Effect of rice husk ash silicon nitride on mechanical, wear, thermal conductivity, and flammability behavior of aluminized glass-kenaf fiber-reinforced polyester composite

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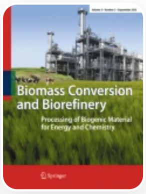

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Aims and scope

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Abstract

The main goal of this present research was to find out how combining hybridized fiber (aluminized glass and kenaf fiber) and biomass-derived bioceramic silicon nitride (Si_3N_4) affected the mechanical, wear, thermal conductivity, and flammability behavior of a composite made of polyester. Using a thermo-chemical method, rice husk ash was used to create Si_3N_4, which was then surface-treated with an aminosilane. Compression molding was used to create the composites, and they were then post-cured at 120 °C. The study's findings showed that the mechanical properties were enhanced by the inclusion of Si3N4 in addition to aluminized glass/kenaf fiber. Composite A3, which contains 3 vol.% Si3N4, has the improved tensile, flexural, impact, interlaminar shear strength, and compression strength of 138 MPa, 192 MPa, 6.7 J/m, 28 MPa, and 152 MPa. The SEM fractographs showed enhanced toughness in the matrix and highly reactive phases of the reinforcements. Similarly, the wear resistance was increased to 0.12 mm^3/Nm of sp. wear rate and 0.24 coefficient of friction by the composite designation A4 with 5 vol. % of Si3N4. Furthermore, the Si_3N_4-rich A4 composite has the lowest recorded thermal conductivity of 0.214 W/mK. Additionally, the A4 designation explicated a lowest flame propagation speed of 6.14 mm/min (V-0 flame rating) with a lower water absorption % of 0.008. Therefore, it is worthwhile to fully incorporate Si_3N_4 in addition to hybridized fiber to enhance load bearing capacity, increase wear resistance, and reduce heat transfer in composites with potential structural, automotive, drones, and military equipment applications.

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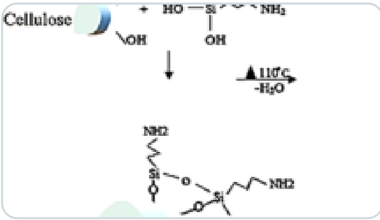

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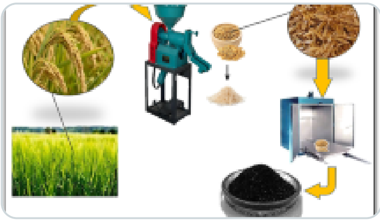

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Data availability

All data in manuscript.

References

1. Ramesh M (2016) Kenaf (Hibiscus cannabinus L.) fibre based bio-materials: a review on processing and properties. Prog Mater Sci 78:1–92

Article Google Scholar

2. Nakkeeran G, Krishnaraj L, Bahrami A, Almujibah H, Panchal H, Zahra MMA (2023) Machine learning application to predict the mechanical properties of glass fiber mortar. Adv Eng Softw 180:103454

Article Google Scholar

3. Yang Q, Cao J, Ding R, Zhan K, Yang Z, Zhao B, … Ji V (2023) The synthesis and mechanism of superhydrophobic coatings with multifunctional properties on aluminum alloys surface: a review. Progr Organ Coat 183:107786

4. Zhao W, Yan W, Zhang Z, Gao H, Zeng Q, Du G, Fan M (2022) Development and performance evaluation of wood-pulp/glass fibre hybrid composites as core materials for vacuum insulation panels. J Clean Prod 357:131957

Article Google Scholar

5. Gaurav S, Mishra RS, Zunaid M (2023) A critical review on mechanical and microstructural properties of dissimilar aluminum (Al)-magnesium (Mg) alloys. J Adhes Sci Technol 37(7):1117–1149

Article Google Scholar

6. Papanicolaou GC, Kontaxis LC, Kouris N, Portan DV (2023) Application of an eco-friendly adhesive and electrochemical nanostructuring for joining of aluminum A1050 plates. Materials 16(6):2428

Article Google Scholar

7. Karunagaran N, Shaafi T, Thiagarajan C, Suthan R, Devi GR, Thanikasalam A (2023) Thermo-gravimetric analysis on stainless steel mesh wire/glass fibre strengthened epoxy matrix hybrid composite laminate. In AIP Conference Proceedings (Vol. 2690, No. 1). AIP Publishing

8. Ferreira JM, Pires JTB, Costa JD, Zhang ZY, Errajhi OA, Richardson M (2005) Fatigue damage analysis of aluminized glass fiber composites. Mater Sci Eng, A 407(1–2):1–6

Article Google Scholar

9. Gudkov AG, Pavlov MV, Karpov DF (2021) Mass transfer in a layer of aluminized glass-fiber material in the treatment of chrome-containing wastewater. In IOP Conference Series: Materials Science and Engineering (Vol. 1079, No. 6, p. 062041). IOP Publishing

10. Xu M, Bao H, Ma J, You J (2010) Research of electrical properties and electromagnetic shielding effectiveness of aluminized glass fiber composite materials. J Mater Sci Eng 4(8)

11. Ramesh M, Nijanthan S (2016) Mechanical property analysis of kenaf–glass fibre reinforced polymer composites using finite element analysis. Bull Mater Sci 39:147–157. https://doi.org/10.1007/s12034-015-1129-z

Article Google Scholar

12. Ramesh M, Nijanthan S, Palanikumar K (2015) Processing and mechanical property evaluation of kenaf-glass fiber reinforced polymer composites. Appl Mech Mater 766:187–192

Article Google Scholar

13. Ghani MU, Siddique A, Abraha KG, Yao L, Li W, Khan MQ, Kim I-S (2022) Performance evaluation of jute/glass-fiber-reinforced polybutylene succinate (PBS) hybrid composites with different layering configurations. Materials 15(3):1055

Article Google Scholar

14. Rajadurai A (2016) Thermo-mechanical characterization of siliconized E-glass fiber/hematite particles reinforced epoxy resin hybrid composite. Appl Surf Sci

384:99–106

Article Google Scholar

15. Shubham SK, Pandey A, Purohit R (2023) Investigations on mechanical properties and stacking sequence of kevlar/banana fiber reinforced nano graphene oxide hybrid composites. Smart Mater Struct

16. Dwivedi SP, Selvaprakash S, Sharma S, Kumari S, Saxena KK, Goyal R, … Djavanroodi F (2023) Evaluation of various properties for spent alumina catalyst and Si3N4 reinforced with PET-based polymer composite. Mech Adv Mater Struct 1–11

17. Behera A, Dehury J, Rayaguru BP (2023) The consequence of SiC filler content on the mechanical, thermal, and structural properties of a jute/kevlar reinforced epoxy hybrid composite. Silicon 1–11

18. Li X, Wang F, Feng X, Xiao Q, Zheng Q, Xu J, … Lu S (2023) A nationwide investigation of trace elements in rice and wheat flour in China: Levels, spatial distributions and implications for human exposure. Environ Sci Pollut Res 1–12

19. Mohan Das Gandhi AG, Sivaraman R, Nagabhooshanam N, Verma R. Effect of adding Indiana red matta rice husk Si3N4 bioceramic on mechanical, wear, flammability and tensile creep behavior of corn husk fiber polyester composite. Polymer Compos

20. Kumar A, Lakshmipathi AR, Nagabhooshanam N, Sahu SK, Patil PP, Satyanarayana V, Praveen N (2023) Effect of adding rice husk ash functional silicon additives on flammability wear and thermal stability of ramie-epoxy composite. Silicon 1–8

21. Lv X, Huang J, Dong X, Yan Q, Ge C (2023) Influence of α-Si3N4 coarse powder on densification, microstructure, mechanical properties, and thermal behavior of silicon nitride ceramics. Ceram Int 49(13):21815–21824

Article Google Scholar

22. Rao AU, Tiwari SK, Goyat MS, Chawla AK (2023) Recent developments in magnetron-sputtered silicon nitride coatings of improved mechanical and tribological properties for extreme situations. J Mater Sci 1–50

23. Vennila T et al (2022) Investigation on tensile behaviour of Al/Si3N4/sugarcane ash particles reinforced FSP composites. Mater Today: Proc 59:1266–1270

Google Scholar

24. Mohan Das Gandhi AG, et al. Effect of adding Indiana red matta rice husk Si3N4 bioceramic on mechanical, wear, flammability and tensile creep behavior of corn husk fiber polyester composite. Polymer Compos

25. Karthick S, et al. (2022) Effect of brown rice husk α-Si 3 N 4 on Ni–P composite coating of austenitic AISI 316L steel: Taguchi grey relational approach. Biomass Convers Biorefinery 1–10

26. Prakash VA, Jaisingh SJ (2018) Mechanical strength behaviour of silane treated E-glass fibre/Al 6061 & SS-304 wire mesh reinforced epoxy resin hybrid composite. SILICON 10:2279–2286

Article Google Scholar

27. Arun Prakash VR, Jayaseelan V, Depoures Melvin Victor (2020) "Effect of silicon coupling grafted ferric oxide and e-glass fibre in thermal stability, wear and tensile fatigue behaviour of epoxy hybrid composite. Silicon 12:2533–2544

Article Google Scholar

28. Hemanth MSK, Dhas JER (2023) Eco-friendly materials for brake pad-ANSYS overview. Materials Today: Proceedings

29. Honestyo A, Ardhyananta H (2023) Tensile properties of woven plastic straw waste fiber-reinforced polymer composites. Int J Eng Appl 11(1):11–17

Google Scholar

30. Madhan NR, Senthil S (2023) Characterization of tamarind fruit shell power-reinforced virgin and recycled polypropylene-based 3D-printed composites. Biomass Convers Biorefin 1–14

31. Mottram JT (1994) Compression strength of pultruded flat sheet material. J Mater Civ Eng 6(2):185–200

Article Google Scholar

32. Genna S, Trovalusci F, Tagliaferri V (2017) Indentation test to study the moisture absorption effect on CFRP composite. Compos B Eng 124:1–8

Article Google Scholar

33. Bhanuprakash L, Salman M, Kansary S, Karthik GV, Reddy YV (2023) Impact resistance studies of 3D printed PLA. In AIP Conference Proceedings (Vol. 2492, No. 1). AIP Publishing

34. Phogat A, Chhabra D, Sindhu V, Ahlawat A (2022) Analysis of wear assessment of FDM printed specimens with PLA, multi-material and ABS via hybrid algorithms. Mater Today: Proc 62:37–43

Google Scholar

35. Prakash VRA, Bourchak M, Alshahrani H et al (2023) Synthesis and characterization of lightweight unmanned aerial vehicle composite building material for defense application. Biomass Conv Bioref. https://doi.org/10.1007/s13399-023-04736-2

Article Google Scholar

36. Kurup VR, Sabarinath S, Shankar B (2023) Review on the recent advances in various properties of epoxy nanocomposites brake pad materials. Trans Indian Institute Metals 1–9

37. Manikandan G, Jaiganesh V, Malarvannan RR, Prakash AV (2021) Mechanical and delamination studies on siliconized chitosan and morinda-citrifolia natural fiber-reinforced epoxy composite in drilling. Polym Compos 42(1):181–190

Article Google Scholar

38. Irawan AP et al (2023) "Influence of varying concentrations of epoxy, rice husk, Al2O3, and Fe2O3 on the properties of brake friction materials prepared using hand layup method. Polymers 15(12):2597

Article Google Scholar

39. Prakash VA, Bourchak M, Alshahrani H, Juhany KA (2023) Development of cashew nut shell lignin-acrylonitrile butadiene styrene 3D printed core and industrial hemp/aluminized glass fiber epoxy biocomposite for morphing wing and unmanned aerial vehicle applications. Int J Biol Macromol 253:127068

Article Google Scholar

40. Fuad MTN (2023) "The effect of Aegle marmelos shell particles volume fraction on hardness, toughness, and wear rate of epoxy matrix composites as motorcycle brake pads. J Mech Eng Sci 9338–9348

41. Akıncıoğlu G (2023) The effects of resin rate (wt-%) on different temperature performance of newly designed friction composites for automobile brake lining applications. Plast, Rubber Compos 52(5):292–303

Article Google Scholar

42. Alshahrani H, VR, AP (2022) Mechanical, wear, and fatigue behavior of alkali-silane-treated areca fiber, RHA biochar, and cardanol oil-toughened epoxy biocomposite. Biomass Conv. Bioref. https://doi.org/10.1007/s13399-022-02691-y

43. Xu W, et al. (2023) Influences of CrFe granularity and proportion on braking performance and dynamic response of Cu-based pads. Wear 205043

44. Vincent VA, Kailasanathan C, Shanmuganathan VK et al (2022) Strength characterization of caryota urens fibre and aluminium 2024–T3 foil multi-stacking sequenced SiC-toughened epoxy structural composite. Biomass Conv Bioref 12:4009–4019. https://doi.org/10.1007/s13399-020-00831-w

Article Google Scholar

45. Prabhu P, Jayabalakrishnan D, Balaji V et al (2022) Mechanical, tribology, dielectric, thermal conductivity, and water absorption behaviour of Caryota urens woven fibre-reinforced coconut husk biochar toughened wood-plastic composite. Biomass Conv Bioref. https://doi.org/10.1007/s13399-021-02177-3

Article Google Scholar

46. Khan MKA, Alshahrani H, Arun Prakash V (2023) Effect of grid pattern and infill ratio on mechanical, wear, fatigue and hydrophobic behaviour of abaca bracts biocarbon-ABS biocomposites tailored using 3D printing. Biomass Conv Bioref. https://doi.org/10.1007/s13399-023-05196-4

47. Alshahrani H, Arun Prakash VR (2023) Load bearing investigations on novel Acrylonitrile butadiene styrene-carbon quantum dots 3D printed core/bamboo fiber polyester sandwich composite for structural applications. Polym Compos. https://doi.org/10.1002/pc.27972

Article Google Scholar

48. Gapsari F et al (2022) Flammability and mechanical properties of Timoho fiber-reinforced polyester composite combined with iron powder filler. J Market Res 21:212–219

Google Scholar

49. Arun Prakash VR, Xavier JF, Ramesh G et al (2022) Mechanical, thermal and fatigue behaviour of surface-treated novel Caryota urens fibre–reinforced epoxy composite. Biomass Conv Bioref 12:5451–5461. https://doi.org/10.1007/s13399-020-00938-0

Article Google Scholar

50. Mokhtar H, Ayob A, Tholibon DA, Othman Z (2023) Preparation and characterization of polysulfone composite membrane blended with kenaf cellulose fibrils. J Adv Res Appl Sci Eng Technol 31(2):91–100. https://doi.org/10.37934/araset.31.2.91100

Article Google Scholar

51. Shuangyu L, Yingjie C, Ping L, Binhua W, Fulong Z, Juan H (2024) Si3N4 slurry with high solid phase, low viscosity prepared via surface-oxidation and silane coupling agent modification hybrid method. J Eur Ceram Soc 44(1):161–172. https://doi.org/10.1016/j.jeurceramsoc.2023.08.056

Article Google Scholar

52. Oyekanmi AA, Saharudin NI, Hazwan CM, HPS, AK, Olaiya NG, Abdullah CK, … Pasquini D (2021) Improved hydrophobicity of macroalgae biopolymer film

incorporated with kenaf derived CNF using silane coupling agent. Molecules 26(8):2254https://doi.org/10.3390/molecules26082254

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Contributions

N. Ram Prakash – Research, writing and testing.

C. Gnanavel – Material arrangement and writing.

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Ethics declarations

Ethical approval

NA.

Consent to participate

NA.

Consent for publication

Yes.

Competing interests

The authors declare no competing interests.

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