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Research Article

Physical and Mechanical Behaviour of Silane-Modified Coconut Inflorecence/Glass Fibril-Fortified Hybrid Epoxy Composites

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Augmenting concern towards effective utilization of agro waste into useful products has fomented the scientific community to look for alternate source of materials. On circular economy contemplation, natural fibers extricated from agro waste have a potential headway towards evolution of newer materials. Natural fiber hybridized with glass fiber and fortified with epoxy matrix has been found to be a promising material with unique characteristics to suit a wide variety of applications. The hydrophilic natural fibers have a resistance to bind with the polymer matrix; as a result, interfacial adhesion is limited, thereby mechanical properties of the composites are not much appreciable. In this present research, the lignocellulose fibrils extracted from coconut inflorescence were subjected to three types of silane modifications, namely, KH550 (amino silane), KH560 (epoxy silane), and KH570 (methyl silane) before hybridization. The effect of silane modification on the functional groups was investigated. The KH570 silane-modified inflorescence fiber hybridized with glass fiber and fortified epoxy composites were found to exhibit utmost tensile and flexural strengths of 102.6 MPa and 166.89 MPa, respectively. FTIR analysis confirmed KH570 silane modification leads to condensation reaction between interface of fibers and matrix. SEM analysis also confronted the elimination of functional groups present in the coconut inflorescence fibers.

1. Introduction

Synthetic fiber-reinforced polymer matrix has several disadvantages, such as high density and nondegradability and also leads to other major issues such as the diminishment of fossil fuels and waste management. The need for environment friendly composites resulted in the extraction of several natural fibers, which are found to be useful as potential reinforcement materials. So, there comes the need to identify biodegradable and sustainable sources of fibrous materials, namely natural lingo cellulose fibers to be reinforced with polymer matrix [1]. Different natural fibers have been extracted by several researchers, namely, snake grass, banana, sisal, and kenaf. The ligno cellulose fibrils extracted from plant sources offer numerous benefits such as low density, better mechanical, and thermal characteristics and also the fibers can be extracted by simple processing techniques. Out of the renewable fibers ripped from distinct sources, plant-based fibers are finding prominent replacement for artificial fibrils in polymer matrixes, owing to the strength and stiffness nature of the lignocellulose fibers.

Extensive literature reported the extraction and pretreatment performed on the physio-mechanical attributes of the lingo cellulose fibrils. There are several extraction methods adopted for the extraction of fiber from natural substances. One of the most widely used methods of extraction is retting. Retting is the process by which the collected natural substances are placed in water over a period of days for the primary walls of the plants to get softened. The physio-mechanical characteristics of lignocellulose fibers may vary based on several parameters, such as the condition of the soil in which the plants are grown, temperature, and crop production. The selection of fiber plays a vital part in deriving the specific composite properties based on the application. The fibril properties are also influenced by the plant's geographical nature [2]. Natural fibrils do exhibit a desirable specific modulus on comparison with man-made fibrils. The nonabrasive nature of the fibril and cost reduction while manufacturing of composites makes the natural fibrils to be a potential reinforcement. These attributes contribute to effective utilization of the lignocellulose fiber for crucial applications [3, 4]. There are several natural fibers, namely, husk, coir, sheath, and spathe, which have been extracted from coconut tree and their possibility of using it as a potential replacement for synthetic fiber and enhancement of mechanical and other composite properties are explored from the extensive scientific survey. Surprisingly one another natural fiber called inflorescence [5] was extracted from the coconut tree, and it was also found that minimal work has been disclosed on coconut inflorescence shown in Figure 1 as the fortification material with polymer matrices. So, the present research focuses on the tensile and flexural behaviour of coconut inflorescence fibril polymer composites subjected to silane coupling reactants to enhance the coherence at the fiber/matrix interface during reinforcement with epoxy matrix.

Figure 1: Coconut inflorescence.

Figure 2: Extracted inflorescence fiber.

2. Materials and Methods

The southern part of India is quiet famous for coconut tree which holds a variety of lignocellulose fibrils in it. Most widely used natural fiber extracted from coconut tree is coir fiber [6], which is extricated from the seed of the coconut palm. The tensile strength and young modulus are quiet less due to its high cellulose and lignin content. The higher microfibrillar angle of the coir fiber also results in low modulus whereas the toughness and percentage of elongation at break is higher for coir fiber in contrast with other natural fibers. The one other part which possesses lignocellulose fiber from the coconut tree is the spathe [7] from which natural fiber can also be extracted. The spathe is high in cellulose and lignin contents. The higher cellulose content restricts adhesion among the interface of polymer matrix and natural fibrils. The fracture surface investigation of coconut fiber fortified polymer composites revealed poor interfacial bonding as a result of higher levels of cellulose and lignin contents in the coconut fibers. The togetherness along the fiber interface and the resin can be enhanced by subjecting the fibers to surface modifications. There are several surface modifications such as mercerization, benzoylation, acetylation, and silane coupling agents [8] by which the amorphous constituents present in the lignocellulose fibers can be removed and interfacial bonding can be improved. For the present research work, fiber has been extricated from coconut inflorescence shown in Figure 2.

Polymer matrix material is a type of material which protects the reinforcement material from the environmental damages while holding the fiber position and orientation in the composites. It is also used to shift the load to the fibrils in the composites. In general, the polymer materials can be categorized into two types, namely, thermoplastic and thermosetting plastic. Thermoset polymers cannot be recycled and reused once cured while the thermoplastics can be recycled and reused. Some of the widely employed thermoset polymers for the manufacturing of composites are epoxy, unsaturated polyester, vinyl ester, and polyamides. For the present research work, epoxy LY556 and hardener HY951 are selected as base matrix and hardener.

The inflorescence fiber before reinforcement is exposed to surface treatment with 5% wt/vol of NaOH solution [9, 10]. Then, the fibrils are washed well with water to remove the alkali contents in the fibrils. Then, the fibrils are subjected to three types of silane coupling agents, namely, γ-Aminopro-pyltriethoxysilane (KH550), 3-Glycid-oxy-propyltri-ethoxysilane (KH560), and γ-Methacryloxy-propyltrimethoxy-silane (KH570) for one hour. Finally, the inflorescence fibrils are washed well with water to remove silane molecules present if any.

The KH550, KH560, and KH570 silane modified inflorescence fibrils were taken for reinforcement with epoxy matrix. The volume fraction used for the manufacturing of composites is 25/75 wt% of fibril and epoxy matrix, respectively. Conventional hand lay-up and subsequent curing by compression moulding methods were used to cure the

Figure 3: Fabricated composite sample.

composite sample. A total of 4 different composites are fabricated as shown in Figure 3. Then, the specimens are sized as per ASTM D638 and D790 for tensile and flexural tests. Universal tensile testing was employed for the tensile and flexural tests with a test speed of 2.0 mm/min. For each test, a total of five different specimens were tested.

3. Results and Discussion

The effect of silane modification on the surface of inflorescence fibers subjected to three silane molecules can be inferred with the help of FTIR analyzer. The analysis was carried out as per KBr pellet technique for a wavelength ranging from 400 cm^{-1} to 4000 cm^{-1} at 32 scans each time for a wave length of 4 cm^{-1}. Finally, morphology of the inflorescence fibrils was examined by scanning electron microscope to perceive the effect of silane molecules on the surface of inflorescence fibrils.

3.1. FTIR Analysis. FTIR analysis is used to investigate the influence of silane modification on the chemical structure of inflorescence fibers. The wave numbers and their corresponding functional group assignment are represented in Figure 4. The apex at 2970 cm^{-1} corresponds to C-H stretching vibration of alkanes. The apex at 1750 cm^{-1} correlates to C=O stretching vibration of esters. The apex at 1100 cm^{-1} relates to C-O stretching vibration of alcohols. The apex at 750 cm^{-1} represents C=C aromatic stretching. In line with virgin fibers, new apex was formed at 3750 cm^{-1} relating to OH stretching vibration, 3610 cm^{-1} correlates to N-H stretching vibration, and 1500 cm^{-1} corresponds to stretching vibration of Si-O-C. The peaks confirm that inflorescence fibers and silane are subjected to condensation reaction [11].

3.2. Mechanical Properties. The mechanical attributes of untreated and silane-modified inflorescence/glass fiber reinforced hybrid composites are shown in Table 1. Figures 5 and 6 show the specimens loaded in tensile and flexural tests setup. From the test results, it can be observed that KH570 silane-modified hybrid composites exhibited better tensile and flexural properties. The reason can be justified by grafting silane coupling agents on the inflorescence fibers [12] which reacts with hydroxyl groups of the fibers thereby inflorescence fibers become hydrophobic and then, finally interfacial coherence increases. An effective interfacial adhesion accounts for better stress transfer among the fiber interface and matrix [13]. The ultimate tensile and flexural strength values were recorded for KH570 silane-modified hybrid composites. KH570 was found to improve the interfacial coherence among the fiber and matrix due to methyl silane, which resulted in the formation of longer CH_2 chains [14]. The long CH_2 created a barrier with epoxy thereby creating physical linkage. As a result, the fiber/matrix interface gets strengthened. The formation of the new apex at 3750 cm^{-1}, 3610 cm^{-1}, and 1500 cm^{-1} proved that the interfacial adhesion is increased as a result of the condensation reaction between the amino silane and inflorescence fibers.

3.3. SEM Analysis. The surfaces of unmodified and silane-modified inflorescence fibers were put through SEM analysis. The surface of unmodified inflorescence fibrils possesses wax and amorphous constituents. The KH570 silane modification of inflorescence fibrils resulted in the grafting of methoxysilane. As a result, the hydrophilic tendency of inflorescence fibrils gets compromised. Figure 7 represents the surface of an unmodified inflorescence fibril, and Figure 8 represents the surface of KH570 silane-modified inflorescence fibrils, which contain cavities as a result of the grafting of silane coupling agents. Figure 9 shows the fracture surface of unmodified inflorescence fibril/glass fiber-fortified hybrid epoxy composites. It was found that fiber pullouts were present, which are due to weak interfacial coherence between the fibrils and matrix. As a result, tensile strength is lower for unmodified hybrid composites.

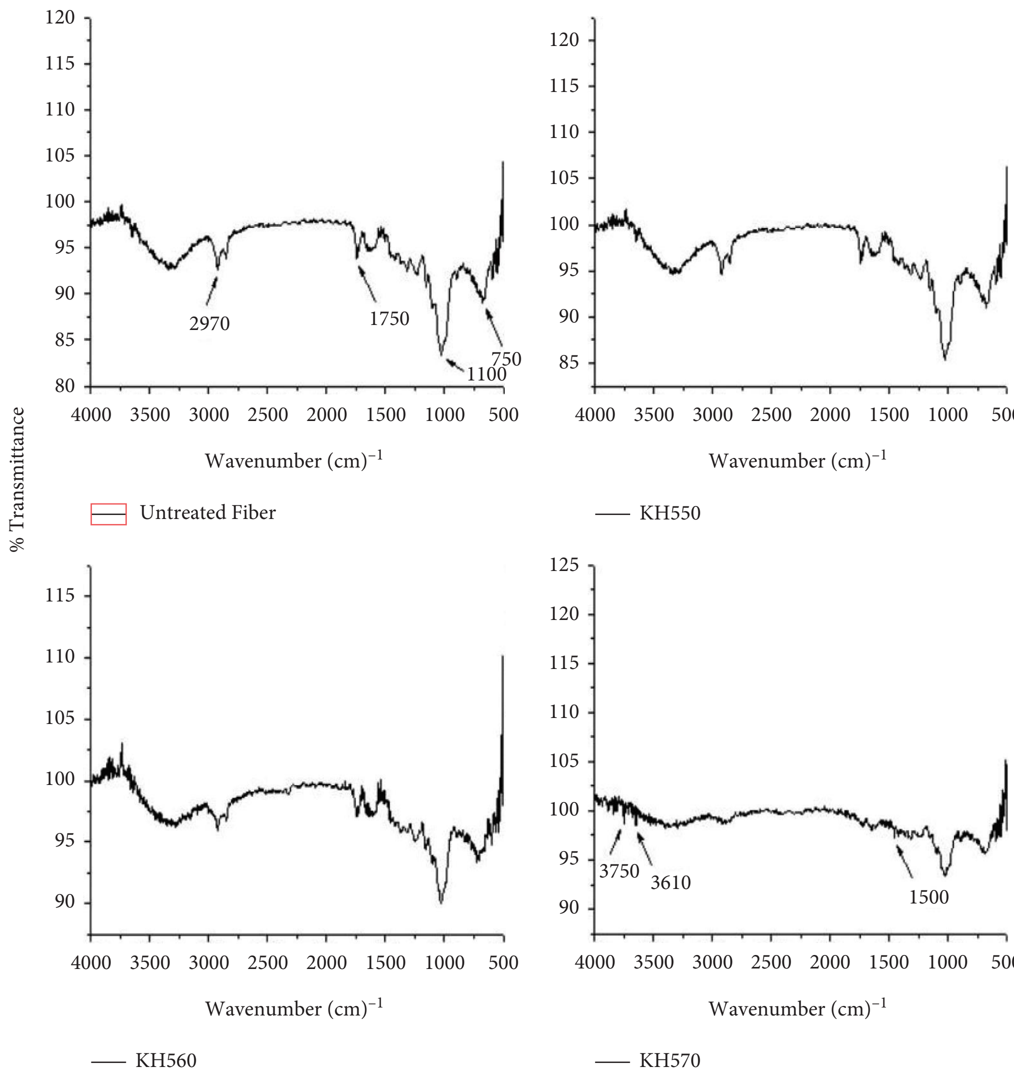

Figure 4: FTIR spectrum apex of unmodified and silane modified inflorescence fibrils.

Table 1: Mechanical properties of untreated and silane-modified inflorescence/glass fiber-reinforced hybrid composites.

Sl. No	Specimen composition	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)
1	Untreated hybrid composites	76.35	531.28	128.56	972.66
2	KH550 modified hybrid composites	84.08	589.32	139.84	1081.41
3	KH560 modified hybrid composites	91.54	661.88	151.03	1181.03
4	KH570 modified hybrid composites	102.6	788.32	166.89	1269.34

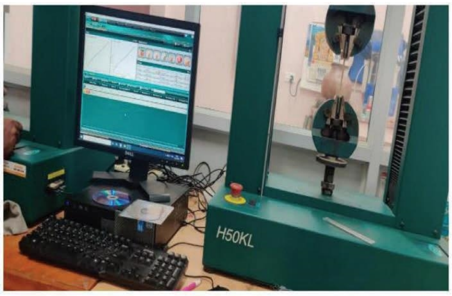

Figure 5: Tensile test.

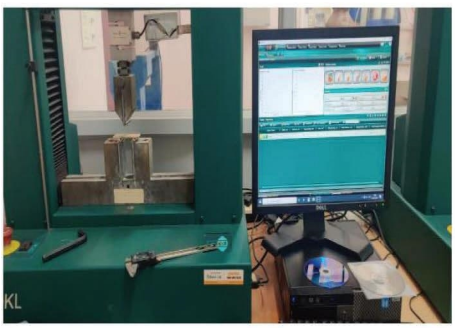

Figure 6: Flexural test.

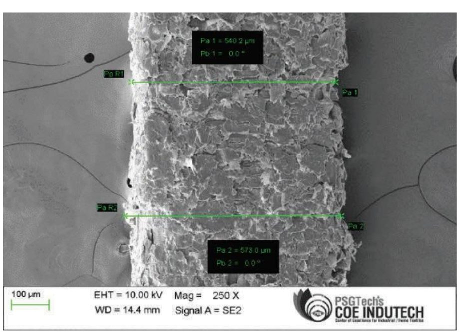

Figure 7: SEM images of untreated fiber.

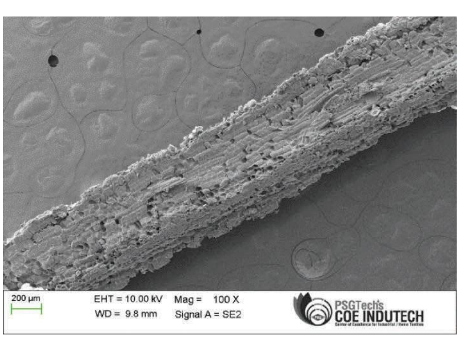

Figure 8: SEM images of KH570 modified fiber.

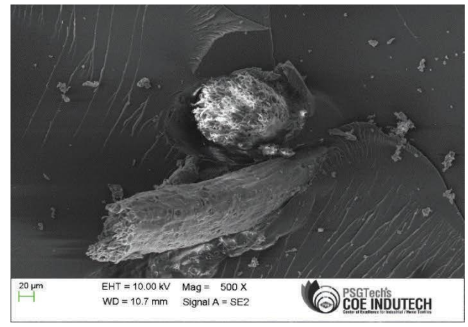

Figure 9: Fractured SEM images of unmodified hybrid composites.

4. Conclusions

The hybridization of silane modified coconut inflorescence fiber/glass fiber-reinforced epoxy composites draws the following conclusions:

(a) Untreated inflorescence fiber found to possess high amount of amorphous constituents.

(b) Alkalization and silane modification of inflorescence fibers contributed to the elimination of an amorphous substance lying in the inflorescence fibers.

(c) FTIR analysis confirmed the formation of new peaks as a result of the condensation reaction between the silane and inflorescence fibers.

(d) A peak tensile strength of 102.6 MPa and flexural strength of 166.89 were recorded for KH570 silane-modified fiber-fortified composites.

(e) The order of improvement between different silane modification is KH570 > KH560 > KH550 > unmodified inflorescence/glass fiber fortified hybrid epoxy composites.

(f) The tensile and flexural properties of KH570 silane-modified hybrid composites were found to be promising than KH560, KH550, and unmodified hybrid composites which is a result of better interfacial adhesion at the fiber/matrix interface.

(g) SEM analysis uncloaked the elimination of amorphous substances in the inflorescence fibers. Better interfacial adhesion was observed at the interface of KH570 modified inflorescence fibers hybridized with glass fibers.

Finally, it can be concluded that KH570 silane-modified inflorescence fibers have a potential role to play in automobile application components.

Data Availability

The data are included within this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] F. P. La Mantia and M. Morreale, "Green composites: a brief review," *Composites Part A: Applied Science and Manufacturing*, vol. 42, no. 6, pp. 579–588, 2011.

[2] D. B. Dittenber and H. V. GangaRao, "Critical review of recent publications on use of natural composites in infrastructure," *Composites Part A: Applied Science and Manufacturing*, vol. 43, no. 8, pp. 1419–1429, 2012.

[3] T. Gurunathan, S. Mohanty, and S. K. Nayak, "A review of the recent developments in biocomposites based on natural fibres and their application perspectives," *Composites Part A: Applied Science and Manufacturing*, vol. 77, pp. 1–25, 2015.

[4] L. Yan, B. Kasal, and L. Huang, "A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering," *Composites Part B: Engineering*, vol. 92, pp. 94–132, 2016.

[5] S. Karthik and V. P. Arunachalam, "Investigation on the tensile and flexural behavior of coconut inflorescence fiber reinforced unsaturated polyester resin composites," *Materials Research Express*, vol. 7, pp. 015345–1, 2020.

[6] A. G. Adeniyi, D. V. Onifade, J. O. Ighalo, and A. S. Adeoye, "A review of coir fiber reinforced polymer composites," *Composites Part B: Engineering*, vol. 176, 107305 pages, 2019.

[7] C. Y. Lai, S. M. Sapuan, M. Ahmad, N. Yahya, and K. Z. H. M. Dahlan, "Mechanical and electrical properties of coconut coir fiber-reinforced polypropylene composites," *Polymer-Plastics Technology and Engineering*, vol. 44, no. 4, pp. 619–632, 2005.

[8] R. B. Jiniraj, P. K. Jayasree, and S. P. Anusha, "Effect of surface modification on the performance of natural fibres—a review," *Ground Improvement and Reinforced Soil Structures*, vol. 10, pp. 609–615, 2022.

[9] A. Oushabi, S. Sair, F. OudrhiriHassani, Y. Abboud, O. Tanane, and A. El Bouari, "The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): study of the interface of DPF–Polyurethane composite," *South African Journal of Chemical Engineering*, vol. 23, pp. 116–123, 2017.

[10] M. Z. Rong, M. Q. Zhang, Y. Liu, G. C. Yang, and H. M. Zeng, "The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites," *Composites Science and Technology*, vol. 61, no. 10, pp. 1437–1447, 2001.

[11] Q. Wang, Yu Zhang, W. Liang, J. Wang, and Y. Chen, "Effect of silane treatment on mechanical properties and thermal behavior of bamboo fibers reinforced polypropylene composites," *Journal of Engineered Fibers and Fabrics*, vol. 15, 155892502095819 pages, 2020.

[12] D. Du, Y. Tang, L. Yang, and C. Tang, "Effects of different grafting density of amino silane coupling agents on thermomechanical properties of cross-linked epoxy resin," *Polymers*, vol. 12, no. 8, p. 1662, 2020.

[13] B. A. Budiman, F. Triawan, F. Adziman, and I. P. Nurprasetio, "Modeling of stress transfer behavior in fiber-matrix composite under axial and transverse loadings," *Composite Interfaces*, vol. 24, no. 7, pp. 677–690, 2017.

[14] S. Yu, K. H. Oh, J. Y. Hwang, and S. H. Hong, "The effect of amino-silane coupling agents having different molecular structures on the mechanical properties of basalt fiber-reinforced polyamide 6, 6 composites," *Composites Part B: Engineering*, vol. 163, pp. 511–521, 2019.