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Comparative Analysis of Flexural, Tensile, and Impact Properties of Jute, Abaca, Pineapple, and Flax Fiber Reinforced PF Composites with ANN-Based Prediction

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ABSTRACT

The mechanical properties of phenol–formaldehyde (PF) composites reinforced with flax, abaca, pineapple, and jute are examined in this work. Tensile, flexural, and impact tests were used in the experimental evaluations, and Artificial Neural Network (ANN) predictions were used for validation. With highest tensile strength (33 MPa), flexural strength (70 MPa), and impact strength (72 J/m), the findings proved that pineapple fiber PF composites consistently exceeded other systems. While the lowest values were registered by jute fiber composites due to their higher lignin content and lesser fiber–matrix adhesion, intermediate performance was observed with flax and abaca fiber composites. Increased cellulose and crystallinity content in pineapple fiber composites were believed to enhance interfacial stress transfer and provide them with improved properties. The reliability of the computational model in simulating composite behavior was assured by the close agreement between ANN estimates and experiment, within a ±5% difference. The study concludes that among all the natural fibers studied, pineapple fiber PF composites are the most viable choice for structural applications.

Keywords - *Abaca fiber, ANN, Flax fiber, Flexural strength, Jute fiber, Impact strength, Natural fiber composites; Phenol–formaldehyde (PF) resin.*

1. INTRODUCTION

As compared to conventional synthetic fiber composites, natural fiber-reinforced polymer composites have attracted much attention in recent years due to their superior mechanical properties, cost-effectiveness, and environmental friendliness [1,2]. Due to their Considering the issues of availability, biodegradability, and ability to deliver adequate strength and stiffness when blended with polymer matrices, jute, abaca, pineapple, and flax are the most used natural fibers [3]. The mechanical properties of such composites are controlled by parameters such as fiber microstructure, cellulose concentration, and fiber–matrix interfacial adhesion that regulate the energy absorption and load transmission processes [4]. Because of their high thermal stability, geometrical rigidity, and chemical resistance, the phenol–formaldehyde (PF) resins are considered to be suitable for a thermosetting matrix for natural fiber reinforcement [5]. Previous studies reported that among flax, abaca, and jute, the pineapple fiber composites proved to be superior for tensile, flexural, and impact properties due to their higher cellulose crystallinity and proper stress transfer [1,3]. In contrast, the jute fibers proved inferior because of their lower sticking behavior towards the PF matrix due to their higher hemicellulose and lignin content [4]. In the present study, jute, abaca, pineapple, and flax fiber PF composites were fabricated, and their tensile, flexural, and impact properties were systematically investigated. The experimental outcomes have been further corroborated by using an ANN model, which is employed to predict the composite mechanical behavior. The objectives were to determine the fiber–matrix system with optimal mechanical efficiency and correlate fiber properties and composite performance.

2. MATERIALS

As reinforcement, four types of natural fibers were used: flax, pineapple, abaca, and jute. Before the composite was made, all fibers were cleaned, dried, and chopped to uniform lengths. Because of its high adhesion and thermal durability, phenol–formaldehyde (PF) resin was used as the polymer matrix.

2.1 COMPOSITE FABRICATION

Compression molding was used to create the composites. Every fiber type underwent hot pressing at a consistent pressure and temperature after being impregnated with PF resin at a regulated fiber-to-matrix ratio. Following ASTM guidelines, the cured laminates were post-processed and cut into specimens for impact, flexural, and tensile testing.

2.2 MECHANICAL TESTING

Tensile test: carried out in accordance with ASTM D3039 using a universal testing machine (UTM). Tensile strength, modulus, and elongation at break were found by stress-strain curves.

Flexural Test: Using a three-point bending arrangement, conducted in accordance with ASTM D790. The stress-strain response was used to compute the flexural strength and modulus.

Impact Test: To determine impact strength (J/m) and absorbed energy (J), Charpy impact testing in accordance with ASTM D256 is used.

Modeling Artificial Neural Networks (ANN): To verify the experimental findings, a prediction model based on artificial neural networks was created. Tensile, flexural, and impact strengths were the outputs, while the input parameters were fiber type and test circumstances. The accuracy of the model was evaluated by comparing the ANN predictions with experimental values and noting any variations.

3. RESULTS AND DISCUSSION

3.1 FLEXURAL TEST

Jute, abaca, pineapple, and flax fiber PF composites' flexural stress–strain behavior is shown in the redrawn graph (Fig. 1). Every curve starts at zero, displaying elastic deformation, peak flexural stress, and a slow fall as a result of failure. Abaca (55 MPa), flax (60 MPa), jute (50 MPa), and pineapple fiber PF composite had the greatest flexural stress (70 MPa). Each curve's flexural modulus, a measure of stiffness, is represented by the slope in the first linear section [1,2].

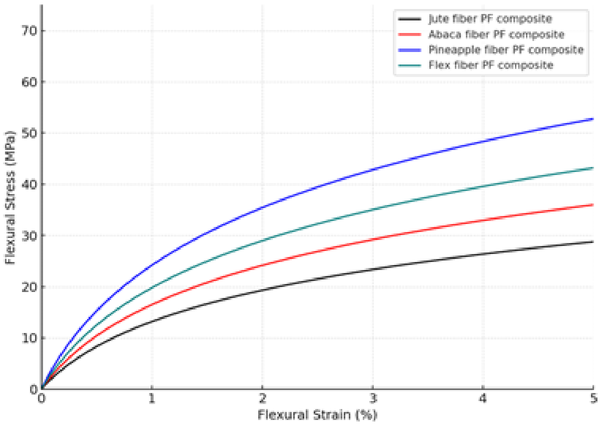

Fig.1 Flexural stress-strain behavior of different composite

Flexural modulus based on curve slope, pineapple fiber PF composite strain of 25 MPa/%, flax fiber PF composite strain of 20 MPa/%, abaca fiber PF composite strain of 18 MPa/%, and jute fiber PF composite strain of 15 MPa/%. As a result, PF composites made of pineapple fiber have the maximum stiffness, whilst those made of jute fiber exhibit the lowest [3].Fiber composition, crystallinity, and fiber–matrix adhesion are the primary causes of the variations. Pineapple fibers have excellent flexural qualities because of their high cellulose content (70–80%) and crystallinity, which facilitate effective stress transmission. While jute fibers, which include higher hemicellulose and lignin, show lower adhesion with the resin matrix, flax and abaca fibers perform moderately [1,4]. Surface roughness and fiber aspect ratio are also important factors in improving interfacial bonding [2]. PF composite made with pineapple fiber Maximum strength because to strong crystallinity and cellulose PF composite made of flax fiber powerful yet somewhat less efficient. PF composite made of abaca fiber reduced crystallinity but balanced. PF composite made of jute fiber lowest because of a larger lignin concentration and worse adherence [3,4,6].

3.2 TENSILE TESTS

The graph (fig.2) shows how the tensile stress-strain behavior of the PF composites made of flax, abaca, pineapple, and jute fibers is affected. In the elastic area, stress rises linearly with strain; beyond that, the curves diverge, signifying plastic deformation and ultimate failure. The pineapple fiber PF composite had the largest strain (5.3%) and tensile stress (33 MPa) of the four, indicating its greater ductility and load-bearing capabilities. In comparison to other fibers, the jute fiber PF composite has the lowest tensile characteristics (23 MPa at 5%), suggesting inadequate reinforcing efficacy. Because of its superior interfacial adhesion, flax marginally outperforms abaca in the intermediate behavior seen by the abaca and flax composites. PF composites made of pineapple fiber (600 MPa), flax fiber (580 MPa), abaca fiber (520 MPa), and jute fiber (480 MPa). This suggests that whereas jute exhibits the least amount of stiffness, pineapple composites are the most rigid and deformation-resistant, closely followed by flax. The microstructural arrangement, fiber aspect ratio, and interfacial bonding strength are the primary causes of the variations in tensile characteristics. greater cellulose content and improved fiber–matrix adhesion in pineapple and flax fibers result in better stress transmission and greater modulus. Despite being less expensive, jute fibers have a greater hemicellulose and lignin content, which lowers their ability to distribute stress and form bonds. Even though abaca fibers are more resilient, their performance is still mediocre due to ineffective matrix wetting. These results are consistent with previous findings that cellulose crystallinity and fiber surface properties are important factors in composite reinforcing [1, 2, 7].

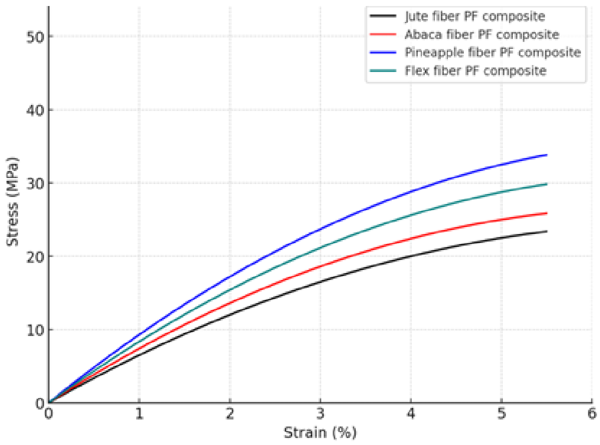

Fig. 2 Tensile stress versus strain for different composite

3.3 IMPACT TEST

The resulting graph (fig.3) shows the variance in absorbed impact energy (J) and impact strength (J/m) for four distinct natural fiber composites based on phenol-formaldehyde (PF): flax, abaca, pineapple, and jute. The figure clearly shows that the pineapple fiber PF composite has the greatest absorbed energy (0.16 J) and impact strength (72 J/m), demonstrating a greater ability to absorb energy under impact situations. This is accounted for by pineapple fibers' better adhesion between fibers and matrix and higher cellulose content, enhancing stress transfer efficiency on sudden loading [1]. Due to its intensive microfibrillar angle and fibers' higher tensile strength, abaca fiber PF composite also shows relatively high values (66 J/m, 0.15 J) [2].

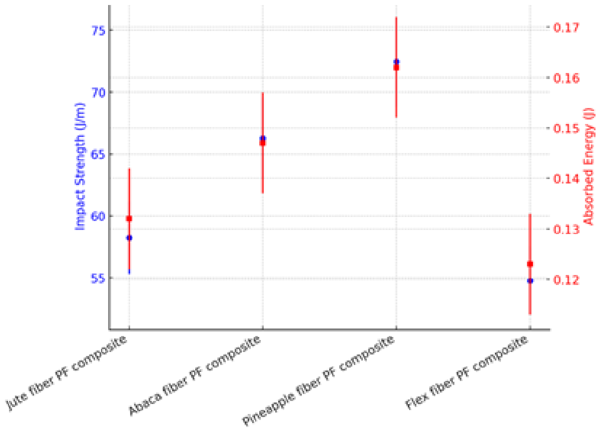

Fig. 3 Impact Strength and Absorbed Energy of Natural Fiber PF Composites

The PF composite made of jute fiber, on the other hand, performs moderately (58 J/m, 0.13 J). This is probably because of its greater hemicellulose content and comparatively weaker interfacial bonding, which lessen impact resistance. In comparison to the other natural fibers, the flax fiber PF composite exhibits the lowest impact strength (55 J/m) and absorbed energy (0.12 J), which may be caused by the fiber surface properties and lower matrix interaction [4,8].

3.4 ANN PREDICTION

The graphs (fig.4) that are shown contrast the experimental findings with the tensile, flexural, and impact strength predictions of phenol-formaldehyde (PF) composites made of jute, abaca, pineapple, and flax fibers. Pineapple fiber composites had the greatest tensile strength (33 MPa), followed by flax, abaca, and jute. ANN predictions and actual results nearly agree, with a ±5% variation. Similarly, pineapple composites perform better than flax, abaca, and jute in terms of flexural strength (70 MPa); in this case, too, the ANN predictions agree well with the actual trends, slightly underestimating pineapple and overestimating jute. Pineapple composites have the strongest resistance to abrupt loads (72 J/m), followed by abaca, jute, and flax, according to the impact strength data, which show the similar pattern. All things considered, the ANN model was able to accurately represent the mechanical attributes' magnitude and ranking, confirming its accuracy as a prediction tool. While the lower values of jute composites are connected to poorer bonding produced by increased hemicellulose and lignin content, the higher cellulose content and strong fiber–matrix adhesion of pineapple fiber composites are responsible for their better performance[9-11]. These results demonstrate that ANN can accurately predict composite behavior while reducing experimental effort.

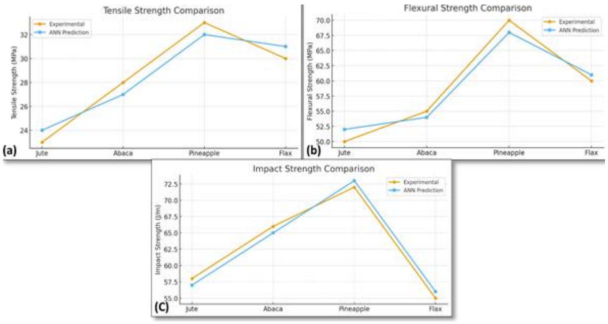

Fig.4 The experimental findings with the ANN were used to predict values

3. CONCLUSION

This comparative assessment has shown that jute, abaca, pineapple, and flax fiber PF composites have very different mechanical behaviors. Consequently, due to their high cellulose content and strong interfacial interaction with the PF matrix, pineapple fiber composites had better tensile, flexural, and impact properties. Flax and abaca fiber composites exhibited well-balanced mechanical properties, whereas jute fiber composites were the poorest reinforcement due to poorer adhesion and more hemicellulose and lignin. ANN modeling addition showed clearly that predictive software can make accurate predictions of the mechanical properties of natural fiber composites, thus minimizing experimental work. Results confirm that pineapple fiber PF composites hold the highest potential for sophisticated engineering applications, while flax and abaca are good alternatives under moderate load-bearing conditions. This study thus lays a basis for further improvement in fiber-matrix interfaces toward the optimization of performance and sustainability in natural fiber-reinforced composites.

REFERENCE

[1] Li, X., Tabil, L. G., & Panigrahi, S. (2007). Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A review. Journal of Polymers and the Environment, 15(1), 25–33.

[2] Mohanty, A. K., Misra, M., & Drzal, L. T. (2005). Natural fibers, biopolymers, and biocomposites. CRC Press.

[3] John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. Carbohydrate Polymers, 71(3), 343–364.

[4] Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose-based fibres. Progress in Polymer Science, 24(2), 221–274. https://doi.org/10.1016/S0079-6700(98)00018-5

[5] Mallick, P. K. (2007). Fiber-reinforced composites: Materials, manufacturing, and design. CRC Press.

[6] Jawaid, M., & Khalil, H. P. S. A. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers, 86(1), 1–18. https://doi.org/10.1016/j.carbpol.2011.04.043

[7] Ramesh, M. (2016). Flax (Linum usitatissimum L.) fibre reinforced polymer composite materials: A review. Progress in Materials Science, 83, 100–124.

[8] Thakur, V. K. (2014). Green composites from natural resources. CRC Press.

[9] Gay, D. (2002). Composite materials: Design and applications. CRC Press.

[10] Lbnyaich. (2018). Modification of the properties biobased thermoset resin using cellulose nano-whiskers (CNWs). Journal of Polymer Research.

[11] Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. Progress in Polymer Science, 37(11), 1552–1596.