. Impact Test Result

Infill Density	PLA		WOOD+PLA	
	Impact in Joules	Angle of cut	Impact in Joules	Angle of cut
35	0.50	141	0.4	143
45	0.65	143	0.45	146

I. Testing and Analysis – Hardness Test

Range of the tester: 0 to 100 HD

Hardness scale: Shore D

Table 4. Hardness Test Result

MATERIAL	SHORE D VALUE	AVERAGE
PLA	44, 41, 46	43.66
PLA+ WOOD	35, 33, 30	32.66

V. RESULTS AND DISCUSSIONS

The mechanical characteristics of PLA (polylactic acid) and Wood + PLA composite specimens made with a Creality Ender 3 FDM printer at infill densities of 25%, 35%, and 45% are examined in this work. Using established tools and techniques, the specimens were examined for hardness, impact resistance, compression strength, and tensile strength. The findings are examined to determine how material composition and infill density affect mechanical performance.

A. Tensile Testing (ASTM D638)

To find the maximum load-bearing capability of PLA and Wood + PLA specimens, tensile tests were performed on a computerized universal testing machine with a 50 kN capacity.

1. PLA Samples:

25% infill: 0.6 kN is the maximum load.

Maximum load with 35% infill is 0.65 kN.

Maximum load at 45% infill is 0.65 kN.

At greater infill densities (35% and 45%), PLA demonstrated consistent tensile strength, suggesting that infill density over 35% has no discernible effect on tensile performance. This implies that at 35% infill, the internal structure of the material achieves optimal load distribution.

2. Specimens of Wood and PLA:

25% infill: 0.25 kN is the maximum load.

Maximum load with 35% infill is 0.65 kN.

Maximum load at 45% infill is 0.25 kN.

The tensile strength of Wood + PLA increased significantly at 35% infill but decreased at 45% infill.

This anomaly could be explained by the uneven distribution of wood particles in the PLA matrix at greater infill densities, which results in lower strength and stress concentration locations.

B. Compression Testing

To assess deformation, stress, strain, and Young's modulus, compression tests were conducted on a standard universal testing apparatus with a 6-ton capacity.

1. PLA Samples:

Deformation = 1.18×10^{-8} mm

Stress is 1.186 N/mm²

Strain is 3.93×10^{-10}

Young's modulus obtained is 3.017×10^9 N/mm²

PLA was shown to be suitable for applications needing rigidity due of its high stiffness and low deformation under compression.

2. Specimens of Wood and PLA:

Deformation = 15.93×10^{-12} mm

Stress is 0.98 N/mm²

Strain is 1.58×10^{-13}

Young's modulus is 3.017×10^9 N/mm²

Compared to PLA, Wood + PLA showed lower stress and strain values, indicating that the material's resistance to compressive pressures is diminished when wood particles are added. Young's modulus, on the other hand, stayed constant, suggesting that the composite maintains its stiffness.

C. Impact Testing

Impact test were conducted to measure the energy absorbed during fracture.

1. PLA Specimens

35% infill: angle of cut = 141°, impact energy = 0.5 J

45% infill: angle of cut = 143°, impact energy = 0.65 J

At higher infill densities, PLA demonstrated enhanced impact resistance because the larger material density facilitated energy absorption.

2. Specimens of Wood and PLA:

35% infill: angle of cut = 143°, impact energy = 0.4 J

45% infill: angle of cut = 146°, impact energy = 0.45 J

When compared to PLA, Wood + PLA showed a reduced impact energy, suggesting that the wood particles give the composite brittleness. The angle of cut did, however, marginally rise with infill density, indicating better resistance to fracture.

D. Hardness Testing (Shore D Durometer)

Surface resistance to indentation was measured through hardness tests using a Shore D Durometer.

Hardness of PLA Specimens: 43.66

Specimens of Wood and PLA: Hardness = 32.66

PLA showed increased resistance to surface deformation because to its higher hardness. Because wood fibers are softer and are distributed unevenly in the PLA matrix, the inclusion of wood particles decreased the composite's hardness.

1. Infill Density: While PLA and Wood + PLA had different effects, higher infill densities generally resulted in better mechanical qualities. Wood + PLA only performed at its best at 35% infill, whereas PLA performed consistently at 35% and 45% infill.
2. Material Composition: While PLA remained stiff under compression, the inclusion of wood particles decreased its tensile strength, impact resistance, and hardness. This implies that applications needing stiffness rather than toughness are better suited for Wood + PLA composites.
3. Anomalies in Wood + PLA: The decrease in impact energy values and the tensile strength drop at 45% infill suggest that the wood particles could cause weak spots in the material, particularly at higher densities. To increase performance, the wood-to-PLA ratio and particle distribution need to be further optimized.
4. Applications: Wood + PLA composites might be more appropriate for lightweight, rigid structures where toughness is not a top concern, but PLA is appropriate for applications needing high strength, stiffness, and surface hardness.

VI. CONCLUSION

In Conclusion, wood composite PLA filament provides a distinctive and sustainable 3D printing option. This filament creates intriguing opportunities for a variety of industries and applications by fusing the aesthetic appeal of wood with the biodegradability and ease of use of PLA. For 3D printed items, the wood composite PLA filament offers an aesthetically pleasing alternative. By incorporating wood fibers or particles into PLA filament, a natural wood-like look is produced, giving printed items a touch of good aesthetics. The filament's ability to mimic the distinctive textures and grain patterns of many wood species improves its aesthetic appeal and qualifies it for use in ornamental items, architectural models, and artistic projects.

Furthermore, sustainability is aided by PLA's biodegradability, which keeps it in the wood composite filament. The wood composite PLA filament provides an eco-friendly substitute for conventional plastic-based filaments because PLA is made from renewable materials. Composting or environmentally responsible disposal are two ways that printed items generated with this filament might lessen their influence on the environment. But it's crucial to take into account the possible drawbacks of PLA filament made of wood composite. When compared to pure PLA, the mechanical characteristics of the filament may be impacted by the inclusion of wood particles, resulting in reduced strength and increased brittleness. This might limit its applicability for uses that call for load-bearing or highly mechanical components. Nevertheless, post-processing and finishing should be done carefully to maintain the wood-like characteristics and prevent sanding or other damage.

The wood composite PLA filament is a useful addition to the selection of filaments for 3D printing in spite of these drawbacks. The wood composite PLA filament may find wider uses and support the ongoing expansion of environmentally friendly 3D printing techniques with additional development and study. Finally, the study emphasizes how material composition and infill density shapes the mechanical characteristics of 3D-printed PLA and Wood + PLA specimens. Although PLA performed better than Wood + PLA in the majority of tests, the combination has special qualities that could be useful in some situations. Future research could concentrate on enhancing particle distribution and investigating various Wood-to-PLA ratios in order to optimize the composite.

VII. APPLICATION

The combination of PLA with Wood Waste creates a bio composite material that enhances the biodegradability of PLA and natural reinforcements of the fibers of wood or husk. According to research, this material combination has gained significant attention in sustainable manufacturing due to its eco-friendly attributes. Some of the specific applications of this material combination are 3D printing filaments, packing materials, home décor, building and construction materials, automotive interior parts, consumer goods, agricultural appliances, and many more applications.

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