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Evaluation of Mechanical Properties of Terminalia Chebula and Teak Wood Sawdust Reinforced Polymer Hybrid Composites

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Abstract

This study examines the mechanical characteristics of polymer hybrid composites augmented with sawdust from teak wood and Terminalia chebula (Kadukkai). To examine their effects on mechanical performance, the composites were made with different percentages of biofiller (10%, 20%, 30%, 40%, and 50%) while keeping the proportions of the two reinforcements same. Tensile, flexural, and impact tests were performed to assess their strength properties. The findings showed that flexural strength varied between 16.11 MPa and 82.78 MPa, while tensile strength values ranged from 6.42 MPa to 28.5 MPa. Furthermore, the range of impact strength was 4.3 KJ/m² to 18.4 KJ/m². The composites with 40% filler content showed the best mechanical performance among the various filler compositions, indicating the ideal concentration of reinforcement. The study highlights the potential of sawdust from teak and kadukkai powder as effective bio fillers in polymer composites. These organic reinforcements preserve the material's lightweight qualities while greatly enhancing its strength features. According to the results, these hybrid composites can be used as ecologically friendly substitutes for traditional synthetic materials in a range of industrial and building applications. This study advances the creation of green composites that support environmental sustainability objectives by employing renewable resources. These composites' encouraging mechanical qualities demonstrate their potential for usage in furniture, automotive applications, and lightweight structural components, hence lowering reliance on non-biodegradable materials. The study's overall findings highlight the viability of adding natural fillers to polymer matrices to produce long-lasting and eco-friendly composite materials.

Keywords: *Terminalia chebula, T*eak Wood Sawdust, Hybrid Composites, Mechanical Properties, bio fillers

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INTRODUCTION

The increasing demand for sustainable and eco-friendly materials in industries such as construction, automotive, and aerospace has driven extensive research into natural fiber-reinforced composites. These materials present a promising alternative to synthetic reinforcements, such as glass and carbon fibers, due to their abundance, biodegradability, and cost-effectiveness [1-4]. In the current scenario, natural fillers play a crucial role in enhancing the performance of composite materials while promoting sustainability and cost efficiency. They not only help reduce material costs but also contribute to environmental conservation by minimizing waste and enhancing biodegradability. Their lightweight nature is particularly beneficial in automotive and aerospace applications, where weight reduction leads to improved fuel efficiency and performance. Additionally, natural fillers enhance the mechanical properties of composites, such as tensile strength, flexural strength, and impact resistance, by improving filler-matrix adhesion. They also contribute to better thermal stability and insulation properties, making them suitable for high-temperature applications. Unlike synthetic reinforcements, which require energy-intensive production and pose disposal challenges, natural fillers are biodegradable and energy-efficient to process, aligning with circular economy principles. Furthermore, their non-toxic and biocompatible nature makes them ideal for applications in consumer goods, biomedical devices, and packaging [5-7].

In recent years, researchers have explored various natural fillers, including sawdust, rice husk ash, shellfish shell powder, peanut shell powder, sirisha bark, tamarind seed powder, bamboo powder, and wheat straw, as reinforcements for polyester and epoxy composites [8-19]. However, despite these efforts, there remains a need for novel bio-waste natural fillers that offer enhanced properties compared to existing options. As industries continue to transition toward eco-friendly alternatives, fillers such as *Terminalia chebula* (Kadukkai) and teak wood sawdust have gained significant attention due to their availability as agricultural and industrial byproducts.

Hybrid composites, which incorporate two or more types of reinforcements within a single matrix, provide an opportunity to leverage the complementary characteristics of different materials [20-21]. In this study, hybrid composites were fabricated by reinforcing polyester matrices with varying proportions of *Terminalia chebula* and teak wood sawdust. The biofillers were combined in equal proportions, with the total filler content varied at 10%, 20%, 30%, 40%, and 50% to analyze their influence on the composite’s mechanical properties and water absorption behavior. The mechanical properties of composite materials, such as tensile and flexural strength, serve as key indicators of their suitability for structural applications. Additionally, water absorption behavior is a critical factor in assessing their performance in moisture-sensitive environments. This study systematically investigates these properties to determine the optimal composition of *Terminalia chebula* and teak wood sawdust in polyester composites.

The findings of this research contribute to the development of sustainable, high-performance materials that can reduce reliance on synthetic reinforcements, thereby promoting environmental sustainability and resource efficiency. By leveraging the synergistic effects of *Terminalia chebula* and teak wood sawdust, this study explores their potential as viable reinforcements for advanced composite materials.

EXPERIMENTAL DETAILS

Materials

Unsaturated polyester was used as the matrix material throughout this study. To facilitate the curing process, cobalt-naphthenate served as an accelerator, while methyl ethyl ketone peroxide (MEKP) functioned as the catalyst. The biofillers included *Terminalia chebula* (Kadukkai) powder and teak wood sawdust, both sourced from agricultural and industrial byproducts.

Fabrication of Composites

Hybrid *Terminalia chebula* and teak wood sawdust-reinforced polyester composites were fabricated using the compression molding method. A steel mold with dimensions of 300 mm × 300 mm × 3 mm was prepared for composite production. The mold was designed to accommodate the specified weight percentages of biofillers (10%, 20%, 30%, 40% and 50%) combined with the polyester matrix. The fabrication process involved uniformly mixing *Terminalia chebula* and teak wood sawdust in equal proportions with the polyester resin and curing agents. The fillers and polyester resin composition is given in Table 1. The mixture was poured into the steel mold, which was preheated to a temperature of 30°C. To ensure uniform distribution and bonding of the materials, the mold was subjected to a compression pressure of 17 MPa. Once filled, the mold was sealed with steel plates and compressed using a compression molding machine. The polymerization process was carried out for 24 hours at a constant temperature of 50°C and a pressure of 17 MPa. The duration of curing was carefully controlled based on the resin-to-inhibitor ratio and the mold temperature to achieve optimal mechanical properties. After curing, the composite sheets were removed from the mold and cut into specimens according to ASTM standards using a diamond wheel cutter. These specimens were prepared for subsequent testing to evaluate their mechanical properties, such as tensile and flexural strength, and water absorption behavior. The systematic fabrication process ensured consistency and reproducibility in the composite samples for accurate analysis. The fabricated *Terminalia chebula* powder and Teak wood sawdust reinforced polymer composites (TCP-TWS-PC) with different filler weights are shown in Figure 1.

Material Characterization

The tensile and three-point flexural tests were performed using an Instron (Series-3382) computerized universal testing machine, adhering to ASTM D638-10 and ASTM D790-10 standards, respectively. The tensile test specimens measured 165 mm in length, 10 mm in width, and 3 mm in thickness, while the flexural test specimens were 127 mm long, 13 mm wide, and 3 mm thick [22-25]. Additionally, the un-notched Charpy impact test was conducted using a digital impact tester in accordance with ASTM D256-10, with specimens measuring 63.5 mm in length, 12.7 mm in width, and 3 mm in thickness [22-25].

Table 1. Composition of Fillers and polyester resin**.**

Composition	Polyester Resin	TCP	TWS
T10	90%	5%	5%
T20	80%	10%	10%
T30	70%	15%	15%
T40	60%	20%	20%
T50	50%	25%	25%

Figure 1. TCP-TWS-PC with different filler weights.

The crosshead speeds were set to 5 mm/min for tensile tests and 1.2 mm/min for flexural tests. For the impact tests, pendulum hammers were installed to operate at a speed of 10 KJ. Each test was performed on five samples, and the average values were calculated and used for further analysis. Figure 2 presents universal testing machine, digital impact tester and composite specimens used for tensile, flexural and impact test.

RESULTS AND DISCUSSION

Tensile Strength

The tensile properties of TCP-TWS-PC were analyzed, emphasizing the effect of different TCP-TWS loadings on tensile strength, as shown in Figure 3. Figure 4 displays sample graphs generated by the UTM, illustrating stress vs. strain and force vs. length for the tensile testing of TCP-TWS-PC.The tensile strength values for the specimens are 6.42 MPa, 19.4 MPa, 23.5 MPa, 28.5 MPa, and 24.5 MPa for T10, T20, T30, T40, and T50, respectively. Initially, from T10 to T30, there is a noticeable increase in tensile strength, with the highest value of 28.5 MPa recorded at T40. This indicates that up to 40% filler content, the matrix and reinforcements form strong interfacial bonding, leading to effective stress transfer under tensile loading. However, at T50, the tensile strength decreases slightly to 24.5 MPa, which suggests that higher filler content can lead to poor stress distribution and possible agglomeration of fillers, reducing tensile performance.

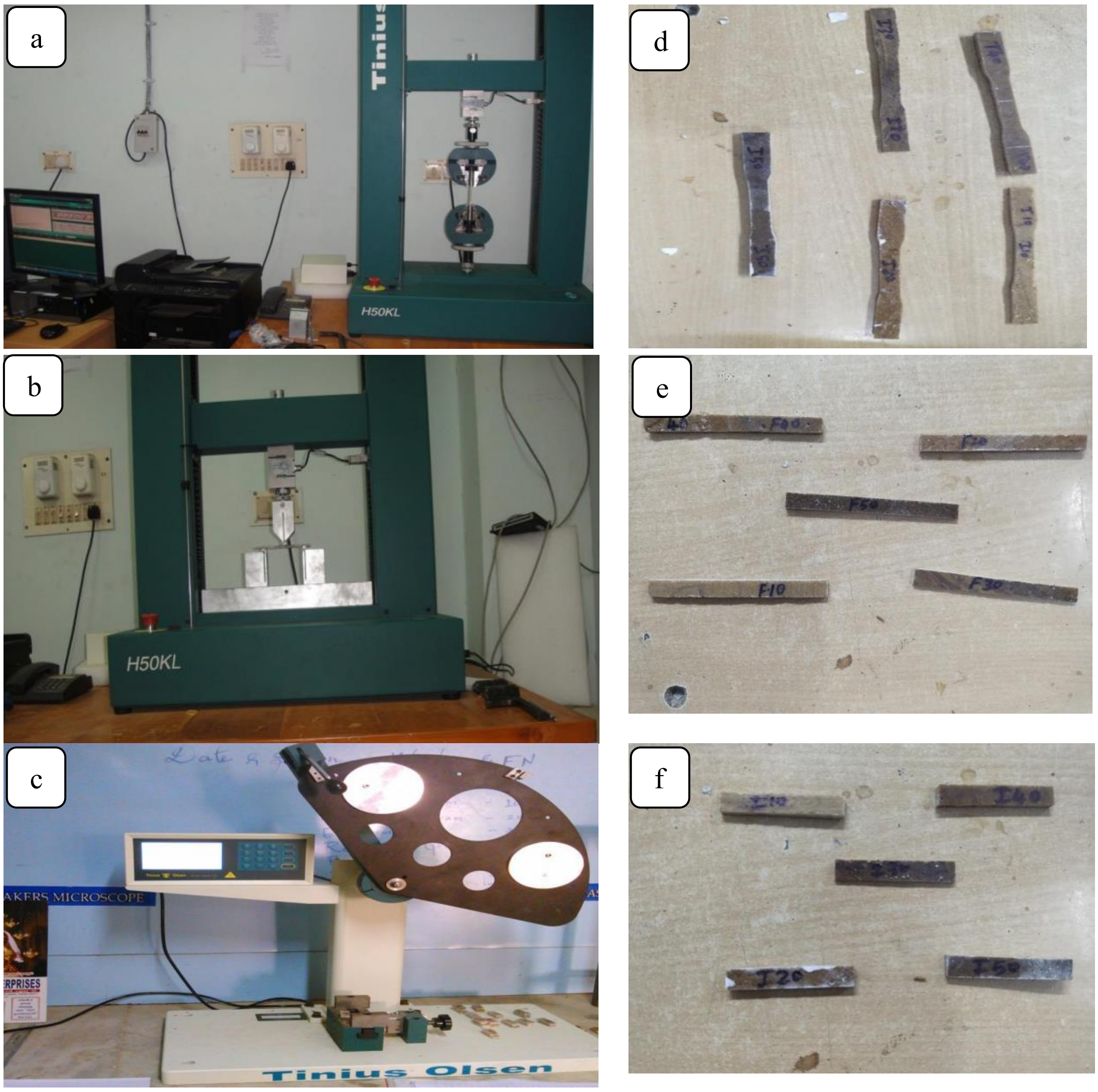

Figure 2. (a,b) Universal testing machine (c) Digital impact tester (d,e,f) Composite specimens for tensile, flexural and impact test.

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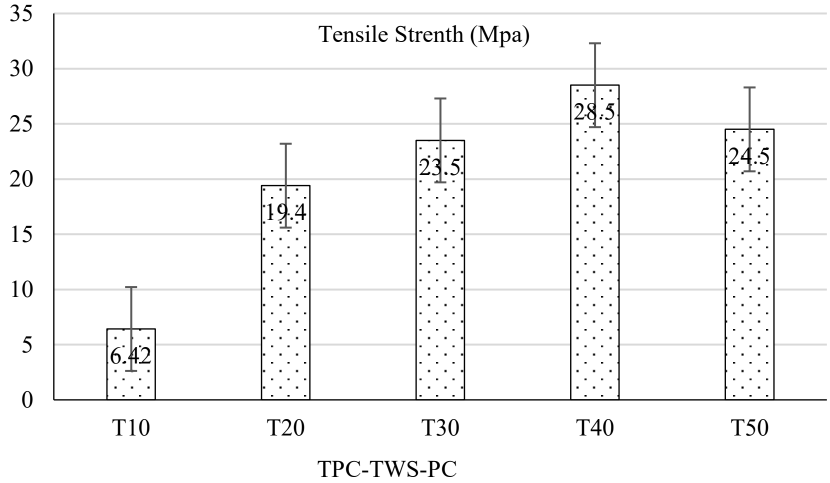

Figure 3. Tensile Strength of TCP-TWS-PC.

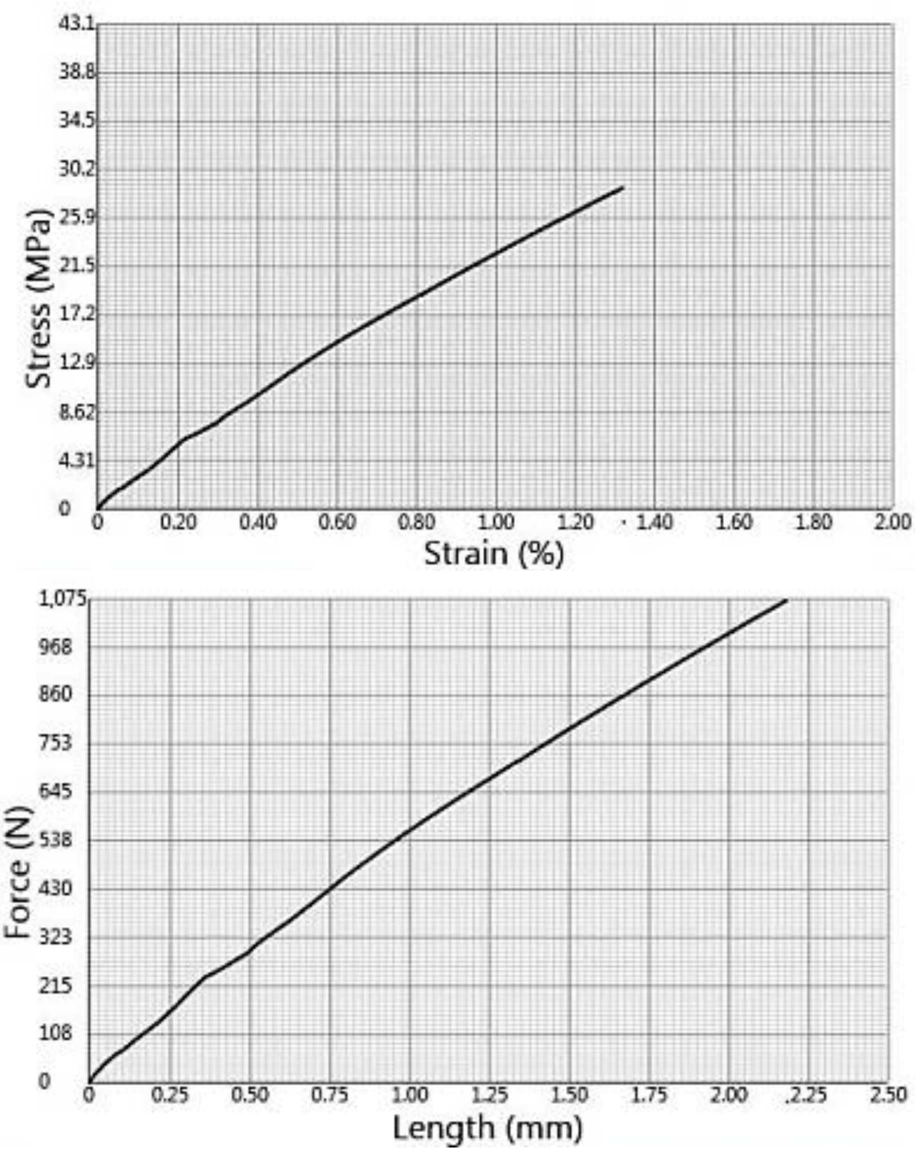

Figure 4. Graph generated from the machine for stress vs strain and force vs length for tensile test of T40 TCP-TWS-PC.

Flexural Strength

The flexural behavior of TCP-TWS-PC was analyzed, with Figure 5 showing the flexural strength of the composites under different TCP-TWS loadings. Figure 6 presents sample graphs generated by the UTM, illustrating stress versus strain for the flexural test of TCP-TWS-PC.The flexural strength of the composites increases significantly from T10 (16.11 MPa) to T40 (82.78 MPa). This consistent improvement indicates that increasing filler content enhances the composite's stiffness and bending resistance. The peak flexural strength at T40 highlights the optimal interaction between the matrix and fillers at this composition. However, at T50, the flexural strength drops to 77.22 MPa, suggesting that excessive filler content compromises the integrity of the matrix, creating weak points that reduce the material's ability to withstand bending forces.

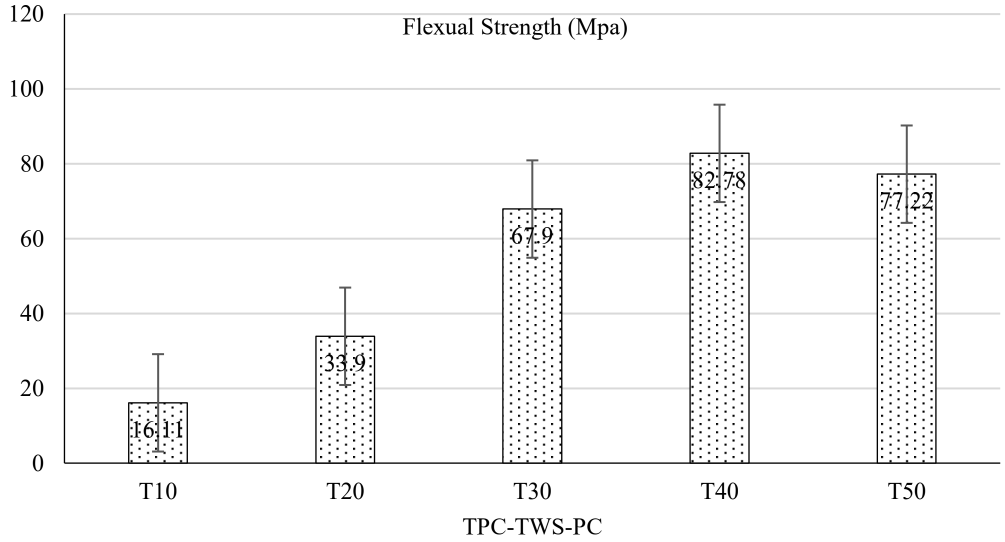

Figure 5. Flexural Strength of TPC-TWS-PC.

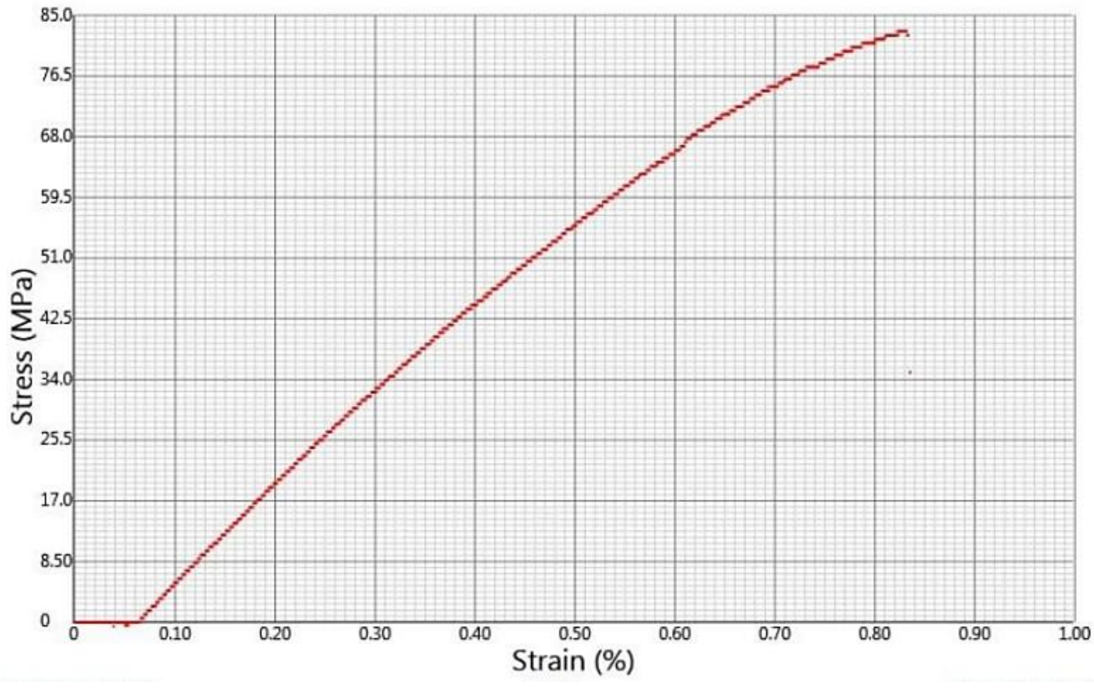

Figure 6. Graph generated from the machine for stress vs strain for flexural test of T40 TCP-TWS-PC.

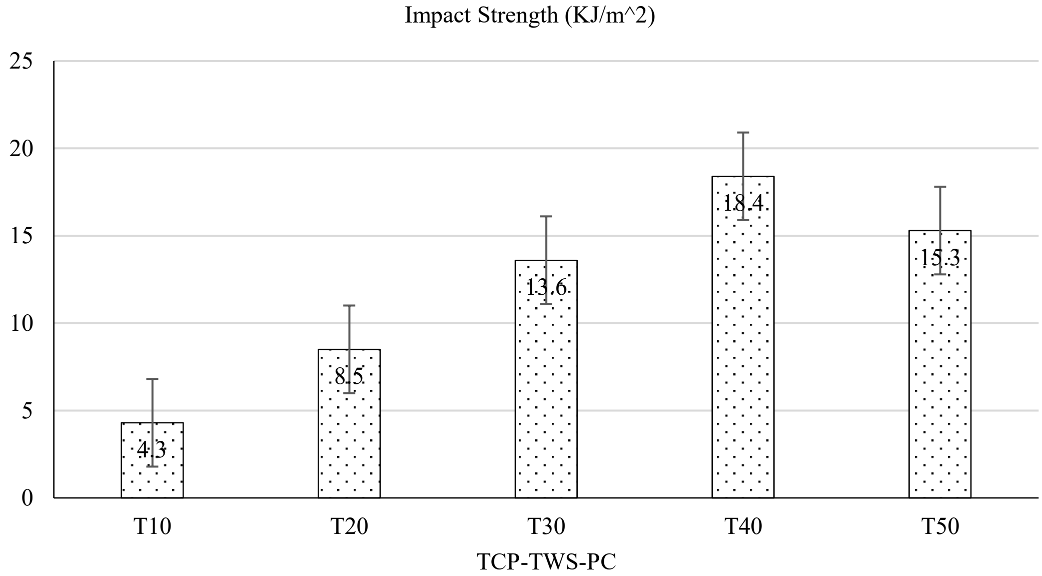

Figure 7. Impact Strength of TCP-TWS-PC.

Impact Strength

The impact behavior of TCP_TWS-PC was analyzed, as shown in Figure 7.The impact strength values are relatively lower compared to the tensile and flexural properties. These values increase slightly from T10 to T40 and then begin to decline. The highest impact strength is observed at T40 (18.4 KJ/m^2), demonstrating the composite's ability to absorb and dissipate energy effectively at this composition. Beyond T40, the impact strength reduces, indicating that higher filler content increases the material's brittleness, making it less capable of withstanding sudden impacts. This trend aligns with the observation that higher filler percentages can disrupt matrix flexibility and create stress concentration points.

CONCLUSION

The study on hybrid polyester composites reinforced with *Terminalia chebula* and teak wood sawdust revealed significant variations in mechanical properties with different filler content levels. The tensile and flexural strengths improved with increasing filler content up to 40%, with the highest tensile strength, flexural strength and impact strength observed at T40 (28.5 MPa, 82.78 MPa, 18.4 KJ/m^2). However, beyond this threshold (T50), mechanical properties declined, likely due to excessive filler content reducing matrix-fiber bonding. These findings suggest that an optimal filler content exists around 30–40% for maximizing mechanical performance. This research highlights the potential of sustainable biofillers as viable reinforcements in composite materials, promoting eco-friendly alternatives to synthetic reinforcements.

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