

Mechanical and Sustainable Enhancement of Epoxy Composites using Tamarind Seed Powder

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Abstract

The investigation examines how tamarind seed powder affects epoxy-based materials for the development of waste-based useful products. The research examines the mechanical behavior of epoxy resin composites which contain tamarind seed powder in increasing percentages spanning from 10% to 40%. The team utilized the hand layup method to produce the composites which then fulfilled the ASTM guidelines for specimen fabrication for mechanical tests. The study examined fundamental mechanical parameters by evaluating tensile strength, flexural strength, and impact strength across different mixture compositions. Experimental results pointed toward composites containing 20% tamarind seed powder as achieving superior mechanical properties than the rest of the formulations. The combination reached a highest tensile strength level at 0.025 KN/mm² and exhibited an exceptional flexural strength at 0.033 KN/mm² together with improved impact resistance. Too great amounts of filler addition below 20% resulted in deteriorating mechanical characteristics. The tamarind seed powder distribution in the epoxy materials was uneven throughout the majority of the test process. Experimental findings confirm that proper utilization of tamarind seed powder at 20% achieves maximum effectiveness as reinforcement agent in epoxy-based composite materials. The study verifies the feasibility of this organic waste material for industrial applications especially in building automobile panels to decrease dependency on synthetic components. The study helps the sustainable composite material field by giving practical knowledge for establishing environmentally friendly alternatives to conventional materials.

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INTRODUCTION

The tropical African plant *Tamarindus indica* exists in the Fabaceae family because it is a leguminous tree. The tamarind tree fruit with its enjoyable flavour exists widely in human utilization worldwide. The employment of composites combined with scrap material usage establishes a way to increase product worth [1]. Scientists have advanced eco-friendly composite manufacturing by adding natural fibers into polymer frameworks due to increased natural fiber research. Industry growth for natural fiber composites occurs because these materials demonstrate high adaptability in construction and automotive applications [2]. Experts show enhanced dedication toward developing biodegradable high-performance composites

because of advancing environmental problems. The development of natural fibers and particle-reinforced composites serves as an effective way to demonstrate eco-materials importance for environmental sustainability according to [3]. A certain technology needs to be specified and detailed for effective purification and final acquisition of agricultural products [4]. The environment faces significant ecological challenges because toxic metals now exist at elevated concentrations mainly in freshwater systems. The quick expansion of metals along with their ingredients across various sectors drives this proportional growth. Polymer composites serve many functions across daily life since they demonstrate outstanding characteristics. Composites perform to the extent that the materials incorporated in their composition are selected. The addition of fibers or powders into polymers results in major alterations in composite material properties [5]. Experimental focus now centres on bio-composites consisting of natural fibers together with synthetic or natural polymer matrices because these composites offer superior value as well as low material density, environmentally friendly decomposition properties, extensive availability and potential power generation abilities, along with substantial CO₂ absorption capabilities [6]. Fully extended Tamarind seed fiber takes a coiled arrangement between 50 to 100 mm lengths. The tamarind tree survives for two centuries and generates between 150 kilograms and 500 kilograms of fruit every year. The tamarind fruit production in India reaches approximately 300,000 tonnes per year to generate 45,000 tonnes of tamarind fruit fiber (TFF). Improper disposal of these fibers leads to offensive odours while simultaneously polluting the environment [7]. The enhanced properties of tensile strength and flexural strength in hybrid composites lead to better load resistance. Tamarind keeps its growing position in tropical territories across Asia and Africa as well as Central America. The tamarind tree successfully grows in poor soil without needing supplemental watering and does not demand human maintenance. Tamil Nadu produces the maximum quantity of tamarind annually in India through its annual production of 45,000 metric tonnes. The estimated metric tonnage of 98,000 total quantities amounts to 45.4% of India's tamarind tree allocation throughout the region. Scientists consider the tamarind fruit as the premier and most costly component that originates from the plant. The major portion of the fruit comprising 25–40% of seeds gets discarded by people as waste material [8]. Tamarind seed has density values of 1350 kg/m³ while the tensile strength ranges from 40 to MPa according to research [9]. Srinivas K. R., a series of mechanical property assessments involved tamarind shell powder combined with epoxy in different percentages. Tensile strength increased when tamarind shell powder mixed with epoxy at a ratio of 80% to 20% according to experimental results [10]. Seed kernel chemical make-up controls the bond characteristics of the complete structure. The kernel powder demonstrates water affinity which leads to formation of gel before transforming into a smooth flexible film. The water content of this substance amounts to 11.3 ± 1.4 percent. Tamarind seed bulk density reaches 8840 kg/m³ when measuring complete raw seeds whereas 7771 kg/m³ is observed in roasted kernels. The water absorption capacity of roasted tamarind kernel amounts to 245.7 ± 6.2 and 196.6 ± 5.0 grams. The kernel minerals determine vital characteristics of material composites through their effects on both physical and thermal characteristics. The tamarind seed that contains 60-65% polysaccharide with a specific component of galactoxyloglucan (GXG) becomes a thick gel when treated with boiling water for five minutes [11]. Tamarind Seed Polysaccharide (TSP) functions as a natural polymer because it demonstrates proper compatibility with biological systems and performs biodegradation. The final product originates from boiling the endosperm component of *Tamarindus indica* seeds. Analysis proves TSP consists of galactoxyloglucan which contains glucose and xylose and galactose molecules at a ratio of 3.1:1.7:1 [12]. Bio-composites with 50% TSP powder reached optimum mechanical performance when the 1:1 hybridization ratio was used [13]. Fiber extraction technologies together with composite production stand as topics in these articles [14]. Experts continue studying these composites because their beneficial properties make them suitable for engineering applications in lightweight structures [15, 16]. Multiple experts identify the need to develop inexpensive natural fiber-reinforced polymer composites which combine superior strength properties with appropriate manufacturing protocols for different materials following filler and resin classifications [17]. Experts produced hybrid composite samples through a compression moulding procedure by integrating epoxy resin that accounted for 70% of total weight along with 30% fiber content. [18]. A material system comprises multiple physically different phases which produce features

that exceed those of the single components, Materials known as composites are essential because their exceptional strength-to-weight ratio and stiffness-to-weight ratio outperforms steel and aluminium by a significant margin [19]. These crucial materials have restricted access to the market. The availability of materials extends only to particular uses. Several applications need materials which have low strength requirements alongside lightweight properties. This research analyses the development process of multi-fiber composites combining natural fibers with synthetic fibers as material components [20]. Natural fiber-reinforced composites stand as a modern sustainable material group with useful mechanical features that cover an array of practical uses according to [21]. The scientific field shows interest in natural fibers since they can enhance polymer properties by integration. Several elements control how natural fiber-reinforced composites present their characteristics. Multiple characteristics of fibers and bonding materials plus the dosage of fiber content together with fiber direction and sequence alignment and bonding effectiveness between fibers and matrix also including surface modifications of fibers as well as dual-fiber combinations and performance enhancement additives combine to determine composite properties [22]. Industrial use of organic materials specifically reinforced and composite materials continues to grow in current modern industries. The market requires sustainable and renewable substances to substitute organic fillers [23]. Compounds resulting from multiple chemical components make up polymers which constitute complex macromolecules. Modern life depends entirely on the numerous functions which synthetic together with natural polymers fulfil. The composite of individual monomers through polymerisation results in polymers that are larger molecular structures [24]. This NFRC shows promise for improving multiple polymer types which results in better mechanical properties together with potential new applications. Multiple trials allow investigators to recognize which polymers deliver the best time-tested performance results [25]. Both natural resins demonstrate high potential as glass replacement materials while synthetic fibers serve as reinforcement elements in thermosetting and thermoplastic polymers. Low-cost lightweight bio-composite products can be manufactured using these sustainable raw materials because their strength and stiffness make them effective for this purpose. The substances demonstrate substantial potential usage in many technical domains [26]. The combination of biological, chemical and environmental together with economic characteristics within natural fibers provides powerful ways to improve both the characteristics and modern applications of fiber composites [27]. The numerous processing methods used in advanced composites need improved physical properties of polymer composites because they help decrease penetration and buckling damage [28]. The inclusion of coupling agent increased both flexural strength and flexibility in the poly-based materials compared to untreated polylactic acid [29]. Mounting different reinforcement materials inside a matrix enables polymer composites to achieve more diverse properties than those containing single reinforcement systems. Scientific research regarding hybridizing natural and synthetic reinforcing agents has gained special prominence in the scientific world [30].

MATERIALS AND METHODS

The experimental study employed tamarind seed powder as a reinforcing agent in epoxy resin to create biopolymer composites. The tamarind seeds were ground into a fine powder using a ball mill. This process involves steel balls inside a rotating cylinder that crush the seeds through impact and friction. The chosen epoxy resin is Araldite LY 556, which is known for being very resistant to chemicals, sticking well to surfaces, and maintaining its shape. The curing process of the composite became possible through the combination of HY 951 hardener with epoxy resin. Seven different composite formulations resulted when tamarind seed powder contents reached between 10% to 40% weight while the epoxy resin made up the remaining 90% to 60%. The research developed seven distinct combination samples of epoxy resin mixed with tamarind seed powder at relationships of 10/90, 15/85, 20/80, 25/75, 30/70, 35/65 and 40/60. The compression moulding method served as the basic production technique to apply a heated mould followed by pressure application on the mixture. The compression moulding apparatus operated continuously using molds sized at 304.8 mm × 304.8 mm. A compression moulding apparatus consisted of two plates where one plate remained stationary and the other plate could move because it contained a hydraulic system for pressure delivery. The test specimens followed

standards from ASTM for mechanical testing purposes. The production of tensile test specimens required dimensions at 180 mm length and 20 mm width with 3 mm thickness. The dog bone shaped specimens follow specifications found in ASTM D638 standards. Laboratory tests on flexural specimens were developed into 130 mm × 12.5 mm × 3 mm shapes according to ASTM D790 testing standards. The data collection for impact tests was executed by making specimens that satisfied the requirements established by ASTM D256. A universal testing equipment with a maximum load of 5000 kg conducted the tensile tests by using speeds of 1.25, 1.5, and 2.5 mm/min. A three-point bending test served to evaluate the flexural strength of the specimens. Energy absorbing tests were conducted to examine how the material handles shock loadings. The laboratory measurements took place at normal temperature under controlled laboratory settings. The mechanical parameters from tested data served as inputs for the existing formulas which generated tensile strength and flexural strength and impact strength measurements. A thorough characterization of the tamarind seed powder-reinforced composite became possible through this well-organized approach. Figure 1 depicts the images of a) tamarind seed b) tamarind seed powder.



Figure 1. (a) Tamarind Seed (b) Tamarind Seed Powder.

EXPERIMENTAL METHOD

The process for creating tamarind seed powder-based bio-polymer composites involved careful steps in choosing materials, preparing them, making the composites, and testing them. Tamarind seed powder, derived from the tamarind pulp industry, was selected due to its notable adhesive and gelling characteristics. The seed powder underwent ball milling to ensure a consistent particle size and surface properties, thereby improving its compatibility with the epoxy matrix. The epoxy resin (Araldite LY 556) and hardener (HY 951) were selected because they are strong, stable with heat, and stick well. This ensures that the composites are strong and last a long time. The fabrication process utilised the hand-layup technique, recognised for being cost-effective and versatile in composite production. Various weight fractions of tamarind seed powder (10%, 15%, 20%, 25%, 30%, 35%, and 40%) were thoroughly mixed with the epoxy resin and hardener. This mixture was poured into preheated moulds, ensuring uniform distribution of the filler material. The moulds were subjected to compression moulding under controlled pressure and temperature conditions to minimize voids and achieve uniform consolidation. The curing process was carefully optimized to enhance the composite's mechanical properties. After curing, the composites were removed from the moulds and machined to meet ASTM standards for subsequent mechanical testing. The mechanical properties of the composites were evaluated using a universal testing machine (UTM) and impact testing apparatus. Tensile strength tests determined the maximum stress the composites could withstand before failure.

Flexural strength tests were done using a three-point bending device to check how well the material can handle bending when weight is applied. The applied evaluations determined what extent the composites could absorb while dissipating energy during shock loading. Three repeated trials were conducted to validate the consistency and repeatability of the obtained experimental results. We conducted additional observations on the surface finish and uniformity of the samples to assess the

quality of fabrication. The work was evaluated mechanical properties of composites as they relate to tamarind seed powder concentrations. The findings were analysed across different filler concentrations to determine the most effective composition. Additionally, the effectiveness of the tamarind seed powder composites was compared to traditional plastic materials to assess their potential for use in applications like automotive panels. The results showed that tamarind seed powder can be a cost-effective and eco-friendly option for strengthening materials, helping to create sustainable products for industrial use. Figure 2 shows the tested sample for 30% tamarind seed powder, a) impact test b) flexural test c) tensile test

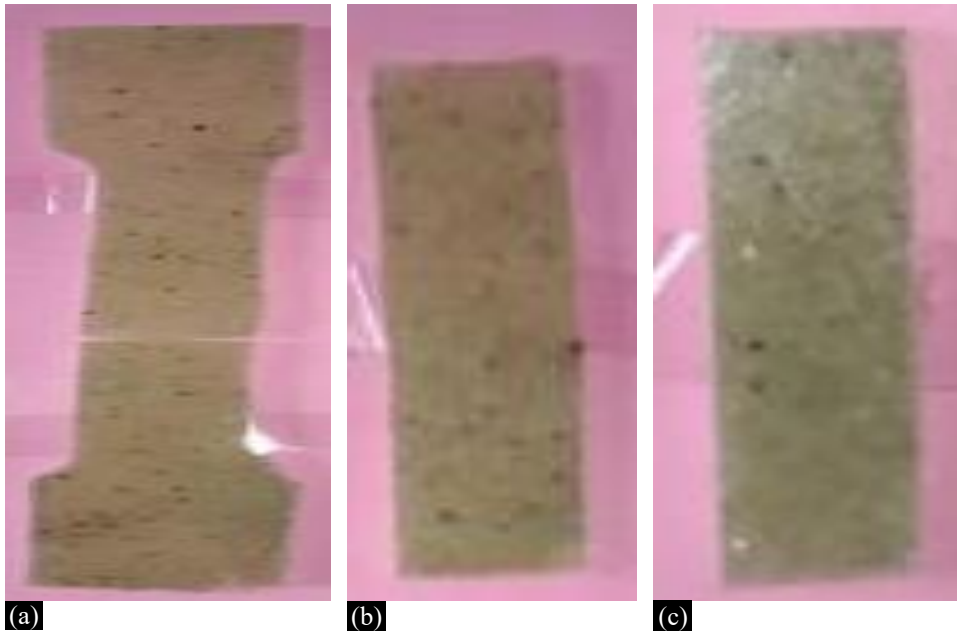


Figure 2. Tested sample for 30% Tamarind seed powder, a) impact test b) flexural test c) tensile test

The tensile, flexural, and impact tests were conducted using the experimental setup illustrated in Figure 3. The tests were done on flat composite samples that measured 400 mm long, 100 mm wide, and 3.5 mm thick. The tensile test followed the ASTM D638-03 standard, and the bending tests were done using a three-point method according to ASTM D790-03. Furthermore, we conducted the impact test in compliance with ASTM D256D256-05 ISO 179 guidelines.

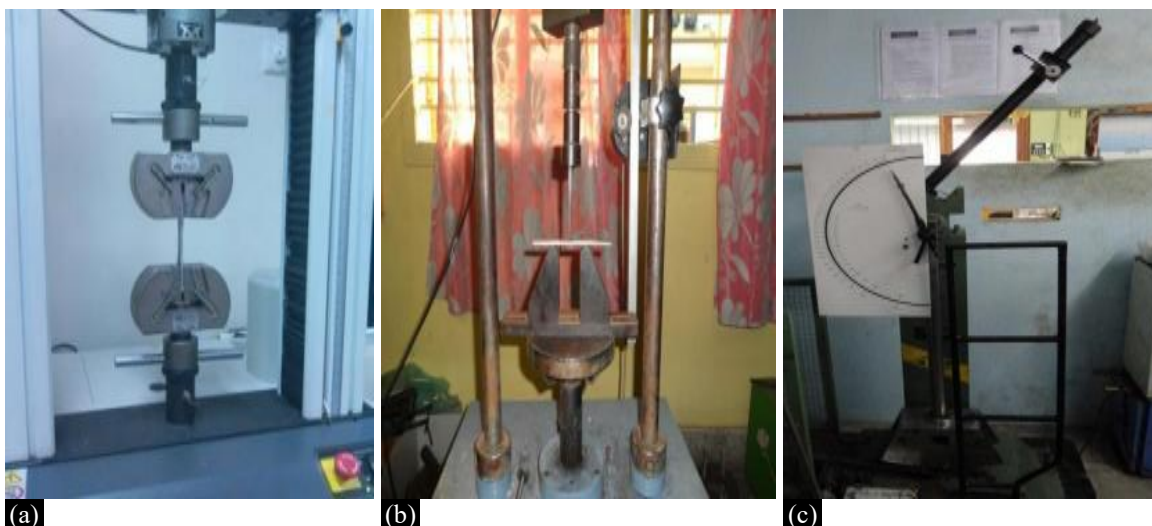


Figure 3. The experimental setup for the following tests: (a) Tensile, (b) flexural, and (c) Impact.

RESULTS AND DISCUSSION

Tensile Properties

The tensile test results for tamarind seed powder reinforced epoxy composites showed varying tensile strengths based on composition. The highest tensile strength of 0.025 kN/mm² was observed with 20% tamarind seed powder and 80% epoxy resin, indicating optimal reinforcement at this ratio. Other compositions displayed lower strengths, including 10% (0.02 kN/mm²), 15% (0.013 kN/mm²), 25% (0.023 kN/mm²), 30% (0.0182 kN/mm²), 35% (0.0123 kN/mm²), and 40% (0.0235 kN/mm²). These results suggest that tensile strength decreases as the filler percentage exceeds 20%, potentially due to poor particle distribution and reduced bonding within the matrix. Figure 4 depicts the tensile test for the samples.

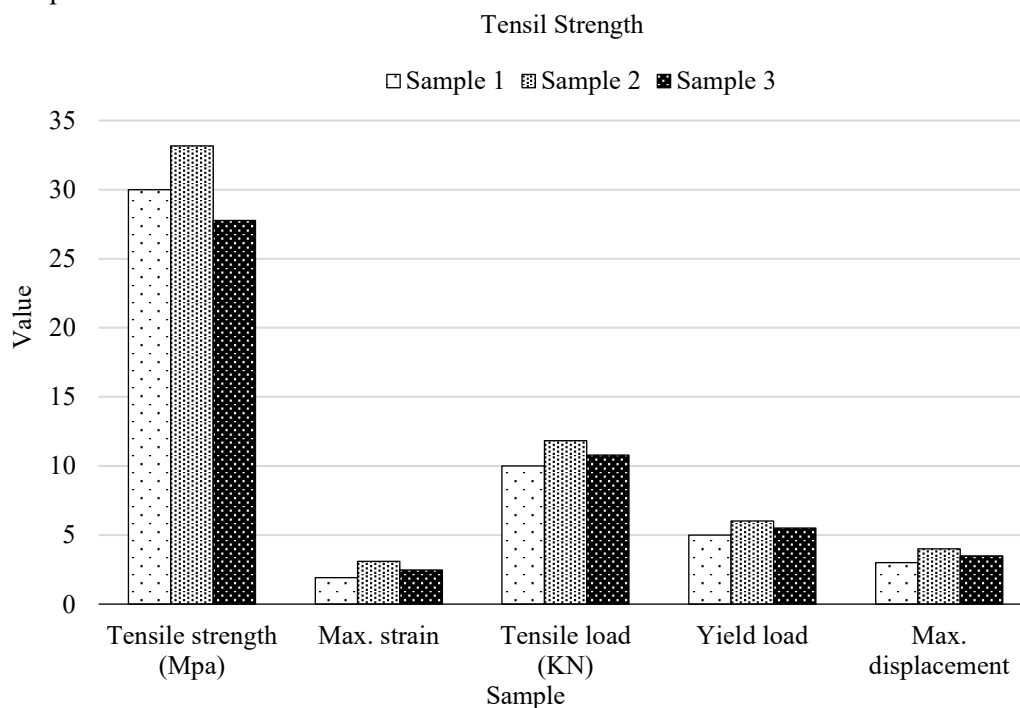


Figure 4. Tensile test for the samples.

Flexural Test

The flexural strength test results for tamarind seed powder reinforced epoxy composites, conducted as per ASTM D790 standards, revealed that the strength varies with the percentage of tamarind seed powder. For 10% filler, the flexural strength was 0.024 KN/mm², decreasing slightly to 0.021 KN/mm² at 15%. The highest value was observed at 20% filler with 0.033 KN/mm², indicating optimal reinforcement. Further increases in filler content to 25%, 30%, 35%, and 40% resulted in values of 0.024, 0.027, 0.021, and 0.027 KN/mm², respectively. These results suggest that 20% tamarind seed powder offers the best flexural performance, while higher concentrations may lead to reduced performance due to uneven distribution. Figure 5 shows the flexural test for the samples.

Impact Test

The impact test conducted on tamarind seed powder and epoxy resin composites followed ASTM D256 standards. The specimens had dimensions of 65.5 x 12.7 x 3 mm. The results revealed that the impact properties varied based on the composition of tamarind seed powder. For 10% tamarind seed powder with 90% epoxy resin, the impact strength was recorded at 2 J/mm, while for 20% tamarind seed powder, it increased to 3 J/mm, and for 30% tamarind seed powder, it measured 2.5 J/mm. These findings highlight that the inclusion of tamarind seed powder enhances the impact absorption properties, particularly at 20%, which exhibited the highest impact strength, making it suitable for applications requiring improved energy absorption capacity. Figure 6 depicts the impact test for the samples.

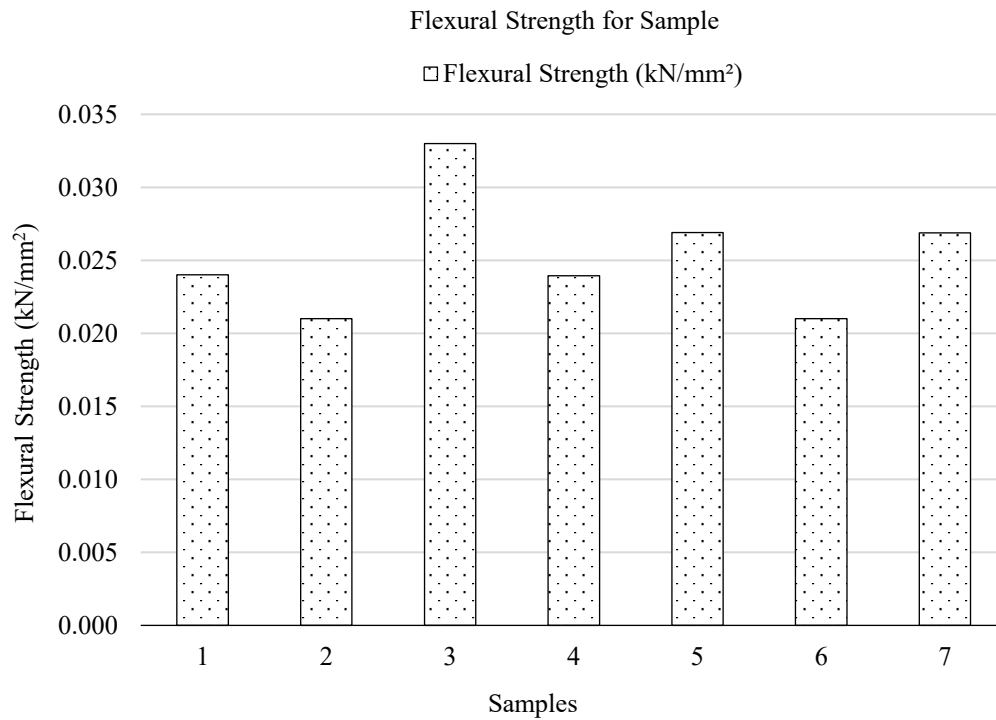


Figure 5. Flexural test for the samples.

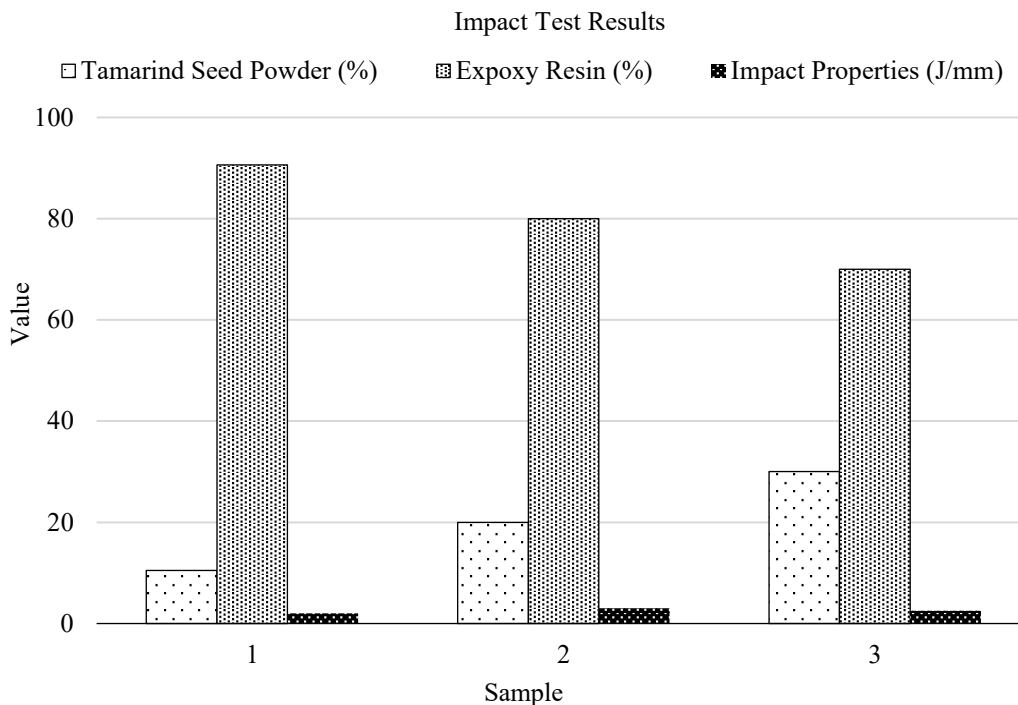


Figure 6. Impact test for the samples.

Comparative Study

Based on the experimental investigation presented in the document, a comparative study of tamarind seed powder reinforced bio-polymer composites revealed interesting mechanical properties across different compositions. The research tested various proportions of tamarind seed powder (10% to 40%) mixed with epoxy resin through tensile, flexural, and impact tests. Figure 7 shows the comparative study of all samples.

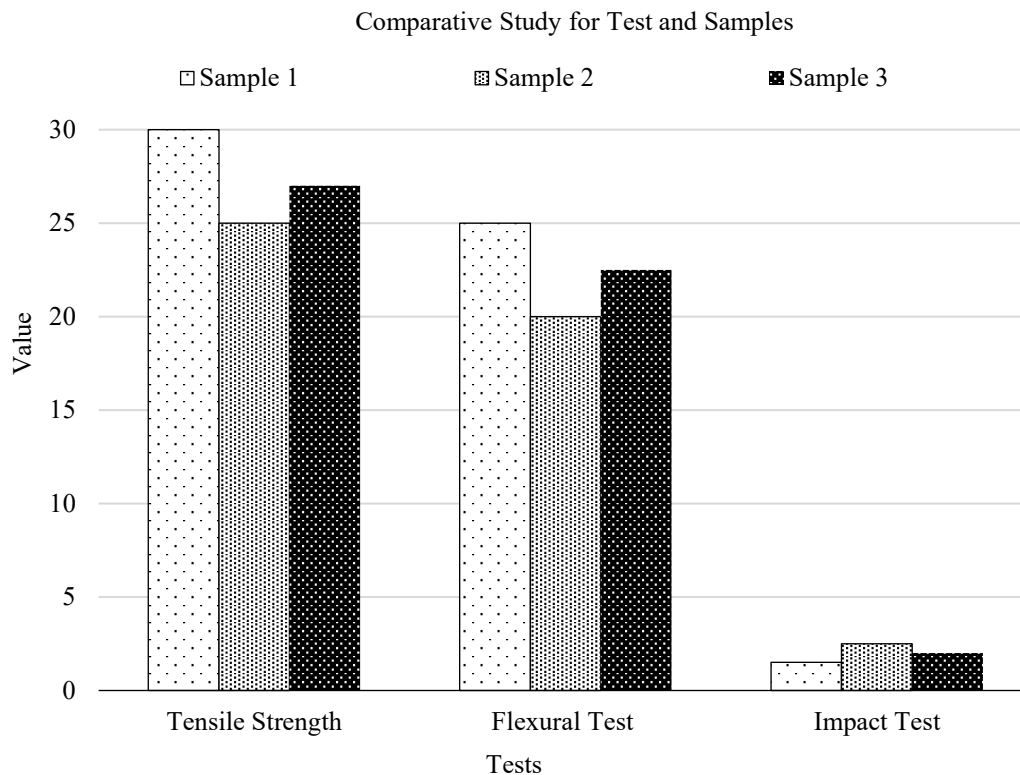


Figure 7. Comparative study of all samples

The results showed that the 20% tamarind seed powder composition exhibited optimal mechanical properties compared to other ratios. Specifically, it demonstrated the highest tensile strength of 0.025 KN/mm², superior flexural strength of 0.033 KN/mm², and maximum impact resistance of 3 J/mm. This composition outperformed both lower (10-15%) and higher (25-40%) concentrations of tamarind seed powder. The enhanced mechanical properties at 20% can be attributed to optimal filler distribution within the epoxy matrix, while higher concentrations showed reduced performance due to non-uniform distribution. This study suggests that tamarind seed powder at 20% concentration could be a viable eco-friendly alternative for automotive panel applications, potentially reducing plastic usage in automobile parts.

CONCLUSION

Tamarind seed powder-reinforced epoxy composites were effectively created and assessed in this work as a sustainable substitute for traditional synthetic materials. Based on the experimental investigation, the composite with 20% tamarind seed powder and 80% epoxy resin demonstrated optimal mechanical properties. This composition achieved the highest tensile strength of 0.025 KN/mm², flexural strength of 0.033 KN/mm², and impact strength of 3 J/mm compared to other compositions (10%, 15%, 25%, 30%, 35%, and 40%). The 20% composition showed a 92.3% increase in tensile strength compared to 15% composition, and a 57.1% increase in flexural strength compared to 15% and 35% compositions which both measured 0.021 KN/mm². Further increasing the tamarind powder content beyond 20% resulted in decreased mechanical properties due to non-uniform distribution in the epoxy matrix. The study demonstrates the viability of tamarind seed powder as an eco-friendly alternative in polymer composites for automotive applications. The research contributes to sustainable manufacturing by utilizing agricultural waste in high-performance composites. The successful development of these bio-composites offers potential applications in automobile panels, interior components, and other structural applications where conventional glass fiber reinforced plastics (GFRP) are currently used, promoting environmental sustainability while maintaining mechanical integrity.

Declaration of Interest

The authors(s) have disclosed no conflicts of interest.

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Not Applicable

Data Availability Statement

This study does not develop nor examines any new data

Ethics Statement

This material was created by the author alone, hasn't been published anywhere else, and isn't currently being considered for publishing anywhere. It fully and properly reflects the study and analysis of the author or authors.

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REFERENCE

1. Karunakaran, K., et al. "Experimental investigations on synthesis and characterization of tamarind seed powder reinforced Bio-composites." *Materials Today: Proceedings* 64 (2022): 760-764.
2. Girimurugan, R., et al. "Experimental investigations on flexural and compressive properties of epoxy resin matrix sugarcane fiber and tamarind seed powder reinforced bio-composites." *Materials Today: Proceedings* 66 (2022): 822-828.
3. Jayaraman, R., M. Viknesh, and R. Girimurugan. "Experimental investigations on mechanical and water absorption properties of epoxy resin matrix treated sugarcane and tamarind shell powder reinforced bio-Composites." *Materials Today: Proceedings* 74 (2023): 636-641.
4. Srinivasan, T., et al. "Experimental investigation and fabrication of palmyra palm natural fiber with tamarind seed powder reinforced composite." *IOP Conference Series: Materials Science and Engineering*. Vol. 988. No. 1. IOP Publishing, 2020. DOI : 10.1088/1757-899X/988/1/012022
5. Prabhu, G.A., Selvam, R. & Kumar, K.M. Enhancing the Mechanical Properties of Basalt Fiber and Stainless Steel Wire Mesh Composites Incorporating Fire Retardants Through Response Surface Methodology Optimization. *Fibers Polym* 25, 1443–1455 (2024).
6. Rahman, Mohammad Musfiqur, et al. "Assessment of green biocomposites based on polyvinyl alcohol and grafted biopolymer tamarind kernel powder with polyacrylic acid." *Results in Materials* 23 (2024): 100601.
7. Binoj, J. S., R. Edwin Raj, and B. S. S. Daniel. "Comprehensive characterization of industrially discarded fruit fiber, *Tamarindus indica* L. as a potential eco-friendly bio-reinforcement for polymer composite." *Journal of Cleaner Production* 142 (2017): 1321-1331.
8. Subramanian PM, Balamurugan L, Ashwin Prabhu G. Novel approaches in developing sustainable and cost-effective semi-active suspension systems for smart vehicles—A review. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*. 2024;0(0).
9. Janani, V. Aruna, et al. "Study of mechanical property of treated teak wood and tamarind seed particles in the applications of reinforced composites." *Materials Today: Proceedings* (2023).
10. Murugapoopathi, S., Ashwin Prabhu, G., Chandrasekar, G. et al. Fabrication and Characterisation of Saw Dust Polymer Composite. *J. Inst. Eng. India Ser. D* (2023).
11. Ambli, K. G., B. M. Angadi, and M. B. Vanarotti. "Thermal behaviour of tamarind seed kernel based bio-composites intended for thermal insulation." *Indian J Sci Technol* 15.19 (2022): 927-937.
12. Mansingh, B. Brailson, et al. "Sustainable development in utilization of *Tamarindus indica* L. and its by-products in industries: A review." *Current Research in Green and Sustainable Chemistry* 4 (2021): 100207.

13. Sathishkumar, T. P., et al. "Effects of cashew nutshell biofillers on the mechanical and thermal behaviour of Basalt/Hibiscus vitifolius hybrid fabrics reinforced polymer biocomposites." *Scientific Reports* 14.1 (2024): 27636.
14. Wortmann, F.-J., and G. Wortmann. "Quantitative fiber mixture analysis by scanning electron microscopy: Part iv: Assessment of light microscopy as an alternative tool for analyzing wool/specialty fiber blends." *Textile research journal* 62.7 (1992): 423-431.
15. Kumar, Nitish, Abhishek Singh, and Rajesh Ranjan. "Fabrication and mechanical characterization of horse hair (HH) reinforced polypropylene (PP) composites." *Materials Today: Proceedings* 19 (2019): 622-625.
16. Ali, Md Farhad, et al. "Fabrication and characterization of eco-friendly composite materials from natural animal fibers." *Heliyon* 7.5 (2021).
17. Prabhu, G. A., Muninathan, K., Kanna, O. L., Monish, G., & Arun, S. R. (2020, September). Static Analysis of Aluminum 6063 Alloy for Steering Knuckle Application in Student Formula Car. In *IOP Conference Series: Materials Science and Engineering* (Vol. 923, No. 1, p. 012007). IOP Publishing.
18. Rajamanickam, Sathish kumar, et al. "Experimental investigation on mechanical and tribological characteristics of snake grass/sisal fiber reinforced hybrid composites." *International Polymer Processing* 38.3 (2023): 331-342.
19. Ashik, K. P., and Ramesh S. Sharma. "A review on mechanical properties of natural fiber reinforced hybrid polymer composites." *Journal of minerals and materials characterization and engineering* 3.05 (2015): 420.
20. Karthick, S., et al. "Experimental investigation on influence of chemical treatment for natural fibers in hybrid composite of G/SB/SB/SB/G." *AIP Conference Proceedings*. Vol. 2283. No. 1. AIP Publishing, 2020.
21. Jagadeesh, Praveenkumara, et al. "Effect of natural filler materials on fiber reinforced hybrid polymer composites: An Overview." *Journal of Natural Fibers* 19.11 (2022): 4132-4147.
22. Prabhu, G.A., Tembhekar, T.D., Gopal, V. et al. Utilizing Machine Learning for Optimizing Composite Materials Derived from Leather Trimming and HDPE Waste. *J. Inst. Eng. India Ser. D* (2025).
23. Elkhouly, Heba I., Ragab K. Abdel-Magied, and Mohamed F. Aly. "An investigation of date palm seed as effective filler material of glass–epoxy composites using optimization techniques." *Polymers and Polymer Composites* 28.8-9 (2020): 541-553.
24. Stalin, B., Arivukkarasan, S., & Prabhu, G. A. (2015). Microstructure and mechanical properties evaluation of aluminium matrix reinforced with tungsten carbide and silicon carbide. *International Journal of Applied Engineering Research*, 10(55), 3994-3999.
25. Girisha, L., et al. "Assessment of mechanical properties on abaca fiber strengthened nano sandstone filler hybrid polymer composite." *Materials Today: Proceedings* (2023).
26. Olusanya, John Olumide, Turup Pandurangan Mohan, and Krishnan Kanny. "Fracture toughness of hybrid natural fiber/nanoclay reinforced starch biocomposite material." *Composites and Advanced Materials* 32 (2023): 26349833231188980.
27. Vigneshwaran, S., et al. "Recent advancement in the natural fiber polymer composites: A comprehensive review." *Journal of Cleaner Production* 277 (2020): 124109.
28. Prabhu, G. Ashwin, et al. "Static Analysis of Aluminum 6063 Alloy for Steering Knuckle Application in Student Formula Car." *IOP Conference Series: Materials Science and Engineering*. Vol. 923. No. 1. IOP Publishing, 2020.
29. Ashwin Prabhu, G., Selvam, R. & Kumar, K.M. Evaluating hybrid basalt and stainless-steel wire mesh laminated composites under low impact velocity tests for naval applications. *J. Mater. Res.* (2025).
30. Mohammed, Mohammed, et al. "Comprehensive insights on mechanical attributes of natural-synthetic fibers in polymer composites." *Journal of Materials Research and Technology* 25 (2023): 4960-4988.