AIP Conference Proceedings

RESEARCH ARTICLE | JUNE 07 2024

Physical characterization of bamboo schizostachyum grande fiber treated by silane coupling agent for hydrophobic applications

Adyla Illyana Roseli; Nik Normunira Mat Hassan; Nur Faezah Yahya; Aida Atiqah Atil; Nofrizalidris Darlis; Mohd Nazrul Roslan; Tuan Noor Hasanah Tuan Ismail

AIP Conf. Proc. 2991, 040044 (2024)
https://doi.org/10.1063/5.0199128

AIP Publishing

Physical Characterization of Bamboo Schizostachyum Grande Fiber Treated by Silane Coupling Agent for Hydrophobic Applications

Adyla Illyana Roseli, Nik Normunira Mat Hassan[a], Nur Faezah Yahya, Aida Atiqah Atil, Nofrizalidris Darlis, Mohd Nazrul Roslan and Tuan Noor Hasanah Tuan Ismail

Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 84600 Pagoh, Muar, Johor, Malaysia.

[a]Corresponding author: normunira@uthm.edu.my

Abstract. The use of bamboo fiber has gained significant attention in various industries, such as construction, packaging, and automotive applications. This study focused on the Schizostachyum Grande species of bamboo fiber and investigated the effect of treatment with a silane coupling agent on its physical characteristics. The characterization was done using techniques such as Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), and Fourier-Transform Infrared Spectroscopy (FTIR) analysis. Results showed that treated bamboo fiber exhibited a stronger and more closely bound fiber structure with a surface that reacted better to silane coupling agents, as seen in SEM images. TGA analysis revealed that thermal degradation occurred completely at a higher temperature for treated bamboo fiber compared to untreated bamboo fiber. FTIR analysis also showed changes in functional groups, with the appearance of peaks related to Si-O-Si and Si-O-C stretching vibrations after treatment. Overall, this study highlights the effectiveness of silane coupling agent treatment in enhancing the surface morphology and chemical properties of bamboo fiber, making it suitable for hydrophobic applications.

INTRODUCTION

Bamboo is a lightweight, functionally-graded material with cylindrical shape, commonly used for building truss elements in civil constructions. The anatomical properties of bamboo play a crucial role in determining its mechanical properties, preservative absorption, and end product characteristics, especially in the pulp and paper industry as Wang et al. [1] pointed out. One of the unique features of bamboo is its ability to regenerate after harvesting without the need for replanting. Its extensive root network constantly produces new shoots that rapidly grow, capturing sunlight and greenhouse gases to facilitate new green growth [2]. Bamboo is known for its anti-UV radiation, antibacterial, breathable, and cool soft handle properties, among others. Its cross-section contains numerous microholes and microgaps, allowing for greater moisture absorption. Bamboo is also used in textiles due to its high tenacity, excellent thermal conductivity, and resistance to bacteria, as well as its ability to absorb high levels of water and perspiration [3].

Schizostachyum grande, (S. Grande) also called as buluh semeliang in Malaysia, has been commercially used. It is the only species with longer internodes than any other commercial Malaysian bamboo. The culms are often used for crafts, sticks, and toothpicks, while the broad and long leaves are used for wrapping particular delicacy. Bamboo utilisation has improved from traditional to modern goods such as laminated bamboo and plybamboo [4]. S. Grande is an evergreen bamboo with short, woody rhizomes that form an open cluster of 3-20 m long culms. The thin-walled, woody culms are 5–12 cm in diameter, with internodes 50–90 cm long, and are erect while young, later dropping to the ground or leaning on neighbouring vegetation [4].

Proceedings of the International Conference on Green Engineering & Technology 2022 (IConGETech 2022)
AIP Conf. Proc. 2991, 040044-1–040044-5; https://doi.org/10.1063/5.0199128
Published under an exclusive license by AIP Publishing. 978-0-7354-4967-1/$30.00

The changes in chemical composition and structure of raw bamboo material after treatment are clarified by the researchers [5], where changes in caramelised and bleached bamboo are dominated by hemicellulose degradation and lignin degradation. Silane can be employed as a silane coupling agent because it possesses two functional groups with varying reactivity. The first of the two functional groups reacts with organic molecules, whereas the second reacts with inorganic elements. When utilized between organic polymers and inorganic fillers, silane coupling agents provide significant benefits and it can increase resin and filler compatibility. Mechanical parameters such as flexural strength, tensile strength, impact strength, and modulus of elasticity can also be improved by silane coupling agents. Because silane coupling agents can promote hydrophobicity, they aid to improve electrical characteristics, especially when exposed to moisture. It can also enhance filling capacity, decrease swelling, and diminish water vapor penetration [6].

METHODOLOGY

This study explains the process for preparing the untreated and treated bamboo fiber via the silane coupling agent method to obtain the hydrophobic property of bamboo fiber.

Materials

Bamboo S. Grande fibers were obtained from HangTerra Bamboo Sdn Bhd in Kedah, Malaysia. In the laboratory, bamboo fiber (BF) was extracted from culm strip to fiber and then cut the length fiber at the ranges of 10 cm.

Bamboo Fiber Surface by Silane Coupling Agent Treatment

A weight ratio of 80:20 followed by Czlonka et al [7] of ethanol and distilled water was used as a solution. 0.1 g 3-aminopropyl (diethoxy) methylsilane hydrolyzed was mixed in ethanol and distilled water, and the mixture was stirred at a constant pace until the solution was diluted. Then 10 g of bamboo fiber was added into the solution and was continually agitated (silane-filler ratio 1:100). The bamboo fiber was soaked in a silane solution for three hours before being adjusted to a pH of 4.00 using the modified method of acetic acid. After that, the bamboo fiber was dried for 24 hours in the drying oven was set to 80 ° C. Figure 1 illustrates the schematic procedure of bamboo fiber treatment by Silance coupling agents.

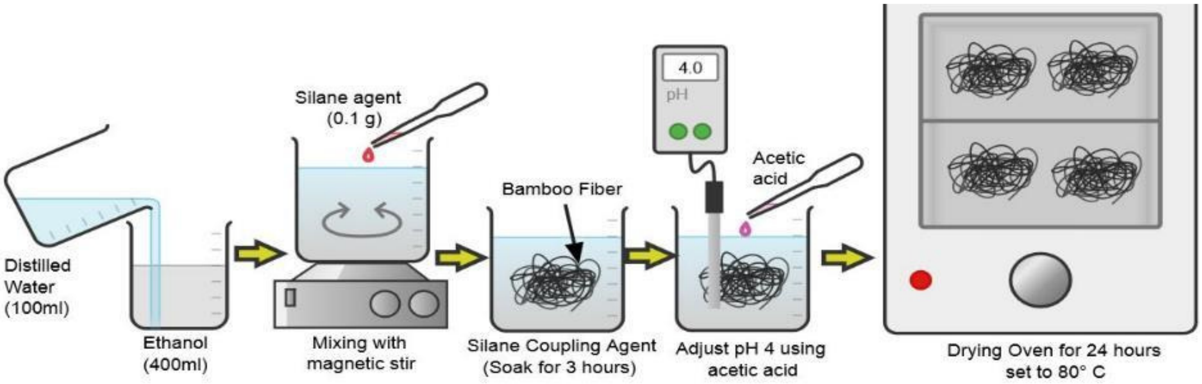

FIGURE 1. Schematic diagram of process bamboo fiber treatment.

Physical Characterization of Bamboo Fiber

A scanning electron microscope (SEM) is a type of electron microscope that uses a concentrated beam of electrons to scan the surface of a sample to produce images. The SEM observation was conducted in the Static and Mechanical Physics laboratory of University Tun Hussein Onn Malaysia, Campus Pagoh. The top surface of the Bamboo S. Grande fiber was scanned in a free-rise direction at the accelerating voltage of 20 kV followed by 500µm magnification. To prevent electrical charge collection, the test samples were gold coated.

Thermogravimetric analysis (TGA) is an analytical method that monitors changes in weight as a sample is heated at a constant rate to determine its thermal stability and the proportion of volatile components. TGA measurements were conducted on untreated and treated bamboo fibers at the chemistry laboratory of Process Instrumental Control at University Tun Hussein Onn Malaysia, Campus Pagoh, to assess their thermal properties. The samples were subjected to a heating rate of 10 °C/min, with a flow rate of 25 ml/min, under a nitrogen atmosphere, and analyzed from 40 °C to 700 °C.

Fourier-transform infrared spectroscopy was used to determine the chemical structure of treated and untreated bamboo fiber. FTIR testing was conducted in the Analytical laboratory at University Tun Hussein Onn Malaysia, Campus Pagoh. The measurement was performed with a maximum resolution of 4 for the wavelength range of 650 to 4000 cm^{-1}.

RESULTS AND DISCUSSION

Characteristics of Surface Bamboo Fiber

SEM images of bamboo fiber surfaces were captured at a magnification of 500X to compare the untreated and silane-treated samples, as presented in Figure 2. The surface of bamboo fibers was examined to evaluate the impact of silane treatment. Figure 2 a) shows the surface of untreated bamboo fibers, which was smooth and clear, with closely aligned fiber strands, as indicated by the yellow line. In contrast, the silane-treated bamboo fibers showed a different structure and morphology. The surface of the treated fibers was cellulose with an amorphous appearance, and impurities were observed, as illustrated in Figure 2 b). Moreover, the surface of bamboo fibers displayed more layers after treatment, which may result in stronger and closer fiber alignment.

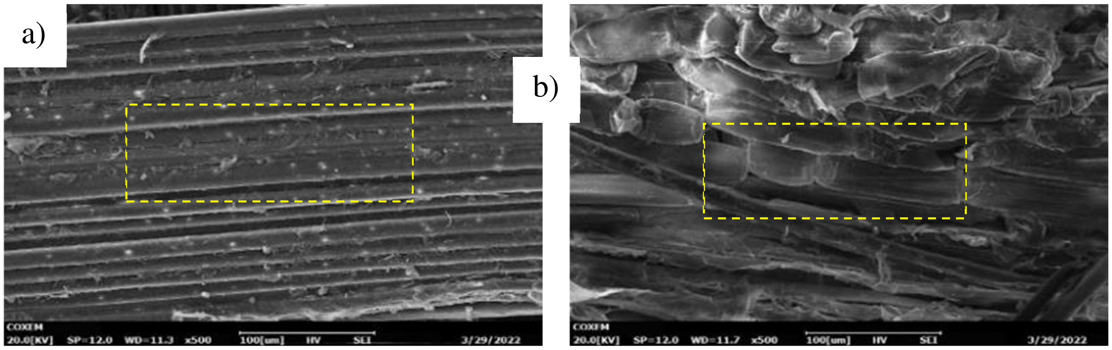

FIGURE 2. a) Untreated bamboo surface, and b) treated bamboo with silane coupling agent

In addition, the treatment caused a disruption in the interaction between the bamboo fibers. As a result, the surface of the bamboo fiber became wrinkled and formed shapes, which could increase the specific area and expand the effective contact area, providing more bonding sites [8]. In comparison to the corresponding untreated bamboo fiber, the surface of the silane-treated bamboo fiber was free from impurities. The strong interfacial bonding could be attributed to the elimination of hydroxyl groups via the chemical modification of fibers using silane coupling agents [9]. Likewise, according to Wang et al [10], silane-treated bamboo fibers displayed a surface free from impurities. Furthermore, applying a thin film onto the surface of bamboo fibers can modify their hydrophilic properties and enhance the interfacial interaction between them. According to previous research [11], the use of a silane coupling agent has been shown to enhance the interfacial bonding between the fibers and the matrix, resulting in improved stiffness and adhesion at the particle-fiber-matrix interface.

Thermogravimetric (TGA) Analysis

Thermal analysis was used to investigate the thermal stability of untreated and treated bamboo fibers treated with silane coupling agent. The weight loss and derivative weight temperature curves are depicted in Figure 3 b). The thermal degradation temperature for untreated bamboo fiber was observed to be lower, at 341.08 °C, than that of treated bamboo fiber, which degraded at 417.16 °C. This could be attributed to the degradation that occurred during the treatment process using a counter rotating mixer, as well as the incorporation of bamboo fiber, which may have affected thermal stability. As shown in Figure 3 a), the weight loss for treated bamboo fiber occurred at a higher temperature compared to untreated bamboo fiber. This may be due to the reduction in the number of hydroxyl groups that had reacted with the coupling agent [12]. The results suggest that there was better interfacial adhesion of the treated silane coupling agent with bamboo fiber due to the reaction, which increased the thermal degradation temperature.

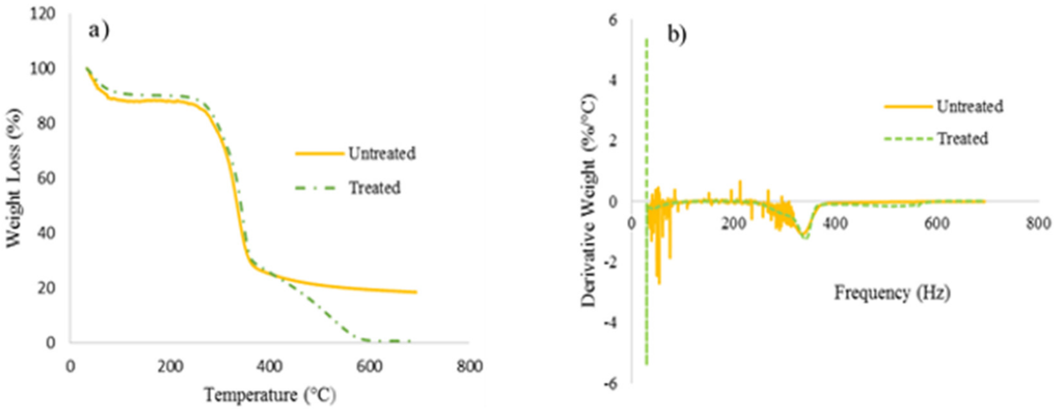

FIGURE 3. Thermogravimetric curve a) weight loss and b) derivative weight loss of bamboo fiber untreated and treated with silane coupling agent.

Significantly, the treated bamboo fiber displayed the highest weight loss at 417.16 °C. It showed the surface compatibility and bonding strength with treatment with silane coupling agent was better than untreated bamboo fiber. After treatment, the chemical bonds of bamboo fiber could enhance the interfacial adhesion and thermal degradation temperature increase consequently.

Fourier Transform Infrared (FTIR) Spectroscopy

To examine the chemical structure of untreated and treated bamboo fibers with silane coupling agent, an FTIR spectrum was conducted, as shown in Figure 4. The broad peak between 1023 and 1026 cm^{-1}, which indicates hydrogen bonding, was not observed in the untreated and treated bamboo fiber spectra. This may be due to the complete cleavage of the ester bond in the hemicellulose, resulting in the absence of the stretching peak in the spectra [13-14]. The range of wave numbers between 1125 and 1190 cm^{-1} represented the characteristic peaks of lignin.

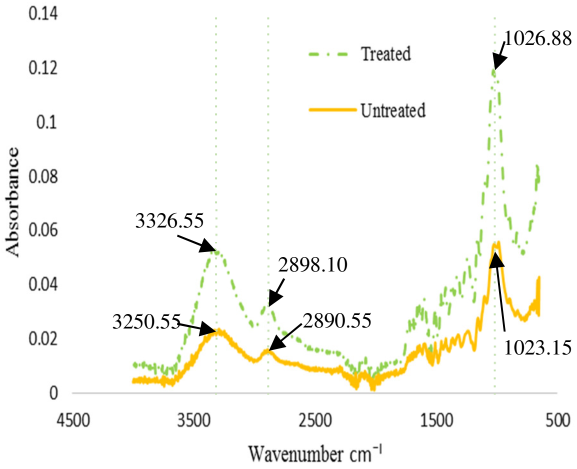

FIGURE 4. FTIR spectra of the bamboo fibers untreated and treated with silane coupling agent.

The untreated cellulose structure of the untreated bamboo fiber did not undergo any introduction of new functional groups. However, after the treatment, a short peak at 2890 to 2898 cm-1 was observed, which indicated the deformation of amines and NH2. In the silane bamboo fiber, the peaks at 3250 to 3326 cm^{-1} were stronger after the silane treatment. These peaks correspond to Si-O-Si ad Si-O-C stretching vibration, indicating that new chemical bonds were formed between the bamboo fibers and the silane coupling agent [14]. Nevertheless, the peak 850 to 750 cm^{-1}, which is assigned as Si-C symmetric stretching bond and Si-O-C asymmetric bending, was not detected in the FTIR analysis. This may be due to the low grafting ratio of the silane coupling agent, which may not show all the peak changes in the FTIR spectrum.

CONCLUSIONS

Based on the analysis of the experimental data, these were possible to conclude that the physical properties of untreated and treated bamboo fibers. In this study, the treatment of silane coupling agent was used on bamboo fiber S. Grande fiber to enhance the hydrophobic property. The morphologies of the surface of bamboo fiber confirmed that the improvement of interfacial adhesion after surface after treatment. The thermal properties represent an improvement of thermal stability of treated bamboo fiber due to of the interfacial adhesion silane coupling agents. In particular, the treated treatment had the best thermal degradation compared to the untreated bamboo fiber. Also, FTIR spectra proved that treated bamboo fiber could react to silane coupling agents, which could generate chemical bonds than untreated bamboo fiber. Additionally, it was demonstrated that S. Grande bamboo fibers can be used for hydrophobic purposes by treated with the silane coupling agent.

ACKNOWLEDGMENTS

The authors would like to thank the Universiti Tun Hussein Onn Malaysia for supporting this project under TIER 1 Grant by UTHM Scheme under Vot H801.

REFERENCES

1. Y. Wang, H. Zhan, Y. Ding, S. Wang and S. Lin, *BioResources*, 11(1), 1202-1213 (2016).
2. C. Prakash, Bamboo fibre, In Handbook of natural fibres, Woodhead Publishing, pp. 219-229 (2020).
3. C. Prakash, G. Ramakrishnan and C. V. Koushik, C. V., *The Journal of The Textile Institute*, 104(12), 1320-1326 (2013).
4. N. A. Siam, M. K. A. Uyup, H. Husain, and M. T. Mustafa, Selected properties of Malaysian Bamboo Schizostachyum grande (buluh semeliang) and Schizostachyum brachycladum (buluh lemang). In THE 7 th International Symposium of Indonesian Wood Research Society, 5, p. 8 (2015).
5. D. U. Shah, B. Sharma and M. H. Ramage, *International Journal of Adhesion and Adhesives*, 85, 15-22 (2018).
6. T. Aziz, A. Ullah, H. Fan, M. I. Jamil, F. U. Khan, R. Ullah and B. Ullah, B, *Journal of Polymers and the Environment*, 29(11), 3427-3443 (2018).
7. S. Członka, A. Strąkowska and A. Kairytė, *Polymer testing*, 87, 106534 (2020).
8. Y. Li, L. Jiang, C. Xiong and W. Peng, *Industrial & Engineering Chemistry Research*, 54(48), 12017-12024 (2015).
9. F. K. Liew, S. Hamdan, M. R. Rahman, M. Rusop and A. Khan, *Polymer Composites*, 41(11), 4830-4841 (2020).
10. Q. Wang, Y. Zhang, W. Liang, J. Wang and Y. Chen, *Journal of Engineered Fibers and Fabrics*, 15, 1558925020958195 (2020).
11. N. A. Ramlee, M. Jawaid, S. A. K. Yamani, E. S. Zainudin and S. Alamery, S., *Construction and Building Materials*, 276, 122239 (2021).
12. G. Hu, S. Cai, Y. Zhou, N. Zhang and J. Ren, *Journal of Reinforced Plastics and Composites*, 37(12), 841-852 (2018).
13. Y. Guan, B. Zhang, X. Qi, F. Peng, C. Yao, and R. Sun, *Carbohydr. Polym.*, 29, 201–207 (2015).
14. T. Lu, M. Jiang, Z. Jiang, D. Hui, Z. Wang, and Z. Zhou, *Composites Part B: Engineering*, 51, 28-34 (2013).