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EVALUATING MECHANICAL PERFORMANCE OF COCONUT FIBRE REINFORCED POLYMER COMPOSITES WITH VARIABLE FIBRE CONTENT

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ABSTRACT

The rapid growth of composite materials, leveraging natural ingredients such as dried fruit, rice husk, wheat husk, straw, and hemp fibres, has expanded their applications and market presence. Among these, coconut fibre stands out due to its high tensile strength, making it a promising reinforcement for polymer composites. However, increasing the coconut fibre content can reduce the cohesion and some properties of the composites. This study investigates the impact of the weight percentage of coconut fibres on the mechanical properties of coconut fibre-reinforced composites. Various composites were prepared with different weight percentages of coconut fibre, and their mechanical properties were evaluated using tensile tests with a Universal Testing Machine Instron 8872 and hardness tests with a Digital Shore Scale “D” Durometer. The results indicate significant changes in tensile strength, tensile strain, and hardness corresponding to the weight percentage of coconut fibre. This research highlights the importance of optimizing fibre content to achieve balanced mechanical properties in coconut fibre-reinforced composites.

Keywords: composites, coconut fibre, mechanical performance.

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INTRODUCTION

Composite materials have gained significant popularity and market share in recent years, with plastics and ceramics emerging as dominant materials in this field. Their rapid growth in volume and applications can be attributed to several advantages, including their lightweight nature, ease of processing, recyclability, and cost-effectiveness [1-2]. Among these, polymer matrix composites are particularly valued for enhancing the mechanical properties of polymers.

Natural composites, also known as bio-composites or green composites incorporate natural fibres as reinforcement within a matrix material. A variety of natural fibres are used globally, including sisal, hibiscus cannabinus, eucalyptus grandis pulp, malva, ramie bast, pineapple leaves, kenaf leaves, coconut, sansevieria leaves, hemp leaves, vakka, banana, jute, hemp, ramie, cotton, and sugarcane fibres [3-5]. These fibres offer numerous advantages: they are renewable, biodegradable, and require low energy for production compared to synthetic fibres. Additionally, natural fibres possess favorable mechanical properties, such as a high strength-to-weight ratio, good impact resistance, and adequate stiffness [6].

One of the key benefits of natural composites is their reduced environmental impact compared to traditional composites made from synthetic fibres. Using renewable and biodegradable fibres contributes to sustainability and a reduction in carbon footprint. Coconut fibre composite is a prime example of a natural composite material, known for its unique properties and environmentally friendly characteristics. Derived from the husk of coconuts, coconut fibre is a renewable and sustainable resource that exemplifies the concept of natural composites.

Coconut fibre composites have diverse applications across various industries, including automotive, construction, marine, and packaging. In the automotive sector, they are used in interior components, door panels, and seat backs, offering both strength and weight reduction. In construction, they serve as panels, partitions, and roofing materials, providing durability and thermal insulation properties.

However, natural composites, including those reinforced with coconut fibre, have limitations. They can be susceptible to moisture absorption, which may degrade their mechanical properties and dimensional stability. Additionally, the mechanical properties of these composites are influenced by the volume of the reinforcement materials [7]. Therefore, this study aims to determine the effect of the weight percentage of reinforcement material on the mechanical properties of coconut fibre-reinforced composites. The study involves performing tensile and hardness tests based on ASTM standards to evaluate the performance of these composites.

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METHODOLOGY

Coconut fibres used in this study were sourced from mature coconut fruits. The fibres were sun-dried for two days before being cut into uniform lengths of 140 mm, as depicted in Figure-1. The fibres underwent an alkaline pre-treatment to remove soluble extractives and improve adhesion between the fibres and the matrix. Following this, the fibres were filtered, thoroughly washed with distilled water, and then dried in an oven at 50°C for 24 hours to ensure complete removal of moisture.

(a) (b)

Figure-1. (a) Old coconut fibre and (b) Coconut fibre with 140mm cutting.

The raw materials used for fabricating the composites in this study include coconut fibre, unsaturated polyester resin, and a hardener. Coconut fibres, each 140 mm in length, were randomly distributed within the polyester resin matrix. The weight percentage (wt%) of coconut fibre incorporated into the composites varied at intervals of 10%, 20%, 30%, 40%, and 60%.

A fixed weight of 0.5 grams of methyl ethyl ketone peroxide (MEKP) hardener was used. The polyester resin and MEKP hardener were thoroughly mixed in a beaker and stirred for 3 minutes. The resulting mixture was then poured into molds along with the coconut fibres, as illustrated in Figure-2.

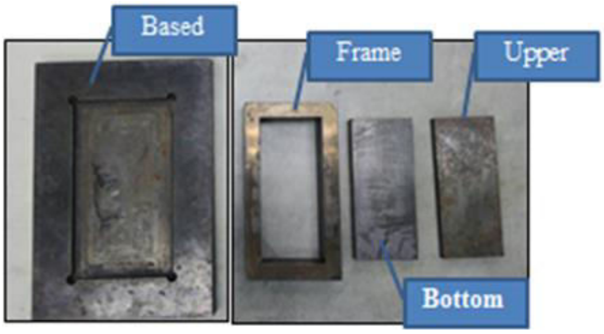

Figure-2. Mould components are used for fabricating composites.

The composite specimens were fabricated using the compression molding method with a Motorized Hydraulic Molding Test Press machine, as shown in Figure-3. The machine temperature was maintained at 90ºC, while the applied pressure varied according to the weight percentage ratio of the components.

Figure-3. Motorise hydraulic molding test press machine for composites fabrication.

Tensile tests were conducted using a Universal Testing Machine, Instron 8872, as shown in Figure 4 following the ASTM D3039 standard. The specimens measured 140 mm in length and 25 mm in width and were clamped between the machine's jaws. The tests were performed at a constant strain rate with a crosshead speed of 5 mm/min [8].

Hardness tests were carried out using a Digital Shore Scale "D" Durometer CV-DSA 001 TM. The samples were placed on a flat surface, and the indenter was pressed to measure the hardness. Data were collected immediately as the readings appeared on the scale. Hardness measurements were taken at five different points on each sample, and the average of these readings was recorded as the hardness value for the respective samples.

Figure-4. Universal Tensile Testing Machine with a load capacity of 25 kN.

RESULTS AND DISCUSSIONS

Figure-5 presents the tensile stress versus tensile strain curves for composites containing 10%, 20%, 30%, 40%, and 60% fibre by weight. The data reveal that the composite with 10 wt% fibre exhibits brittle behavior, fracturing at a maximum tensile stress of 28.66 MPa. Conversely, composites with 20%, 30%, 40%, and 60% fibre show increased ductility, indicated by the higher tensile strain in their stress-strain curves.

The composite with 20 % fibre also demonstrates an increase in ultimate tensile strength compared to 10 wt%, but as the fibre content increases from 20% to 60%, the ultimate tensile strength progressively decreases. This trend suggests that higher fibre content (up to 10 wt%) enhances the ductility and strength of the composite, contributing to better mechanical performance.

The findings indicate that increasing the volume fraction of coconut fibre in the polymer matrix results in composites with better mechanical properties, including improved ductility and tensile strength. This enhancement is attributed to the better fibre-matrix interaction and load distribution provided by the higher fibre content. This improvement in mechanical properties aligns with previous studies on natural fibre composites, which have demonstrated that optimal fibre-matrix adhesion and appropriate fibre distribution are key factors in achieving high-performance composites [7, 9].

The observed increase in ductility with higher fibre content also can be explained by the improved stress transfer between the fibre and matrix, reducing the likelihood of catastrophic failure. Additionally, the presence of more fibres in the matrix allows for greater energy absorption during deformation, contributing to the material's overall toughness.

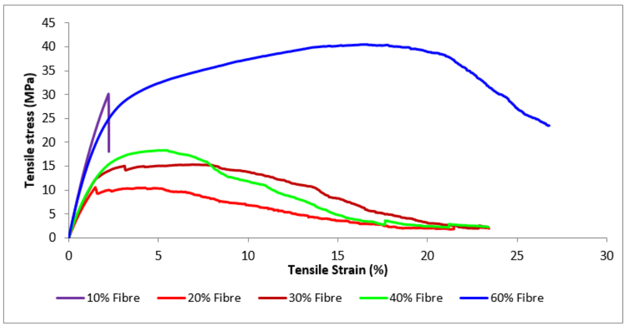

Figure-5. Tensile stress vs tensile strain of coconut fibre reinforced composites with different wt% fibre.

Figure-6 demonstrates that the strain exhibits the lowest percentage at a fibre content of 10 wt%, specifically 1.97%. This trend corresponds to the highest modulus of elasticity observed at the same fibre content. According to Rethwisch and Callister [10], a higher modulus of elasticity indicates a stiffer material, resulting in smaller elastic strain under a given stress. Therefore, samples with a lower quantity of coconut fibre are stiffer.

Additionally, for fiber contents greater than 10 wt%, the elastic strain of the samples drastically increased due to the increase in the ductility of the composites. Then, it slightly decreases as the fibre content increases from 20 wt% to 60 wt%.

The relationship between fibre content and composite ductility is further elucidated by the extension at break and strain (%) graphs in Figure-5, which display similar trends at 10 wt% and 20 wt% fibre content. Mallick [11] explains that the extension at break or strain is directly related to the matrix content in the composite. A higher matrix content typically results in reduced ductility, making the composite more brittle. Consequently, the composite with 10 wt% fibre content is more brittle due to the higher proportion of matrix material, which restricts the material's ability to undergo plastic deformation before fracturing.

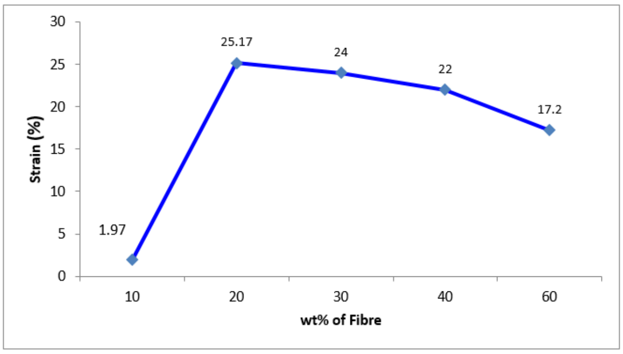

Figure-6. Tensile strain of coconut fibre reinforced composites with different wt% fibre.

Figure-7 illustrates the modulus of elasticity for coconut fibre-reinforced composites at various fibre weight percentages. The data indicate a clear trend: as the fibre content increases from 20 wt% to 60 wt%, the modulus of elasticity also rises. This suggests that the addition of coconut fibres significantly enhances the stiffness of the composite material. Notably, at 10 wt% fibre, the composite exhibits a higher modulus of elasticity compared to other samples. This anomaly can be attributed to the higher matrix content of 90 wt%.

The trend observed from 20 wt% to 60 wt% fibre content aligns with the principle that fibre reinforcement generally improves the mechanical properties of composites. As the fibre weight fraction increases, the fibres effectively distribute applied stress, reducing the strain on the matrix and enhancing the composite's modulus of elasticity. This behavior is particularly significant in applications where material stiffness is crucial. The improved modulus of elasticity at higher fibre contents can be linked to the increased interaction between fibres and the matrix, resulting in a more efficient load transfer and better mechanical performance [12].

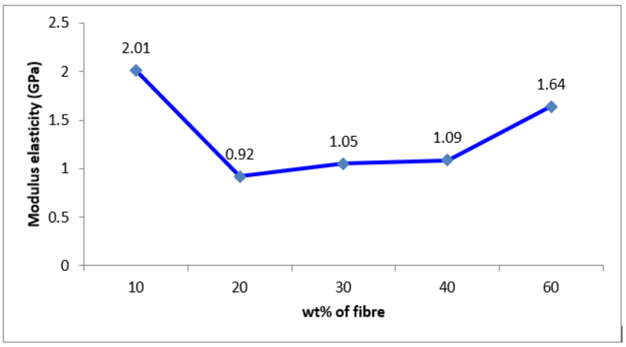

Figure-7. Modulus elasticity of coconut fibre reinforced composites with different wt% fibre.

Figure-8 presents bar charts illustrating Shore-D hardness values plotted against varying weight percentages (%) of fibre in composite materials. Shore-D hardness is a critical measure used to evaluate the resistance of materials, particularly polymers and rigid plastics, to indentation or penetration by a harder object, indicating their mechanical durability.

The results show a consistent trend: as the fibre content increases from 10% to 60%, Shore-D hardness decreases steadily. At 10% fibre content, the composite exhibits its highest hardness, reaching 74 Shore-D. This suggests that a lower volume fraction of fibres allow for more effective matrix-fibre interaction, enhancing the material's stiffness and resistance to deformation.

Conversely, higher fibre contents, such as 60%, result in reduced hardness, with the composite registering its lowest value at 50 Shore-D. This decline can be attributed to challenges in achieving strong bonding between the polymer matrix and an increasing volume of fibres. Such bonding is crucial for effective stress transfer and mechanical reinforcement.

These findings are consistent with literature findings by Choh *et al*. [13], indicating that higher fibre content can compromise the interfacial bonding between polyester and fibres due to mismatched thermal expansion or chemical interactions. Askeland *et al*. [14] further suggest that beyond a certain fibre volume fraction, typically around 80%, fibres may not be fully encapsulated by the matrix, leading to diminished mechanical properties.

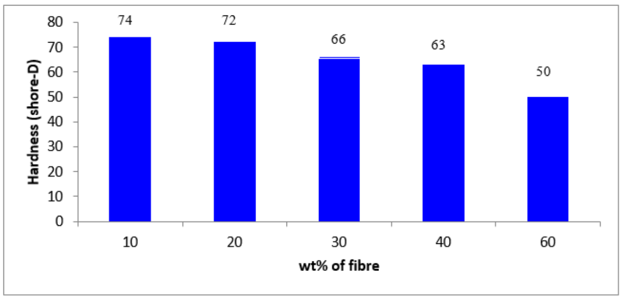

Figure-8. Hardness (shore-D) of coconut fibre reinforced composites with different wt% fibre.

CONCLUSIONS

In this study, natural fibre composites were successfully fabricated using coconut fibres as a sustainable alternative to synthetic composites. The aim was to investigate the impact of the weight percentage of reinforcement material on the mechanical properties of coconut fibre-reinforced composites. Experimental results demonstrated that the mechanical properties of these composites are significantly influenced by the weight percentage (wt%) of coconut fibres.

At 10 wt% fibre content, the composite exhibited brittle behavior due to the dominance of the matrix over the fibre content. As the fibre content increased, the ductility of the composites improved, displaying more ductile behavior. Tensile strength and tensile strain increased with coconut fibre content up to 10 wt%, beyond which tensile strength gradually decreased. Therefore, the optimal fibre content for these composites is 10 wt%.

Therefore, based on the results, the optimal fibre content for maximizing the mechanical properties of the composite is determined to be 10 wt%. These findings provide valuable insights into the application of coconut fibre-reinforced polymer composites, suggesting their potential for various industrial applications. Moreover, the results obtained from this study can serve as a reference for future research, guiding further improvements and optimizations in the development of natural fibre composites.

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REFERENCES

[1] Benitez A. N., Monzón M. D., Angulo I., Ortega Z., Hernández P. M. and Paz R. 2020. Mechanical properties of hemp fiber Composite Using Hybrid Epoxy Resin, Journal of Composite Materials. 54(10): 1363-1372.

[2] Zakaria K. A., Jimit R. H., Ramli S. N. R., Aziz A. A., Bapokutty O. and Ali M. B. 2016. Study on fatigue life and fracture behaviour of fibreglass reinforced composites, Journal of Mechanical Engineering and Sciences. 10(3): 2300-2310.

[3] Mohanty S., Nayak S. K., Verma S. K. and Tripathy S. S. 2020. Green composites from waste agricultural residues: mechanical and thermal properties. Composites Part A: Applied Science and Manufacturing. 32(2): 313-320.

[4] Kumar R., Ul Haq, M. I., Raina, A. and Anand, A. 2021. A Review of the Mechanical Properties of Natural Fiber-Reinforced Hybrid Polymer Composites. Journal of Industrial Textiles. 50(6): 964-992.

[5] Ali M., Liu A., Sou H. and Chouw N. 2012. Mechanical and dynamic properties of coconut fibre reinforced concrete. Construction and Building Materials. 30: 814-825.

[6] Zulkafli N., Dhar Maligam S., Fadzullah S. H. S. M., Mustafa Z., Zakaria K. A. and Subramonian S. 2019. Mechanical properties of cross-ply banana-glass fibre reinforced polypropylene composites. Defence Science and Technology Technical Bulletin. 12(1): 124-135

[7] Patel R. V., Yadav A. and Winczek J. 2023. Physical, mechanical, and thermal properties of natural fiber-reinforced epoxy composites for construction and automotive applications. Applied Sciences. 13: 1-28.

[8] Singha A. S. and Thakur V. K. 2008. Mechanical properties of natural fibre reinforced polymer composites, Bulletin of Materials Science. 31(5): 791-799.

[9] Anand P. B., Lakshmikanthan A., Chandrashekarappa M. P. G., Selvan C. P., Pimenov D. Y., Khaled Giasin K. 2022. Experimental investigation of the effect of fiber length on mechanical wear and morphological behavior of silane-treated pineapple leaf fiber reinforced polymer composites. Fibers. 10(56): 1-16.

[10] Rethwisch D. G. and Callister W. D. 2018. Materials Science and Engineering: An Introduction, Wiley Publisher, USA.

[11] Mallick P. K. 2000. Particulate and short fiber reinforced polymer composites, Comprehensive Composite Materials. 2: 291-331.

[12] Ismail N. I. and Ishak Z. A. M. 2018. Effect of fibe loading on mechanical and water absorption capacity of Polylactic acid / Polyhydroxybutyrate-cohydroxyhexanoate / Kenaf composite, Material Science Engineering. 368: 1-11.

[13] Choh J. L., Chee C. Y., Gan, S. N. and Rozali S. and Sabariah J. 2016. Effects of oil palm empty fruit bunch fiber on electrical and mechanical properties of conductive filler reinforced polymer composite, Bioresources. 11: 913-928.

[14] Askeland D. R., Fulay P. P. and Wright W. J. 2010. Essentials of Materials Science and Engineering, Cengage Learning, USA.