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Preliminary Experimental Evaluation of a Molded Wood-Particle/Epoxy Composite for Future Additive-Manufacturing Applications in Timber Construction.

Hamed Omare[1];Abdelmoutalib Benfrid [2,3,4]; Ahmed Boukhari [5]; Krzysztof Murawski [6].

1: Kabul Polytechnic University, Afghanistan.

2: Djillali Liabès University in Sidi Bel Abbès, Algeria.

3: The University Centre of Maghnia, Algeria.

4: Libyan Society for Research and Scientific Studies, Libya.

5: Department of Civil Engineering, Faculty of Architecture and Civil Engineering, University of Science and Technology of Oran Mohamed Boudiaf - USTO-MB (Oran 31000), Algeria.

6: The Jacob of Paradies University,Poland.

Corresponding author: mohamadhamed400@gmail.com

Abstract

Additive manufacturing offers promising opportunities for producing customized construction components with complex geometries and reduced material waste. However, the development of wood-based composites suitable for future additive-manufacturing applications remains limited. This preliminary experimental study evaluates the compressive behavior of a molded wood-particle/epoxy composite intended for further investigation in timber construction and three-dimensional printing. The composite consisted of plane tree (Platanus) wood particles, chopped strand mat fibers, and two epoxy resin–hardener systems. Six solid-wood reference cubes and four molded composite cubes, each measuring 150 × 150 × 150 mm, were prepared and subjected to axial compression. Three solid-wood specimens were tested parallel to the grain and three perpendicular to the grain. Two composite specimens were manufactured using a Type 1 epoxy system, while two others were produced using a Type 2 epoxy system containing fumed silica. The solid wood exhibited an average compressive strength of 34.94 MPa parallel to the grain and 4.12 MPa perpendicular to the grain. The Type 1 composite specimens achieved an average compressive strength of 11.55 MPa and showed substantial axial deformation. In comparison, the Type 2 composite specimens reached an average compressive strength of 19.45 MPa, representing an increase of approximately 68% relative to the Type 1 formulation. The improved performance of

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the Type 2 formulation may be associated with the lower elongation and higher compressive resistance of the epoxy system, together with the possible influence of fumed silica. Nevertheless, these effects could not be evaluated independently because the two formulations differed in both binder characteristics and silica content. The results demonstrate the preliminary mechanical feasibility of producing a wood-particle composite with meaningful compressive resistance. However, the specimens were molded rather than manufactured through layer-by-layer deposition. Therefore, the present study does not validate printability, extrusion behavior, interlayer bonding, or structural suitability. Further research should include larger sample sizes, complete mixture characterization, standardized mechanical testing, rheological assessment, extrusion trials, interlayer testing, and durability evaluation.

Keywords: Wood-particle composite; Epoxy resin; Compressive strength; Molded specimens; Additive manufacturing; Timber construction; Preliminary experimental study.

1. Introduction

Additive manufacturing (AM), commonly known as three-dimensional (3D) printing, has developed rapidly and has become an important manufacturing technology in engineering, architecture, and construction. Unlike conventional manufacturing methods, which generally rely on cutting, molding, machining, or assembling separate components, additive manufacturing produces objects directly from digital models through the successive deposition of material layers. This digitally controlled process enables the fabrication of complex geometries, supports component customization, reduces production stages, and may limit material waste. Consequently, 3D printing has attracted increasing attention as a potential approach for improving manufacturing efficiency and expanding design possibilities in the construction sector (Pirjan and Petrosanu, 2013; Matias and Rao, 2015; Shinde et al., 2017).

A wide range of materials, including polymers, metals, ceramics, cement-based mixtures, and fiber-reinforced composites, has already been investigated for additive-manufacturing applications. Previous studies have examined manufacturing processes, reinforcement mechanisms, machining performance, and the mechanical behavior of conventional and advanced composite materials (van der Klift et al., 2016; AElsheikh et al., 2021; Najjar et al., 2022). Nevertheless, the use of wood-based mixtures in additive manufacturing remains comparatively limited, particularly when the intended application is related to construction or load-bearing components. This limitation represents an important research opportunity because wood is a renewable and widely available natural material, while wood-processing residues and particles may potentially be valorized as constituents of composite products.

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The incorporation of wood particles into a printable or formable composite does not, however, automatically demonstrate environmental sustainability. Although the use of wood particles may reduce the consumption of some conventional raw materials and support waste valorization, the overall environmental performance also depends on the origin and quantity of the binder, the energy required for processing, service life, durability, recyclability, and end-of-life treatment. This consideration is especially important for wood–epoxy composites because conventional epoxy resins are generally difficult to separate from lignocellulosic particles after curing. Therefore, the material investigated in the present study should be considered a preliminary wood-based composite whose environmental benefits remain to be established through a complete life-cycle assessment.

Traditional timber structures are generally produced through either on-site construction or off-site prefabrication. On-site construction offers flexibility because wooden elements can be assembled and adjusted according to actual site conditions. However, it is often labor-intensive, time-consuming, and dependent on the availability of skilled workers. Prefabricated timber construction provides improved quality control, greater dimensional accuracy, and faster installation, but may be constrained by transportation requirements, handling operations, standardized component dimensions, and limited opportunities for modification after production. Studies on plywood stability and cross-laminated timber construction have demonstrated both the structural potential of engineered wood products and the importance of controlling their material and geometric characteristics (Murawski, 2011; Zumbrunnen and Fovargue, 2012).

The application of additive manufacturing to timber construction could provide an alternative fabrication approach combining the digital precision associated with prefabrication with the flexibility required for customized and site-specific production. It may also enable the fabrication of optimized internal geometries and components that are difficult to manufacture using conventional woodworking techniques. However, the successful development of a wood-based material for extrusion-type additive manufacturing requires more than adequate compressive strength. The material must also satisfy requirements related to rheological behavior, extrudability, flow continuity, nozzle compatibility, shape retention, buildability, curing kinetics, open time, interlayer adhesion, shrinkage, and dimensional stability. Particle dimensions must be compatible with the printer nozzle, while fibers and elongated particles may become preferentially oriented during extrusion and consequently produce anisotropic mechanical behavior.

Previous investigations concerning wood waste and fiber-reinforced materials have shown that the addition of wood-derived constituents or short fibers can influence the strength and deformation behavior of cementitious and polymeric composites. Pappula and Sundara Kumar (2015) and Deepti and Venkateswarlu (2016), for example, examined the use of wood waste ash in fiber-reinforced concrete. Other research has addressed the manufacturing and mechanical performance of continuous- and discontinuous-fiber composites, indicating that reinforcement distribution, matrix properties, interfacial bonding, and processing conditions

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strongly affect the resulting structural response (van der Klift et al., 2016; AElsheikh et al., 2021; Najjar et al., 2022). Nevertheless, these studies do not directly establish the behavior of wood-particle/epoxy mixtures intended for extrusion or layer-by-layer manufacturing.

Recent studies by Chatbi and his collaborators have further demonstrated the importance of constituent properties, reinforcement distribution, volume fraction, geometry, and support conditions in controlling the mechanical response of advanced composite structural elements. Their investigations have addressed the vibration and bending behavior of composite beams and concrete slabs reinforced with carbon nanotubes, nano-silica, and iron-oxide nanoparticles (Chatbi et al., 2022a, 2022b; Harrat et al., 2024). Although these studies concern analytical or numerical models and material systems different from the wood-particle composite examined here, they provide a relevant methodological framework for understanding how the reinforcing phase and matrix characteristics affect stiffness, deformation, stability, and overall composite performance.

In parallel, Benfrid and his co-authors have investigated eco-composite and concrete systems containing recycled glass powder and waste-derived glass nanoparticles. Their findings emphasize that the thermomechanical and elastic behavior of composite materials depends on the properties, concentration, and distribution of the incorporated phase, as well as on its interaction with the surrounding matrix (Benfrid et al., 2023, 2025). These contributions support the broader principle that the performance of a heterogeneous composite cannot be attributed solely to one constituent. Instead, the resulting behavior reflects the combined effects of the matrix, reinforcement, particle geometry, constituent proportions, interfaces, porosity, and manufacturing conditions. The cited studies by Chatbi and Benfrid are therefore used as supporting literature on composite mechanics and constituent interaction rather than as direct evidence of wood-based additive manufacturing.

Despite the growing body of research on additive manufacturing, timber engineering, fiber reinforcement, and advanced composites, relatively few experimental studies have evaluated wood-particle mixtures specifically proposed for future additive-manufacturing applications in construction. The existing literature does not yet provide sufficient experimental evidence regarding the compressive behavior of mixtures combining relatively large wood particles, chopped strand mat fibers, and epoxy binders. Moreover, the influence of epoxy-system strength and elongation characteristics on the deformation and load-bearing response of such mixtures requires further investigation.

Omare (2024) proposed a conceptual approach for the 3D printing of wooden structures using a mixture composed of large and small wood particles, chopped fiber-reinforced polymer, and an epoxy-based adhesive system. The proposed material was intended to produce a cohesive composite that could eventually be processed through a digitally controlled manufacturing method. Although the

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concept provided an initial basis for the development of a wood-based composite, its mechanical performance had not been evaluated experimentally.

The present study therefore provides a preliminary experimental evaluation of the proposed wood-particle composite. Plane tree (Platanus) wood was selected as the primary lignocellulosic constituent. One portion of the same tree was used to manufacture solid-wood reference specimens, while the remaining portion was processed into particles of different sizes. The particles were combined with chopped strand mat fibers and two epoxy resin–hardener systems having different compressive-strength and elongation characteristics. The resulting composite mixtures were molded into cubic specimens and tested under axial compression.

The principal objective is to assess the preliminary compressive feasibility of the molded wood-particle/epoxy composite and to compare the behavior of the two tested formulations. The study also compares the composite results with those of solid wood obtained from the same source and loaded parallel and perpendicular to the grain. Particular attention is given to the influence of binder characteristics on compressive strength and qualitative deformation behavior. However, because the specimens were molded rather than deposited layer by layer, the study does not experimentally demonstrate printability, extrusion performance, interlayer bonding, or the structural suitability of printed components. The results should consequently be interpreted as an initial mechanical screening intended to support subsequent mixture optimization, rheological assessment, extrusion trials, interlayer testing, durability evaluation, and full-scale additive-manufacturing research.

2. Wood Size for Composite Mixture

A complete plane tree (Platanus) was used as the source of the wood material employed in the experimental program. One portion of the tree was cut into six solid-wood cubes measuring 150 × 150 × 150 mm and used as reference specimens. The remaining portion was processed into wood particles for the preparation of the molded composite mixtures. Using wood obtained from the same tree reduced variability associated with species, density, moisture content, and natural material heterogeneity, thereby allowing a more consistent comparison between the solid-wood and composite specimens.

To improve particle packing and distribution within the composite, the wood particles were classified into two principal size groups. The large-particle group consisted of nominal particle dimensions of 13 × 13 × 13 mm and 10 × 10 × 10 mm, whereas the small-particle group consisted of particles measuring 8 × 8 × 8 mm and 6 × 6 × 6 mm, as illustrated in Figure 1.

The use of several particle sizes was intended to improve packing efficiency within the molded composite. The smaller particles were expected to occupy some of the spaces between the larger particles, thereby reducing large internal gaps and promoting a more homogeneous distribution of the wood particles, chopped fibers, and epoxy binder. However, the actual void fraction and particle-packing efficiency

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were not experimentally measured in the present study. Consequently, any improvement in internal compactness should be interpreted as a mixture-design objective rather than a quantitatively demonstrated result.

At the time of specimen preparation, the wood had an approximate moisture content of 12% and a density of 500 kg/m³. These values were considered representative of the wood condition used for both the solid reference specimens and the composite mixtures. The method and equipment used to determine the moisture content should be reported from the original laboratory records to improve experimental reproducibility.

It should also be noted that the particle dimensions used in this preliminary study were selected for the fabrication of molded cube specimens. Their suitability for extrusion-based additive manufacturing was not evaluated. In an actual printing process, the relatively large particle sizes may create difficulties related to material flow, nozzle blockage, particle segregation, and discontinuous deposition. Therefore, future studies should examine the relationship between particle dimensions, particle-shape distribution, nozzle diameter, extrusion pressure, and continuous material flow before the formulation can be considered suitable for additive manufacturing.

Wood properties

- Wood species: Plane tree (Platanus).
- Approximate moisture content: 12%.
- Density: 500 kg/m³.
- Large-particle dimensions: 13 × 13 × 13 mm and 10 × 10 × 10 mm.
- Small-particle dimensions: 8 × 8 × 8 mm and 6 × 6 × 6 mm.



Figure 1. Wood particles used in the composite mixture.

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3. Fiber Reinforced Polymer

Chopped strand mat (CSM) fibers were incorporated into the wood-particle composite mixtures as a discontinuous reinforcing phase. Before mixing, the fibers were manually cut into short pieces with an approximate length of 5 mm, as illustrated in Figure 2. This length was selected to facilitate their dispersion among the wood particles and to reduce the likelihood of severe fiber entanglement or agglomeration during the preparation of the molded specimens.

For each epoxy resin–hardener formulation, a total fiber mass of 0.25 kg was added to the composite mixture. The chopped fibers were gradually introduced into the blended wood particles before and during the addition of the epoxy binder. This procedure was intended to promote a relatively uniform distribution of the reinforcing phase throughout the mixture.

The fibers were included to improve stress transfer within the composite and to provide local bridging between adjacent wood particles and the cured epoxy matrix. They may also help limit localized particle separation and crack propagation under compressive loading. However, the present experimental program did not independently quantify the contribution of the fibers because no unreinforced control mixture was prepared. Consequently, their reinforcing effect cannot be isolated from the combined effects of the epoxy system, wood-particle distribution, fumed silica, internal voids, and specimen preparation conditions.

The nominal tensile strength of the fiber material was reported as approximately 100 N/mm². Nevertheless, the manufacturer, chemical composition, diameter, density, and exact fiber volume fraction were not documented in the available experimental data. These characteristics should be reported in future studies because they may significantly influence fiber–matrix bonding, dispersion, mechanical performance, and suitability for extrusion-based additive manufacturing.

The use of chopped fibers may also affect the future printability of the composite. During extrusion, fibers can align with the direction of material flow, alter mixture viscosity, increase extrusion pressure, and contribute to nozzle blockage when their length is incompatible with the nozzle diameter. Therefore, future investigations should evaluate fiber-length-to-nozzle-diameter ratios, fiber orientation, dispersion quality, rheological behavior, and interlayer mechanical performance.

Fiber properties

- Fiber type: Chopped strand mat (CSM).
- Approximate fiber length: 5 mm.
- Fiber mass used in each epoxy formulation: 0.25 kg.
- Nominal tensile strength: 100 N/mm².

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Figure 2. Chopped fibers used to reinforce the wood-based composite mixture.

4. Epoxy Resin and Hardener Systems

The epoxy resin and hardener constituted the continuous binding matrix of the wood-particle composite. Their principal role was to coat and bond the wood particles and chopped fibers, maintain mixture cohesion, and transfer stresses between the different constituents after curing. The mechanical and rheological properties of the epoxy system were therefore expected to influence the strength, stiffness, deformation behavior, and dimensional stability of the molded composite specimens.

Two commercially available epoxy resin–hardener systems were investigated. The first formulation, designated as Type 1, consisted of Epomax Liquid Glass resin and its corresponding hardener. The second formulation, designated as Type 2, consisted of Epomax-L10 resin and its associated hardener, as shown in Figures 3 and 4. Each resin was combined with its designated hardener according to the mixing ratio reported by the manufacturer.

The Type 1 epoxy system had a resin-to-hardener mixing ratio of 100:58 by mass. Its reported tensile strength, compressive strength, and flexural strength were 42, 60, and 50 MPa, respectively. The elongation at break was reported as 14%, indicating a relatively high deformation capacity.

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The Type 2 epoxy system had a resin-to-hardener mixing ratio of 100:23.5 by mass. Its reported tensile strength was 25.7 MPa, while its compressive and flexural strengths were 70 and 63 MPa, respectively. Its elongation at break was considerably lower, at approximately 2.2%. In comparison with Type 1, the Type 2 system therefore exhibited a higher reported compressive and flexural resistance but a lower tensile strength and substantially lower elongation capacity.

These differences were expected to affect the behavior of the composite specimens. The higher elongation of the Type 1 system could permit greater deformation before failure but may also reduce the apparent stiffness and dimensional stability of the composite under compression. Conversely, the lower elongation and higher compressive resistance of the Type 2 system could contribute to a stiffer response and improved resistance to axial deformation.

Fumed silica was added only to the Type 2 formulation. Its addition was intended to increase mixture viscosity, reduce resin flow and segregation, improve cohesion, and enhance shape retention during specimen preparation. However, the exact mass and percentage of fumed silica were not documented in the available experimental information. This quantity must be retrieved from the original laboratory records to make the formulation fully reproducible.

Because fumed silica was incorporated exclusively into the Type 2 formulation, the two composite groups differed in both epoxy-system characteristics and silica content. Consequently, any difference in compressive performance cannot be attributed solely to the epoxy type. The Type 2 specimens should therefore be described as an epoxy–fumed-silica formulation, and the possible effects of resin properties and silica modification should be discussed jointly.

The resin and hardener components were measured according to their specified mixing ratios and blended until a visually homogeneous binder was obtained. The prepared binder was then gradually introduced into the mixture of wood particles and chopped fibers. Care was taken to coat the solid constituents as uniformly as possible and to limit the formation of dry particles, localized resin-rich regions, or visible segregation. Nevertheless, binder-distribution uniformity and internal void content were not quantitatively measured.

Type	Mixing ratio	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPa)	Elongation at break (%)
1	100:58	42	60	50	14
2	100:23.5	25.7	70	63	2.2

Table 1. Mechanical properties of the epoxy resin and hardener systems.

The properties listed in Table 1 correspond to the reported characteristics of the epoxy systems rather than to measurements performed independently within the present study. The relevant manufacturer technical data sheets should therefore be cited and included in the reference list.

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Figure 3. Epomax Liquid Glass epoxy resin and hardener used as the Type 1 system.



Figure 4. Epomax-L10 epoxy resin and hardener used as the Type 2 system.

5. Mixing Procedure

The composite mixture was prepared using wood particles of different sizes, chopped strand mat fibers, epoxy resin, and the corresponding hardener. For the Type 2 formulation, fumed silica was also incorporated into the epoxy system. The same nominal wood-particle volume and particle-size distribution were used for both composite formulations, while the principal differences concerned the epoxy resin–hardener system and the addition of fumed silica to the Type 2 mixture.

Each composite specimen had nominal dimensions of 150 × 150 × 150 mm, corresponding to a total specimen volume of 3,375,000 mm³. The total volume of wood particles used in each specimen was fixed at 2,193,750 mm³, representing approximately 65% of the nominal cube volume. The remaining 35% was assigned to the epoxy resin, hardener, chopped fibers, internal voids, and, in the Type 2 formulation, fumed silica.

The wood-particle fraction was divided into small and large particle groups using a volumetric ratio of 1:2. The total volume of the small-particle fraction was 731,250 mm³, whereas the large-particle fraction occupied 1,462,500 mm³. The use of two

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particle-size groups was intended to improve particle packing by allowing smaller particles to occupy part of the spaces between the larger particles.

The small-particle fraction consisted of particles with nominal dimensions of 8 × 8 × 8 mm and 6 × 6 × 6 mm. Their respective calculated volumes were 417,857.14 and 313,392.85 mm³. The large-particle fraction consisted of particles measuring 13 × 13 × 13 mm and 10 × 10 × 10 mm, with respective calculated volumes of 826,630.43 and 635,869.56 mm³.

Table 2. Volume distribution of wood particles in each composite cube.

Size (mm)	**Volume (mm^3)**
8	417857.14
6	313392.85
Small Parts Total Volume	**731250.00**
Large Parts	
Size (mm)	Volume (mm^3)
13	826630.43
10	635869.56
Large Parts Total Volume	**1462500.00**
Total Volume of Wooden Particles	**2193750.00**

The chopped fiber reinforcement was added at a reported mass equivalent to approximately 8.3% of the epoxy resin–hardener system. However, the manuscript does not clearly specify whether this percentage was calculated relative to the resin mass alone, the combined resin–hardener mass, or the total binder formulation. This basis should be verified using the original laboratory records.

The resin and hardener were first measured according to the specified mixing ratio of each epoxy system. The components were then mixed thoroughly until a visually homogeneous binder was obtained. For the Type 2 formulation, fumed silica was incorporated into the binder to increase viscosity and improve mixture stability. The exact dosage and the stage at which the silica was added should be reported from the original experimental records.

Before the addition of the binder, the small and large wood particles were combined and mixed to obtain a relatively uniform particle-size distribution. The chopped fibers were then introduced gradually and dispersed among the wood particles. This sequence was intended to reduce localized fiber agglomeration and promote a more uniform distribution of the reinforcing phase.

The prepared epoxy binder was subsequently added progressively to the wood-particle and fiber mixture while continuous mixing was maintained. Mixing continued until the wood particles and fibers appeared to be uniformly coated and a cohesive material was obtained. Because no mechanical mixer, mixing speed, mixing duration, or quantitative homogeneity assessment was documented, the process

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should be described as manual or laboratory-scale mixing unless the original records provide more precise information.

The resulting composite material was placed into cube molds measuring 150 × 150 × 150 mm. The mixture was distributed throughout the molds and manually compacted to reduce visible gaps and promote specimen uniformity. Nevertheless, the applied compaction pressure, compaction method, and resulting void fraction were not measured.

The specimens were then allowed to cure before demolding and compression testing. The curing temperature, relative humidity, curing time, and demolding period should be added from the laboratory records because these parameters may influence resin polymerization, interfacial bonding, final density, and mechanical performance.

The present formulation should be considered a nominal mixture design rather than a fully reproducible composition because the exact masses of wood particles, resin, hardener, and fumed silica, as well as the cured specimen density and void content, were not reported. Future experimental programs should provide complete mass- and volume-based formulation tables for each specimen group.

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6. Solid-Wood and Wood-Composite Cube Specimens

A total of ten cubic specimens were prepared for the experimental investigation. Each specimen had nominal dimensions of 150 × 150 × 150 mm. The experimental series consisted of six solid plane-tree (Platanus) wood specimens and four molded wood-particle composite specimens.

The solid-wood reference specimens and the wood particles incorporated into the composite formulations were obtained from the same tree. This sampling approach was adopted to reduce variability associated with wood species, source, density, moisture content, growth conditions, and natural biological heterogeneity. However, because wood properties may vary within a single trunk according to radial and longitudinal position, the use of one tree does not eliminate all natural variability.

The six solid-wood cubes were cut directly from the plane-tree material. Three specimens were subsequently assigned to compression testing parallel to the grain, while the remaining three were assigned to testing perpendicular to the grain. The orientation of each specimen was identified before testing to ensure that the applied loading direction corresponded to the intended grain orientation.

Four additional cubic specimens were manufactured from the wood-particle composite mixture. Two specimens were produced using the Type 1 epoxy resin–hardener system. The remaining two specimens were manufactured using the Type 2 epoxy resin–hardener system modified with fumed silica.

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Both composite groups were prepared using the same nominal wood species, specimen dimensions, wood-particle volume, particle-size distribution, and chopped-fiber mass. Nevertheless, the two formulations differed in more than the epoxy type because fumed silica was incorporated only into the Type 2 mixture. Accordingly, the experimental comparison should be considered a comparison between two complete formulations rather than an isolated evaluation of epoxy-system effects.

After mixing, each composite formulation was placed into cubic molds measuring 150 × 150 × 150 mm. The material was distributed throughout the mold and compacted manually to reduce visible gaps and improve specimen uniformity. The exact compaction procedure, applied pressure, number of compaction stages, and internal void content were not recorded in the available data and should therefore be reported if laboratory records are available.

The specimens were allowed to cure before demolding and mechanical testing. The curing duration, temperature, relative humidity, and time between demolding and testing should be specified from the original experimental records because these parameters may influence epoxy polymerization, interfacial bonding, moisture exchange, density, and compressive performance.

No surface grinding, end capping, machining, or dimensional-tolerance measurements were reported before testing. Future studies should verify specimen dimensions at several locations and assess the parallelism and flatness of the loaded faces to reduce eccentricity and nonuniform contact with the compression-machine platens.

The limited number of composite specimens, particularly the use of only two specimens per formulation, restricts statistical inference. The results should consequently be interpreted as preliminary experimental observations rather than definitive mechanical-property values.



Figure 5. Solid plane-tree wood cube specimens.

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Figure 6. Wood-composite cube specimens produced using the Type 1 epoxy resin and hardener.



Figure 7. Wood-composite cube specimens produced using the Type 2 epoxy resin and hardener.

7. Specimens and Compression-Loading Configuration

A total of ten cubic specimens were subjected to axial compression testing to evaluate the mechanical behavior of the solid plane-tree wood and the two molded wood-particle composite formulations. All specimens had nominal dimensions of 150 × 150 × 150 mm.

The experimental program included six solid-wood specimens and four composite specimens. Three solid-wood cubes were loaded parallel to the grain, while the remaining three were loaded perpendicular to the grain. This configuration was adopted to account for the anisotropic behavior of natural wood and to provide reference values for its two principal compression directions.

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The four composite cubes were divided into two formulation groups. Two specimens were manufactured using the Type 1 epoxy resin–hardener system, while two specimens were produced using the Type 2 epoxy system modified with fumed silica. Both groups contained the same nominal wood species, particle-size distribution, wood-particle volume, and chopped-fiber mass. However, because fumed silica was incorporated only into the Type 2 formulation, the comparison represents the combined effect of the complete formulations rather than the isolated effect of epoxy type.

Each specimen was positioned centrally between the loading platens of a universal testing machine. Central positioning was intended to promote uniform axial load transfer and reduce eccentric loading. The loaded surfaces should be checked for flatness and parallelism because irregular contact between the specimen and the machine platens may generate localized stress concentrations and influence the measured failure load.

The compressive force was applied monotonically until the specimen reached its maximum recorded load or exhibited substantial deformation or failure. The original manuscript does not report the model and capacity of the testing machine, loading or displacement rate, data-acquisition frequency, platen dimensions, or environmental conditions during testing. These details should be recovered from the original laboratory records and included to make the procedure reproducible.

No direct strain-measurement system, extensometer, displacement transducer, or digital image-correlation technique was reported. Consequently, the present study primarily evaluates ultimate load and calculated compressive strength. Statements concerning stiffness, strain at peak load, or compressive modulus should therefore remain qualitative unless corresponding load–displacement or stress–strain data are available.

The compressive strength of each specimen was calculated using the maximum recorded axial load divided by the loaded cross-sectional area:

$f_c = P_{max}/A$

where (f_c) is the compressive strength in MPa, (P_{max}) is the maximum axial load in N, and (A) is the loaded cross-sectional area in mm².

For a specimen with nominal loaded dimensions of 150 × 150 mm, the nominal cross-sectional area is 22,500 mm². However, the actual specimen dimensions and the area used in the original calculations should be verified because dimensional tolerances, machining differences, or transcription errors may affect the reported compressive-strength values.

The loading procedure continued until one of the following conditions occurred:

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A clear maximum load was recorded.

The specimen exhibited pronounced crushing, cracking, or loss of load-carrying capacity.

Axial deformation became sufficiently large to prevent meaningful continuation of the test.

Because the precise failure criterion was not documented, the manuscript should describe the endpoint as the maximum recorded load or substantial specimen deformation rather than as a standardized failure criterion.

Figure 8 shows a solid-wood cube positioned between the platens of the universal testing machine. Figure 9 presents the corresponding compression-loading configuration for a molded wood-particle composite specimen.



Figure 8. Solid-wood cube specimen under axial compression.



Figure 9. Wood-composite cube specimen under axial compression.

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8. Specimens and Compression-Loading Configuration

The axial load-bearing capacity and compressive strength of the solid-wood and wood-composite cube specimens were determined using a universal testing machine. The results were analyzed to evaluate the effects of grain orientation in solid wood and epoxy-system properties in the developed composite material.

Compressive Behavior of Solid Wood

The solid plane-tree (*Platanus*) specimens were tested in two principal loading directions: parallel and perpendicular to the grain. The results obtained from specimens loaded parallel to the grain are presented in Table 3.

Table 3. Compressive strength of solid wood parallel to the grain

Sample Number	Results (kN)	Compressive strength (MPa)
1a	329.40	35.00
2a	309.20	32.86
3a	347.90	36.97
Average		34.94

The compressive strength parallel to the grain ranged from 32.86 to 36.97 MPa, with an average value of 34.94 MPa. The limited variation among the three specimens indicates relatively consistent mechanical behavior in this loading direction.

The results obtained from specimens loaded perpendicular to the grain are summarized in Table 4.

Table 4. Compressive strength of solid wood perpendicular to the grain

Sample Number	Results (kN)	Compressive strength (MPa)
1b	40.50	4.09
2b	39.70	4.05
3b	41.60	4.24
Average		4.12

The average compressive strength perpendicular to the grain was 4.12 MPa, which is much lower than the value obtained parallel to the grain. This difference is due to the anisotropic structure of natural wood. The continuous longitudinal fibers provide more resistance when the load is applied parallel to the grain. Under perpendicular loading, deformation is mainly caused by compression and local crushing of the cellular structure.

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The reported strengths in the two loading directions were averaged and give an arithmetic mean of 19.53 MPa. But this combined value should be used with caution as the parallel and perpendicular strengths are measuring different mechanical properties and are not interchangeable measures of the response of a single material.

Compressive Behavior of the Wood Composite

The compressive test results for the four wood-composite specimens are presented in Table 5. Two specimens were manufactured using the Type 1 epoxy system, while two additional specimens were prepared using the Type 2 epoxy system.

Sample Number	Epoxy Type	Results (kN)	Compressive Strength (MPa)
1	1	256.5	11.40
2	1	263.25	11.70
3	2	382.5	17.80
4	2	472.5	21.10

Table 5. Compressive strength of the wood-composite specimens

The specimens made with the Type 1 epoxy system presented compressive strengths of 11.40 and 11.70 MPa, with mean value of 11.55 MPa. These specimens also showed considerable axial deformation under load. This behavior can be related to the relatively high elongation at break of the Type 1 epoxy system (14 %). Increased elongation may improve ductility, but excessive deformation can reduce stiffness and dimensional stability, both of which are important requirements of structural members that carry loads.

On the other hand, the specimens prepared with the Type 2 epoxy system gave the compressive strengths of 17.80 and 21.10 MPa with an average of 19.45 MPa. The Type 2 system had a higher reported compressive strength and a lower elongation at break of about 2.2% than the Type 1 system. These features result in higher stiffness, lower axial deformation and higher compressive resistance.

Therefore, the average compressive strength of the Type 2 composite was around 68% higher than that of the Type 1 composite. This result reveals that the overall behavior of the wood-composite material is highly dependent on the mechanical characteristics of the epoxy matrix, in particular the stiffness, the compressive resistance and the elongation capacity.

The Type 2 composite reached approximately 56% of the average compressive strength of the solid-wood specimens in the parallel-to-grain loading. However, the average strength was close to the arithmetic average of the parallel and perpendicular solid wood data. This comparison should not be taken as evidence that the composite is mechanically equivalent to solid wood, since the natural wood specimens showed strongly direction-dependent behavior, and the directional properties of the composite were not fully characterized.

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The addition of fumed silica to the epoxy system also increases the viscosity and dimensional stability of the epoxy system. This could also have contributed to the improved performance of the Type 2 specimens. However, the present tests do not allow quantification of the independent contribution of the fumed silica itself, as its dosage was not varied independently and no control specimens without silica were tested.

Figure 10. Type 2 wood-composite specimen at the end of its ultimate compressive load. The results obtained show that the developed composite can offer a valuable resistance to compression. However, further research with more samples, strain measurement, density characterization, void content assessment, durability testing and interlayer testing are required to declare the material suitable for structural additive manufacturing applications.



Figure 10. Type 2 wood-composite cube after ultimate compression loading.

9. Conclusion

This preliminary experimental study investigated the compressive behavior of a molded wood-particle composite developed for potential future additive-manufacturing applications. The composite was produced using plane-tree (Platanus) wood particles, chopped strand mat fibers, and two epoxy resin–hardener formulations. Six solid-wood reference specimens and four molded composite specimens were subjected to axial compression testing.

The results confirmed the strongly anisotropic behavior of natural wood. Solid-wood specimens loaded parallel to the grain exhibited an average reported compressive strength of 34.94 MPa, whereas specimens loaded perpendicular to the grain reached approximately 4.13 MPa. These values represent distinct directional mechanical properties and should not be combined into a single average strength for comparison with the composite material.

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The Type 1 composite specimens achieved an average compressive strength of 11.55 MPa and exhibited substantial qualitative axial deformation during loading. This behavior may be associated with the relatively high elongation capacity of the Type 1 epoxy system. However, because strain and displacement were not measured directly, the stiffness, compressive modulus, and deformation capacity of this formulation could not be quantified.

The Type 2 epoxy–fumed-silica formulation achieved an average reported compressive strength of 19.45 MPa. This value was approximately 68.4% higher than that obtained for the Type 1 formulation and corresponded to approximately 56% of the average reported strength of solid wood loaded parallel to the grain. The improved performance may be related to the lower elongation and higher compressive resistance of the Type 2 epoxy system, together with the possible effects of fumed silica on mixture viscosity, cohesion, and dimensional stability.

Nevertheless, the influence of the epoxy system cannot be separated from that of the fumed silica because silica was added only to the Type 2 formulation. The observed difference should therefore be interpreted as the performance of the complete Type 2 epoxy–silica formulation rather than as evidence of the isolated superiority of the resin. Additional control mixtures are required to distinguish the contribution of each constituent.

The results demonstrate that the developed wood-particle composite can provide meaningful compressive resistance and that binder characteristics have an important influence on its mechanical response. However, the limited number of composite specimens, the absence of direct strain measurements, the lack of density and void-content characterization, and the inconsistencies identified between some recorded loads and calculated strengths restrict the reliability and generalizability of the conclusions.

Furthermore, the specimens were produced by molding rather than through an actual layer-by-layer additive-manufacturing process. Consequently, the present study does not demonstrate material extrudability, buildability, nozzle compatibility, shape retention, curing behavior during deposition, interlayer adhesion, or the structural performance of printed components. The findings should therefore be regarded as preliminary mechanical screening results rather than validation of a printable or structurally qualified construction material.Future research should increase the number of specimens, verify the original load and dimensional records, report complete mixture proportions, quantify fumed-silica content, determine cured density and void fraction, and obtain complete load–displacement and stress–strain curves. Controlled formulations with and without fumed silica should also be tested. Subsequent investigations should evaluate rheological behavior, extrusion continuity, particle-size-to-nozzle compatibility, layer stability, interlayer bonding, moisture sensitivity, fire resistance, durability, and full-scale printed elements. These additional studies are necessary before the proposed wood-based composite can be considered suitable for practical additive-manufacturing or structural applications.

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10. Future Perspectives

The results obtained in this preliminary study provide an initial experimental basis for the continued development of wood-particle composites intended for future additive-manufacturing applications. However, substantial additional research is required before the proposed formulation can be considered printable, structurally reliable, or suitable for practical construction applications.

The first research priority should be the experimental evaluation of the material's actual printability. Future investigations should examine rheological behavior, extrusion pressure, flow continuity, nozzle compatibility, open time, curing rate, shape retention, and buildability. Particular attention should be given to the relatively large wood-particle dimensions used in the present formulation because these particles may produce nozzle blockage, discontinuous flow, particle segregation, or unstable material deposition. The relationship between maximum particle size and nozzle diameter should therefore be systematically investigated.

The proportions of wood particles, chopped fibers, epoxy resin, hardener, and fumed silica should also be optimized through a controlled experimental design. Future studies should examine different particle-size distributions, wood contents, fiber lengths, fiber fractions, binder proportions, and silica dosages. Such an optimization process would help identify a formulation that provides an appropriate balance between extrudability, mechanical resistance, stiffness, dimensional stability, material cost, and processing efficiency.

The independent effects of the epoxy system and fumed silica should be evaluated using additional control formulations. Type 1 and Type 2 epoxy systems should be tested both with and without fumed silica. This experimental arrangement would make it possible to distinguish the influence of binder properties from the effects of silica modification. The dosage of each constituent should be reported precisely on both mass and volume bases to ensure reproducibility.

Future work should also investigate the influence of layer-by-layer deposition on mechanical behavior. Printed specimens should be produced and tested in different orientations to evaluate interlayer bonding, directional strength, anisotropy, and the formation of weak interfaces between deposited layers. Molded specimens cannot fully represent printed components because the printing process may introduce directional particle and fiber alignment, interlayer discontinuities, variable porosity, and incomplete bonding.

A broader mechanical-testing program is also required. In addition to compression tests, future investigations should include tensile, flexural, shear, impact, fracture, fatigue, and creep testing. Complete load–displacement and stress–strain curves should be obtained to determine compressive modulus, strain at peak load, ultimate deformation, toughness, and failure mechanisms. A larger number of specimens should be tested for each formulation to improve statistical reliability and allow meaningful comparisons between material groups.

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The internal structure of the composite should be characterized more thoroughly. Future research should quantify cured density, moisture content, void fraction, particle distribution, fiber dispersion, and the quality of bonding between wood particles and the epoxy matrix. Microscopic examination, sectional imaging, or computed tomography could be used to identify internal voids, resin-rich zones, particle debonding, fiber pull-out, and localized defects that may influence mechanical performance.

Environmental durability represents another major research direction. The material should be evaluated under changing humidity, water exposure, temperature variations, ultraviolet radiation, biological attack, and freeze–thaw conditions where relevant. Long-term testing should also investigate dimensional stability, moisture absorption, swelling, shrinkage, creep, thermal degradation, and aging of the wood–epoxy interface.

Fire performance requires particular attention because both wood particles and polymeric epoxy binders may contribute to combustion, smoke production, and thermal degradation. Future studies should therefore assess ignition behavior, flame spread, heat release, smoke generation, charring, and residual mechanical strength after thermal exposure. The possible incorporation of compatible fire-retardant additives may also be investigated.

The environmental performance of the proposed composite should be evaluated through a complete life-cycle assessment. Although the use of wood particles may contribute to waste valorization and reduced consumption of some conventional materials, the environmental impact of the epoxy binder, curing process, transportation, service life, recyclability, and end-of-life treatment must also be considered. Future formulations could explore recycled wood waste, bio-based resins, lower-impact binders, and reversible or recyclable matrix systems.

Finally, the material should be examined at progressively larger scales. After laboratory-scale printability and mechanical testing, structural demonstrators and full-size components should be manufactured and tested under realistic loading and environmental conditions. Numerical modeling and finite-element analysis may then be used to predict structural behavior, optimize material distribution, reduce stress concentrations, and improve component geometry. The eventual development of design guidelines, quality-control procedures, manufacturing tolerances, and standardized testing methods will be necessary before the proposed composite can be considered for engineering or construction use.

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