

TENSILE STRENGTH OF COMPOSITE MATERIALS MADE OF COMPOSITIONS POLYLACTIC ACID (PLA), THERMOPLASTIC URETHANE (TPU) AND BAMBOO

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Abstract:

*The objective of this study was to evaluate tensile strength of experimental material made from combinations of polylactic acid (PLA), thermoplastic urethane (TPU) and bamboo (*Phyllostachys edulis*). Two type of composites were prepared for the test to compare tensile performances of both. Composites were made having 50 % PLA and 50 % TPU in addition to these sample with the content of polymers added 15 % bamboo fibers by weight. Based on the results the composites produced from bamboo-PLA-TPU materials had an average tensile strength value of 8.71 MPa while the composite produced from only PLA and TPU had 9.006 MPa as a corresponding value. The difference between both average values were not significant. Conversely, the Young's modulus of the bamboo-reinforced composite reached 1700 MPa, while the composite composed only of PLA and TPU exhibited a modulus of 450 MPa. The loading time along with the displacement values of the 100 % polymer based samples results in higher values than those of the samples having bamboo due to its higher rigidity.*

Key words: PLA, TPU, PLA, bamboo, tensile strength.

INTRODUCTION

Wood composites are divided into two main classes: wood composites produced with thermosetting adhesives or materials such as thermoplastics and cement. Thermosetting wood composites are produced using wood materials and thermosetting adhesives. They are combined under heat in a hot press. Thermoplastic-based wood composites consist of wood materials and plastics such as polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC). Materials called Wood Plastic Composites (WPCs) are produced by blending wood flour and thermoplastic-based polymers (Güller 2001). WPCs have found many uses in industry due to their superior properties, such as moisture resistance, good dimensional stability, the ability to use waste materials in production, customizable colors and sizes, and resistance to fungi and insects. They have become one of the fastest-growing sectors, especially in the forest products sector (Tufan et al. 2015).

Wood composites refer to materials obtained by bonding woody materials with one another using adhesives. Composites encompass not only sheet products but also molded products and products created by combining wood with other materials. These products range from fiberboard to laminates (Güller 2001).

Wood composites are classified as follows. Board Products: Plywood, Particleboard, Waferboard, Flakeboard, OSB (Oriented Strand Board), Fiberboard (MDF, HDF, LDF- Insulation Board).

Structural Composites: PSL (Parallel Strand Lumber), LSL (Laminated Strand Lumber), OSL (Oriented Strand Lumber), LVL (Laminated Veneer Lumber), GLULAM (Glued Laminated Timber), Cross-laminated Timber CLT, Structural plywood, Structural flakeboard (waferboard, OSB), Wood I-beams.

Wood-Non-Wood Composites: Composites using inorganic materials as binders (gypsum boards, magnesium cement boards, Portland cement boards), Wood fiber-thermoplastic composites (composites with high thermoplastic content, composites with low thermoplastic content, non-woven textile type composites) (Güller 2001).

Bamboo is a plant that grows in tropical climates, reaches maturity in a short period of 3-4 years, and it is used in many areas such as paper, furniture, construction, food, and the chemical industry (Okur 2006). Bamboo is a plant consisting of many different types of woody grasses. One of them is the bamboo type that grows like a tree, has lignified bark, thin leaves, but produces quite large flowers. The other one of them is the thin bamboo, weak type that grows like a grass, reaching no more than a meter in height which is also known as calamus (URL 1, 2025). Bamboo grows mostly in tropical climates worldwide. It has a thick, underground trunk and grows by branching. The length of these trunks varies depending on the species. Its strap-like leaves

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grow from the branches of older plants and from the trunk of younger ones. Bamboos are long-lived plants (URL 1, 2025).

Polylactic acids are rigid thermoplastic and aliphatic polymers with a semi-crystalline or amorphous structure. This polymer has the unique feature of possessing both the characteristics of polyethylene terephthalate (PET) and the properties of polypropylene (PP) (Gupta et al. 2008). Another characteristic of PLA is that it is a biodegradable polymer produced from starch-rich plant sources such as corn, sugarcane, and wheat. In addition to these properties, PLA's environmental friendliness and biocompatibility provide potential uses in plastic applications, packaging, agricultural products, disposable products, and the medical field (Gupta et al. 2008).

Thermoplastic polyurethane (TPU) is a melt-processable thermoplastic elastomer with high durability and flexibility. Replacing malleable plastic or hard rubber, TPU offers high elongation and tensile strength, flexibility, and the ability to withstand varying degrees of oil, grease, solvents, chemicals, and abrasion (Mengeloğlu and Çavuş 2020). Inherently flexible, it can be extruded or injection molded on conventional thermoplastic manufacturing equipment to create rigid components, typically for footwear, cable and wire, hose and tubing, film and sheet, or other industrial products. It can also be compounded to create robust plastic molds or processed using organic solvents to create laminated textiles, protective coatings, or functional adhesives. (URL 3 2025).

TPU provides a wide range of physical and chemical properties for the most demanding applications, such as automotive, agriculture, food packaging, sports and textile, aerospace, electronics, and more (URL 2 2025). Its thermoplastic nature provides several advantages unmatched by other elastomers, including excellent tensile strength, high elongation at break, and good load-carrying capacity (URL 2 2025). TPU softens at high temperatures and can withstand low pressure, has a higher tensile modulus than rubber (Allami et al. 2021).

OBJECTIVE

The main objective of this study was to compare tensile strength of the composite produced from only PLA-TPU mixture and the composites produced from bamboo-PLA-TPU mixture. The specific objective was to produce 1) the composite from PLA and TPU and composite from PLA, TPU, and bamboo, 2) subject them to tensile test, and 3) compare the tensile and Young's modulus values to the tensile.

MATERIALS AND METHODS

Material

Three different materials were used in the production of the composites, which are Poly Lactic Acid (PLA), Thermoplastic Polyurethane (TPU), and bamboo material which is shown in Fig. 1.



Fig. 1.
The bamboo stems used in this study.

Method

Chipping of Bamboo Material

In the production of the bamboo-PLA-TPU composite material produced for this study, the bamboo was chipped using a coarse chipping machine. The chips are shown in Fig. 2.



Fig. 2.
Coarse bamboo chip.

After the bamboo material was chipped, it was placed in a container filled with enough water to just above the water level as shown in Fig. 3. After 24 hours, the chips are softened. This process facilitates the easier separation of the chips into fibers within the refiner.



Fig. 3.
Soaking coarse bamboo chips in water.

Fiber Refining of Chips

The bamboo, once cut into chip size, was then separated into fibers using a disc refiner. The refiner machine is shown in Fig. 4.



Fig. 4.
Refinery machine.

The coarse chips, soaked in water, were wetted before entering the refiner. The chips are then fed into the refiner while water is added. Adding water facilitates defibration chipping. This allows water to penetrate the gaps in the bamboo chips. This also allows the chips to fibrillate more easily between the refiner discs and prevents damage to the fibers during the fibrillation process. Fig. 5 shows bamboo fibers exiting the refiner.



Fig. 5.
Bamboo undergoing fibrilization process in refinery.

Filtering the Fibers

As shown in Fig. 6, the bamboo fibers were filtered. After the filtration process, the bamboo fibers obtained are sieved in a wet environment to remove excess water. The solids are collected immediately after the water is manually filtered.



Fig. 6.
The process of filtering the fibrillated bamboo fibers in the refiner.

Drying Bamboo Fibers

Drying process of bamboo fiber lasted approximately two weeks at room temperature as shown in Fig. 7. The purpose of this drying process was to eliminate defects such as cracking and warping, which would otherwise occur if the fibers were dried in a drying oven due to their high moisture content. The prepared bamboo fiber pastewere dried in an oven at 100°C for 45 minutes, reducing the moisture content of the bamboo fibers to 5%.



Fig. 7.
Drying of bamboo fibers at room temperature.

Sieving of Bamboo Fibers

After drying, the dried bamboo fibers were sorted using a vibrating sieve into 1 mesh, 1.5 mesh, and 3 mesh sizes. Fig. 8 shows the vibrating sieve and the smallest bamboo fibers obtained from the vibrating sieve.

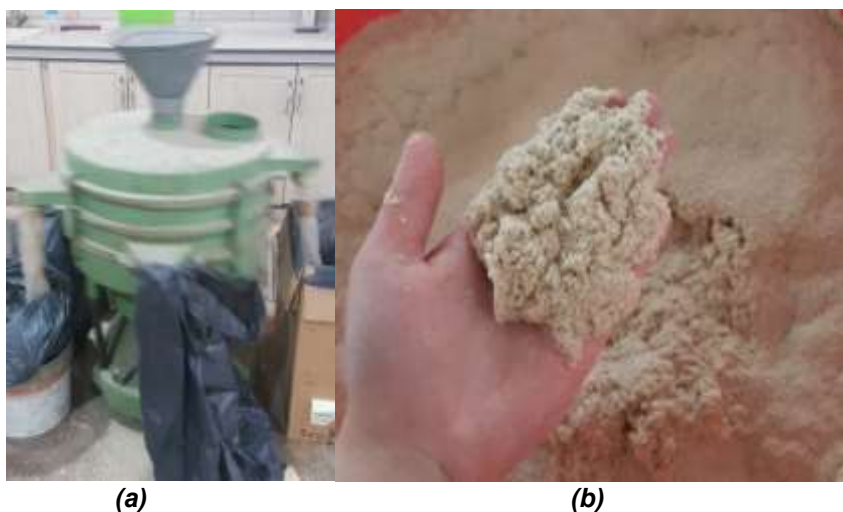


Fig. 8.
a) Vibrating sieve; b) Bamboo fibers of 1 mesh size coming out of the shaking sieve.

The bamboo fibers remaining in the 3-mesh sieve were ground using a mill until they became powder again. Following these processes, 15% by weight of bamboo fiber was added to a 50%:50% PLA-TPU mixture prepared in an extrusion machine, enabling the composite production process to be carried out using high temperatures. Fig. 9 shows the extrusion machine and the parameters used in its operation.



a



b

Fig. 9.

a) Extrusion machine; b) Parameters used in the extrusion machine.

To ensure this aggregation process was completed flawlessly, the temperature in Zone 1 was set at 175°C, gradually increasing by 5°C until the outlet temperature reached 195°C as shown in Fig. 9b. The product from the outlet was immersed in a cold water pool and directed to the crusher. Fig. 10a shows the product leaving the cold water pool being granulated using a crusher. The long, single-piece product is granulated using a crusher for use in the injection molding machine. Fig. 10b shows the granules emerging from the crusher.



(a)



(b)

Fig. 10.

a) Crusher machine; b) Bamboo-PLA-TPU blend granules.

The granulated product is then remelted using heat in an injection molding machine, which uses the same logic as an extrusion machine. The melted product is poured into a mold and pressed to produce the final product. The injection molding machine is shown in Fig. 11.



Fig. 11.

Injection machine.

Tensile Test

A typical test sample with dimension of 165×50×5 mm for the bamboo fiber-reinforced PLA-TPU composite prepared for tensile testing is shown in Fig. 12. Four test samples were produced from only PLA-TPU mixture and 4 test samples produced from bamboo PLA-TPU mixture. Therefore, 8 test samples were subjected to tensile loading.



Fig. 12.
PLA-TPU-bamboo composite test specimen.

Composite test specimens made from a PLA-TPU-bamboo mixture were subjected to tensile testing on the MTS Universal Testing Machine at a loading rate of 25 mm/min, in accordance with ISO 527-1 and ISO 527-2 standards. An extensometer was mounted on the specimen during loading to measure elongation. Fig. 13 shows the tensile loading applied to the tensile specimen.



Fig. 13.
Tensile testing of the composite material produced from bamboo-PLA-TPU materials under a certain load using an extensometer.

Young's Modulus

Following equation was used to calculate Young's Modulus Values:

$$E = \frac{\sigma}{\epsilon}$$

where: E is Young's Modulus, σ is stress, and ϵ is strain.

Statistical Analysis

The SAS Software 9.4 (SAS Institute Inc., Cary, NC, USA) statistical package program was employed in the analysis of the data. The effects of the bamboo content on tensile strengths of the PLA-TPU composites were investigated at the 5% confidence level.

RESULTS and DISCUSSIONS

The results are shown in Table 1. Accordingly, the tensile strength of the composite material produced from only PLA and TPU mixture was very close to the composite material produced from PLA, TPU, and bamboo mixture. They are not statistically different with LSD value of 0.83 as shown in Table 1.

Table 1

Tensile strength and Young’s modulus values of composite materials produced using bamboo-PLA-TPU materials

Component in Composite	Tensile Strength (MPa)	Strain (%)	Young Modulus (MPa)
PLA-TPU	9,006 (A)*	5.0	450
PLA-TPU-Bamboo	8,714 (A)	0.75	1700

*Letters in parenthesis shows statistical difference

On the other hand, Young’s modulus value for the composite with bamboo content was 1700 MPa. while the one of the composite made of only PLA and TPU mixture was 450 MPa. This could be that the adding bamboo to PLA-TPU mixture increased Young’s modulus for 3.8 times than the one made from only PLA-TPU mixture. Nurul Fazita et al. (2021) studied on parameter optimization by adding bamboo fiber to the PLA composites. They investigated that adding bamboo to the PLA composites improved the tensile modulus of the composite material.

PLA-TPU Composite

Fig. 14 shows the curve obtained from the tensile test of a composite material made of PLA and TPU materials.

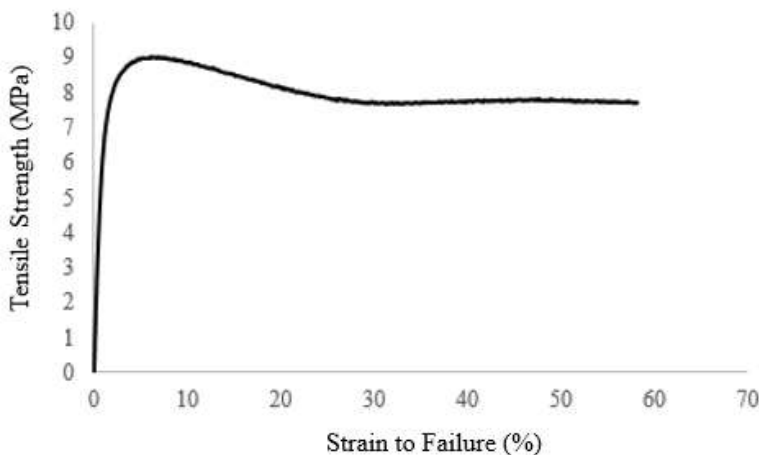


Fig. 14.

Load-displacement curve of composites made of only PLA and TPU mixture under tensile load.

The composite material reached its maximum strength in a longer time under tensile load, possibly due to the TPU content in its structure, which increased its resistance to the load. Thus, the material elongated and held itself together under the load without breaking. Demirel et al (2024) studied on 3 D printed dowel made of PLA and TPU in a furniture joint. The dowel produced from PLA and TPU mixture showed more elongation compared to the one produced from PLA. Çava and Aslan (2023) studied on the printability of recycled pet and found that the inclusion of TPU increases flexibility, elasticity, and impact resistance, making it suitable for applications requiring durability and flexibility.

PLA-TPU-Bamboo Composite

The Fig.15 shows the curve obtained from the tensile test of the PLA-TPU-Bamboo composite material.

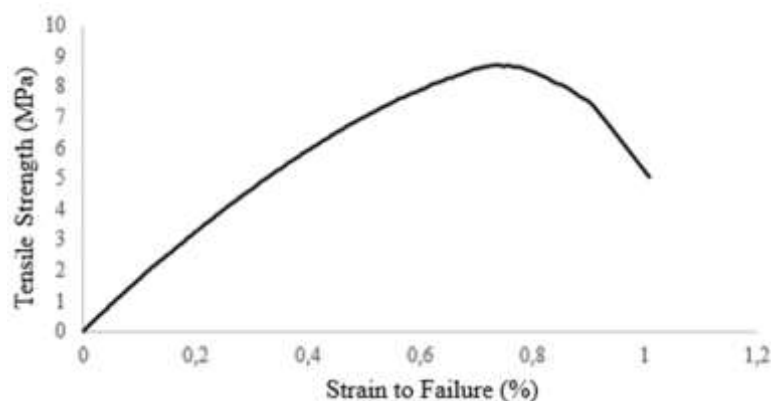


Fig. 15.

Load-displacement curve of composites made of PLA, TPU and bamboo materials under tensile load.

While the material produced from only PLA and TPU reached its maximum strength in longer time, the composite with bamboo took shorter time to reach its maximum strength due to the bamboo in its structure. However, unlike the composite material produced from only PLA and TPU, it was unable to sustain the load for a long time after reaching its maximum strength. The curve obtained after the tensile test showed a 3% decrease in the maximum strength of the composite material compared to the composite produced from only PLA and TPU. This is thought to be due to the bamboo adding rigidity to the chemical structure of the composite material. Radzi et al (2022) stated in their study that the mechanical properties of bamboo composites are relatively low due to less brittleness. It is also believed that the production conditions were not fully suitable. This study demonstrated that better production conditions will yield better results.

CONCLUSIONS AND RECOMMENDATIONS

In this study, a composite material was produced from PLA and TPU mixed at a 50%:50% ratio. This composite material was compared with another composite material by adding 15% by weight of bamboo fibers to a mixture of PLA and TPU mixed at a ratio of 50% to 50%. Accordingly:

- The maximum tensile strength of the composites produced from only PLA-TPU materials was not significantly different from the ones with bamboo content.
- Composites made from PLA-TPU-bamboo materials reached maximum tensile strength more quickly and at a lower displacement rate than those made with only PLA-TPU mixture.
- In general, it can be said that TPU material increased the elongation, while bamboo material increased the brittleness in composite materials.

During production, difficulties were encountered at the material joining points, and the other ratios (65% PLA, 35% TPU, and 15% bamboo by weight; 80% PLA, 20% TPU, and 15% bamboo by weight) could not be subjected to mechanical testing. By varying the ratios of bamboo and other polymer materials, composite materials with optimal mechanical properties will be produced.

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REFERENCES

- Allami T, Alamiery A, Nassir MH, Kadhum AH (2021) Investigating physio-thermo-mechanical properties of polyurethane and thermoplastics nanocomposite in various applications. *Polymers* 13(15): 2467. <https://doi.org/10.3390/polym13152467>
- Backes EH, Harb SV, Pinto LA, de Moura NK, Morgado GFM, Marini J, Passador R, Pessan LA (2024) Thermoplastic polyurethanes: synthesis, fabrication techniques, blends, composites, and applications. *J Mater Sci* 59, 1123-1152. <https://doi.org/10.1007/s10853-023-09077-z>
- Çava K, Aslan M (2023) Investigating printability and mechanical performance of 3d printed recycled pet with PLA and TPU hybrid additives. *IJ3DPTDI* 7(2):252-258
- Demirel S, Kuvel NT, Çava K, Aslan M (2024) The performance of 3D printed dowel with three different surface designs in furniture joints. *DOAJ* 25(1):100-106.
- Güller B (2001) Wood composites. *Turkish Journal of Forestry*, 2(1):135-160.

Mengeloğlu F, Çavuş V (2020) Preparation of Thermoplastic Polyurethane-based Biocomposites through Injection Molding: Effect of the Filler Type and Content. *Bioresources*, 15(3):5749-5763.

Nurul Fazita MR, Johary N, Abdulul Khalil HPS, Norazli N, Azniwati AA, Mohamad Haafiz MK (2021) **Parameter optimization via the Taguchi method to improve the mechanical properties of bamboo particle reinforced polylactic acid composites.** *Bioresources*, 16(1):1914-1939. <https://doi.org/10.15376/biores.16.1.1914-1939>

Özmen N, Çetin NS, Narlıoğlu N, Çavuş V, Altuntaş E (2014) Utilisation of MDF waste for wood plastic composites production. *Turkish Journal of Forestry* 15:65-71.

Okur N (2006) Comparative analysis of bamboo fiber and yarn properties with performance properties of other fibers and yarns PhD diss, İstanbul Technical University, Türkiye.

Gupta B, Revagade N., Hilborn J (2007) "Poly (Lactic Acid) fiber: An overview" *Prog Polym Sci* 32:455-482. <https://doi.org/10.1016/j.progpolymsci.2007.01.005>

ISO (2019) Part 1: General principles: Determination of tensile properties. ISO 527-1, INTERNATIONAL STANDARDIZATION ORGANISATION, Geneva, Switzerland.

ISO (2019) Part 2: Test conditions for moulding and extrusion plastics: Determination of tensile properties. ISO 527-2, INTERNATIONAL STANDARDIZATION ORGANISATION, Geneva, Switzerland.

Radzi AM, Zaki AA, Hassan MZ, Ilyas RA, Jamaluddin KR, Daud MYM, Aziz AA (2022) Bamboo-fiber-reinforced thermoset and thermoplastic polymer composites: A Review of Properties, Fabrication, and Potential Applications. *Polymers*, 14(7):1387-1408. <https://doi.org/10.3390/polym14071387>

Tesema HA, Durai J, Alamarew NA (2025) Bamboo biomass estimation for sustainable forest management and climate mitigation: a comprehensive review of allometric models and emerging technologies. *Discover Sustainability*. 6:1315-1334. <https://doi.org/10.1007/s43621-025-02001-2>

Tufan M, Güleç T, Çukur U, Akbaş S, İmamoğlu S (2015) Some properties of wood plastic composites produced from waste cups. *Kastamonu Univ., Journal of Forestry Faculty* 15(2):176-182.

URL 1: <https://bilgihanem.com/bambu-agaci-nedir/>, 24.08.2025

URL 2: <https://omnexus.specialchem.com/selection-guide/thermoplastic-polyurethanes-tpu> 24.08.2025

URL 3: <https://www.ema.gen.tr/wp-content/uploads/2020/05/Termoplastik-Poli%C3%BCretan-TR-TPU-Rehberi.pdf>, 24.08.2025