Effect of Silica Loading on the Mechanical Performance of Polypropylene Composites Reinforced With Neem Fiber Processed Via Injection Molding

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Abstract: The integration of natural fibers and nanofillers into thermoplastic matrices has gained significant interest for sustainable and lightweight engineering applications. This study examines the influence of nano-silica (30 nm) incorporation into polypropylene (PP) composites reinforced with short neem fibers (3 mm) using an injection molding process. Five composite formulations were developed: neat PP, PP with 20 wt% neem fiber, and PP with 20 wt% neem fiber reinforced with 1, 2, and 3 wt% nano-silica. Mechanical and thermal performance was evaluated through stress–strain analysis, impact toughness, and thermogravimetric mass loss. Results showed that silica loading improved tensile strength, modulus, and thermal stability while slightly reducing elongation at break due to increased stiffness. The 2 wt% silica-filled composite demonstrated the best balance of strength, toughness, and thermal resistance, indicating its suitability for lightweight automotive cabin applications.

# Introduction

In the automobile industry polypropylene is a thermoplastic that is often utilized because of its low density affordability and simplicity of processing. However it is use in structural components is limited by its comparatively poor strength and thermal stability [1-2]. In an effort to increase stiffness while lessening their environmental impact natural fibers like neem fiber are being investigated more and more as reinforcements and the increasing interest in polymer based nanocomposites reinforced with natural fillers and nanoparticles for better mechanical, thermal and sustainable performance is highlighted by recent research. The polypropylene based nanocomposites reinforced with silica nanofillers via melt processing and injection molding demonstrating improved mechanical and thermal stability [3-7]. Silica coatings and hydrothermal treatment to improve the endurance of natural plant fibers in cementitious composites and in order to achieve lightweight structural benefits presented a hybrid polymeric composite reinforced with cellulose microfillers produced from agro-industrial waste in addition to basalt and banana fibers [8-12]. In a similar, neem fiber composites with nanofillers and found that processing them using vacuum infusion molding significantly improved their tensile properties [13-16].

The significance of heat resistance in structural applications was highlighted by Neto et al. Thorough summary of thermal evaluation of natural and hybrid fiber composites at the review levelcombined structural resilience with functional biomaterial qualities to create self healing dental composites enhanced with silica nanoparticles for use in biomedical settings [17-19]. By adding DOPO modified halloysite nanotubes to silica aerogel composites, Silicone resin durability, thermal insulation and flame retardancy [20-21]. Parallel analytical and the experimental investigations [22-23] showed that graphene based fillers greatly improve the mechanical and thermal performance of polypropylene nanocomposites. These results by confirming that the mechanical characteristics of polymer nanocomposites are crucially governed by nanoparticle size [24-26].

Surface modification has also been sought after for example, created ZnO/SiO₂ nanocoatings for polyester that had flame retardant, antibacterial and self cleaning properties [27]. Neem leaves waste as reinforcement in composites, demonstrating viable applications of agro waste [28-30]. There are similar to this advanced sustainable material usage by creating neem and Arjuna filler composites and in their assessment of natural fiber reinforced polymer composites in vehicle lightweighting highlighted the importance of these materials for environmentally friendly mobility solutions [31-33].

Interfacial bonding, load transmission, and resistance to thermal deterioration are further improved by the use of nanoscale ceramic fillers such as silica and this processes including particle–matrix interlocking, fracture deflection and limited polymer chain mobility silica nanoparticles have been shown in earlier research to enhance the mechanical and thermal durability of polymer composites. Thus combining neem fiber reinforcement with silica nanoparticles presents a promising pathway to develop sustainable, lightweight composites for automotive interiors.

# Materials and Methods

## Materials

The basic matrix was polypropylene granules reinforced with nano silica particles for secondary strengthening and 3 mm alkali treated neem fibers for improved adherence. Twin screw extrusion and injection molding were used to create five different formulations of the composites: clean PP PP with 20 weight percent neem fiber and PP/neem fiber reinforced with 1, 2 and 3 weight percent SiO₂. Thermal stability was assessed using thermogravimetric analysis under nitrogen impact toughness was assessed using Izod testing and tensile characteristics were assessed in accordance with ASTM D638 [34-39].

## Composite Formulations

Impact toughness was determined using the Izod technique and tensile characteristics were assessed using ASTM D638 to determine stress strain behavior. Thermogravimetric analysis in a nitrogen environment was used to examine thermal stability and mass loss [40-43].

**TABLE 1.** Composite Configurations Table

|  |  |
| --- | --- |
| **Sample ID** | **Composition** |
| Sample 1 | PP (neat) |
| Sample 2 | PP + 20 wt% Neem fiber |
| Sample 3 | PP + 20 wt% Neem fiber + 1 wt% SiO₂ |
| Sample 4 | PP + 20 wt% Neem fiber + 2 wt% SiO₂ |
| Sample 5 | PP + 20 wt% Neem fiber + 3 wt% SiO₂ |

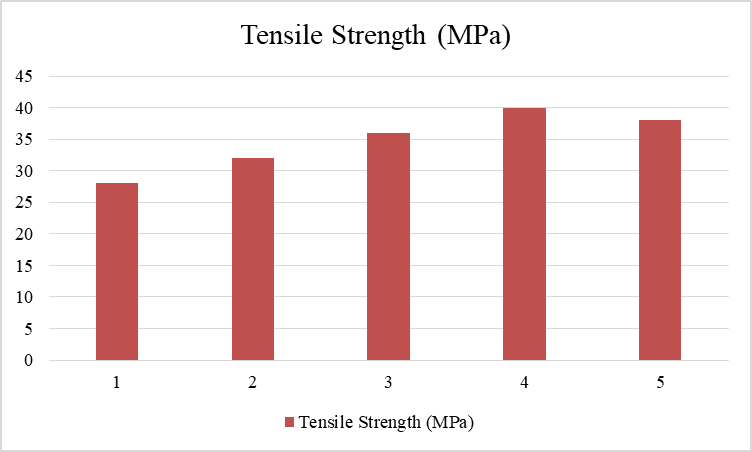
# Results and Discussion

## Stress–Strain Behavior

Neat PPs modulus and tensile strength were comparatively low. Because neem fiber is brittle, adding 20% of it decreased elongation while increasing stiffness. Youngs modulus and tensile strength were further improved by adding silica nanoparticles (1–3% weight percentage). The maximum tensile strength was shown by the 2 weight percent silica composite, which was around 25% stronger than PP + neem fiber alone. A little decrease was seen at 3 weight percent as a result of particle agglomeration creating stress concentration sites.

**TABLE 2**Tensile Strength

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample ID | Composition | Young’s Modulus (GPa) | Tensile Strength (MPa) | Elongation at Break (%) |
| 1 | PP (neat) | 1.2 | 28 | 12.5 |
| 2 | PP + 20 wt% Neem fiber | 1.8 | 32 | 7.2 |
| 3 | PP + 20 wt% Neem fiber + 1 wt% SiO₂ | 2 | 36 | 6.9 |
| 4 | PP + 20 wt% Neem fiber + 2 wt% SiO₂ | 2.2 | 40 | 6.5 |
| 5 | PP + 20 wt% Neem fiber + 3 wt% SiO₂ | 2.1 | 38 | 6.3 |



**Figure 1.** Microhardness

## Impact Toughness

PP showed minimal stiffness but good impact strength. Because to fiber pull out neem fiber reinforcement decreased impact toughness. By adding silica nanoparticles, fiber matrix adherence was enhanced and toughness was partly restored [44-47]. The ideal balance was reached by the 2 weight percent silica composite which had stiffness much greater than plain PP but toughness similar.

**TABLE 3.** Hardness

|  |  |  |
| --- | --- | --- |
| Sample ID | Composition | Impact Toughness (kJ/m²) |
| 1 | PP (neat) | 28 |
| 2 | PP + 20 wt% Neem fiber | 18 |
| 3 | PP + 20 wt% Neem fiber + 1 wt% SiO₂ | 21 |
| 4 | PP + 20 wt% Neem fiber + 2 wt% SiO₂ | 27 |
| 5 | PP + 20 wt% Neem fiber + 3 wt% SiO₂ | 24 |

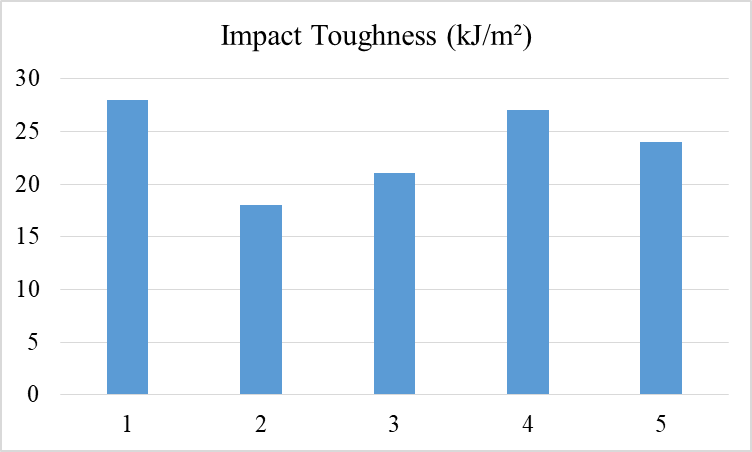
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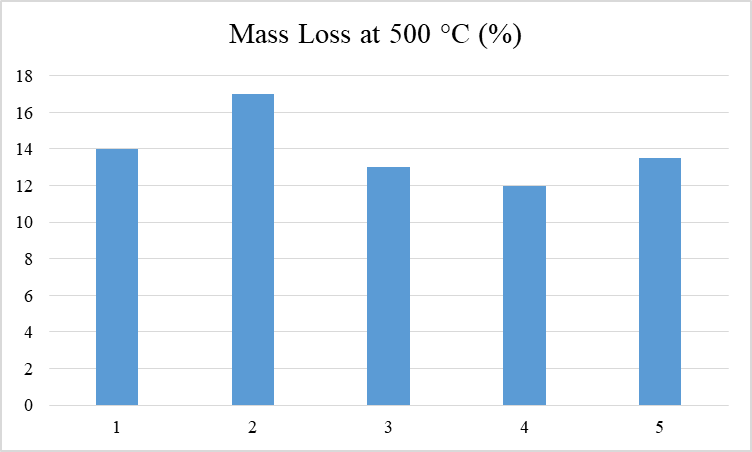
Figure 2. Hardness

## Thermal Stability (Mass Loss)

TGA showed that at 390 °C clean PP began to lose mass significantly. Because neem fiber is organic its insertion somewhat decreased stability. On the other hand the inclusion of silica reduced deterioration rates by acting as a heat barrier. Mass loss was around 14% for PP at 500 °C, 17% for PP + neem fiber and 12% for 2 weight percent silica. This demonstrates how silica limits the routes that lead to heat deterioration.

**TABLE 4.** Thermal Stability

|  |  |  |
| --- | --- | --- |
| Sample ID | Composition | Mass Loss at 500 °C (%) |
| 1 | PP (neat) | 14 |
| 2 | PP + 20 wt% Neem fiber | 17 |
| 3 | PP + 20 wt% Neem fiber + 1 wt% SiO₂ | 13 |
| 4 | PP + 20 wt% Neem fiber + 2 wt% SiO₂ | 12 |
| 5 | PP + 20 wt% Neem fiber + 3 wt% SiO₂ | 13.5 |



**Figure 3.** Thermal Stability

# Applications in Automotive Cabins

The created PP/neem fiber/silica composites provide a special blend of mechanical strength environmental friendliness and lightweight qualities which makes them ideal for next generation car interiors and the manufacturing of cabin panels that need resilience under mechanical vibrations and everyday use such as dashboards, door trims and roof liners is made possible by their increased strength, stiffness, toughness and thermal stability. Additionally the composites show great promise for load bearing interior fittings where fatigue resistance and dimensional stability are essential. Additionally they are appropriate for lightweight insulation components that function in environments with varying cabin temperatures due to the enhanced thermal resistance offered by silica reinforcing and these composites directly contribute to the automobile industrys shift to lighter more environmentally friendly and energy efficient cars by lowering reliance on petroleum based plastics while maintaining performance and sustainability [48-50].

# Conclusion

This work clearly proves the favorable function of nano-silica inclusion in adjusting the performance of PP/neem fiber composites for engineering applications and the addition of 20 wt% neem fiber greatly enhanced stiffness however it lowered impact toughness because to the intrinsic brittleness of natural fibers. The use of nano-silica 1–3 wt% substantially boosted tensile strength, modulus and thermal stability with 2 wt% silica providing the optimum balance between mechanical reinforcement and thermal resistance. At greater loading 3 wt% modest property decreases were detected mostly owing to nanoparticle agglomeration and stress concentration effects and overall the optimized PP/neem fiber/2 wt% silica composite emerges as a promising candidate for lightweight automotive cabin applications offering a sustainable and high performance alternative to conventional plastics by uniting mechanical strength toughness and environmental compatibility in a single material system.

# References

1. Seshweni, Mantsha Hennie Erna, Mamookho Elizabeth Makhatha, Orebotse Joseph Botlhoko, Babatunde Abiodun Obadele, Vijeesh Vijayan, Dundesh S. Chiniwar, Pawan Kumar, and Vishwanatha HM. "Evaluation of mechanical and thermal properties of polypropylene-based nanocomposites reinforced with silica nanofillers via melt processing followed by injection molding." Journal of Composites Science 7, no. 12 (2023): 520.
2. Ezugwu, Emeka Kingsley. "Enhancing the durability of natural plant fibres in cementitious composites with hydrothermal treatment and application of silica-based coatings." (2023).
3. Jagadeesan, Rantheesh, Indran Suyambulingam, Manivel Selvaraj, Divya Divakaran, K. Kumaresan, N. S. Balaji, Sanjay Mavinkere Rangappa, and Suchart Siengchin. "Comprehensive characterization of novel agro-industrial waste Azadirachta indica A. juss oil cake derived cellulose micro fillers reinforced with basalt/banana fiber based hybrid polymeric composite for lightweight applications." Fibers and Polymers (2025): 1-17.
4. Shunmugasundaram, M., A. Praveen Kumar, M. Ahmed Ali Baig, and Yamini Kasu. "Investigation on the effect of nano fillers on tensile property of neem fiber composite fabricated by vacuum infused molding technique." In IOP Conference Series: Materials Science and Engineering, vol. 1057, no. 1, p. 012019. IOP Publishing, 2021.
5. P. Murugadoss et al. (2025). Study of mechanical, barrier and tribological behaviour of jute & glass fiber epoxy hybrid polymer. SAE Technical Paper Series, 1. 400 Commonwealth Drive, Warrendale, PA, United States: SAE International.
6. Neto, Jorge SS, Henrique FM de Queiroz, Ricardo AA Aguiar, and Mariana D. Banea. "A review on the thermal characterisation of natural and hybrid fiber composites." Polymers 13, no. 24 (2021): 4425.
7. Abid Althaqafi, Khaled, Abdulrahman Alshabib, Julian Satterthwaite, and Nikolaos Silikas. "Properties of a model self-healing microcapsule-based dental composite reinforced with silica nanoparticles." Journal of functional biomaterials 13, no. 1 (2022): 19.
8. V.V. Upadhyay et al. Trapezoidal fin featured heat exchanger performance enriched by using alumina/GNP hybrid nanofluid: thermal characteristics study. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-025-13997-0>
9. A. Sharma et al. Hybrid Reinforcement Actions on Microstructural, Physical and Mechanical Properties of Magnesium Alloy Composite by Two-Step Stir Casting Process. Inter Metalcast (2025). <https://doi.org/10.1007/s40962-024-01537-9>
10. M. Aruna et al. Vacuum Die Casting Process and Microstructure/Mechanical Characteristics Study of Magnesium Alloy Composite Hybridize with Zirconium Dioxide and Silicon Nitride. Inter Metalcast (2025). <https://doi.org/10.1007/s40962-025-01550-6>
11. Manzoore Elahi M. Soudagar, et al. Enrichment of Solar Heat Exchanger Thermal Performance by the Integration of Beeswax and Hybrid Nanofluid (ZnO/MgO). ASME. J. Thermal Sci. Eng. Appl. (2025) <https://doi.org/10.1115/1.4067929>
12. Ali, H. M., Mothilal, T., & Reddy, V. (2024). Evaluation of Lightweight Cotton Textiles for Durable and Comfortable Automotive Interior Applications (No. 2024-01-5015). SAE Technical Paper. DOI: https://doi.org/10.4271/2024-01-5015
13. Kelagadiet al., (2024). An Analysis on the Integration of Machine Learning and Advanced Imaging Technologies for Predicting the Liver Cancer. In 2024 4th International Conference on Pervasive Computing and Social Networking (ICPCSN) (pp. 1082-1086). IEEE. <https://doi.org/10.1109/ICPCSN62568.2024.00180>
14. Singh et al., (2024). Enhancing Mobile Robot Speed Control: PID Controller Optimization with Bio-Inspired Algorithms. In 2024 International Conference on Expert Clouds and Applications (ICOECA) (pp. 365-370). IEEE. https://doi.org/10.1109/ICOECA62351.2024.00071
15. Rafi et al., (2024). Improving Prostate Cancer Diagnosis with Weakly Supervised Learning and Radiology-Confirmed Negative MRI Data. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1183-1188). IEEE. https://doi.org/10.1109/ICICT60155.2024.10544551
16. Padhyet al., (2024). Enhancing IoT-Enabled Healthcare with Genetic-based Encryption and Authentication for Secure and Efficient wireless Data Transmission. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1873-1878). IEEE. https://doi.org/10.1109/ICICT60155.2024.10544722
17. Anitha, Cuddapah, Naveena Kumar RR, Swapnil Uttamrao Deokar, Harshal Shah, and Praful V. Nandankar. Optimal Scheduling of Microgrid with Electric Vehicle Integration in Smart Grid using Progressive Graph Convolutional Network. In 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), pp. 375-380. IEEE, 2025.
18. Socrates, S., Bharathi, G. B., &Aluvala, S. (2024). A Framework for Automated Diagnosis and Management of Autoimmune Disorders with Neural Networks. In 2024 International Conference on Advancements in Smart, Secure and Intelligent Computing (ASSIC) (pp. 1-6). IEEE. https://doi.org/[10.1109/ASSIC60049.2024.10507903](https://doi.org/10.1109/ASSIC60049.2024.10507903)
19. Saadh M J et al., (2024). Recent progress and the emerging role of lncRNAs in cancer drug resistance; focusing on signaling pathways. Pathology-Research and Practice, 253, 154999. <https://doi.org/10.1016/j.prp.2023.154999>
20. Lakshmaiya, N. (2024). High ionic permeability of Piper ION membrane boosts efficiency in CO2 electrolysis cells. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 172-180). SPIE. <https://doi.org/10.1117/12.3030841>
21. R, Rajarajan et al. (2025). Improving Tribological Performance and Structural Analysis of Aluminium Hybrid Nanocomposites with Nano ZrO2/SiC Reinforcement via Stir Casting Assisted with Ultrasonic Vibration. International Journal of Cast Metals Research, February, 1–14. <https://doi.org/10.1080/13640461.2025.2467611>
22. P. K. Singh et al. Enhancement of silicon nitride layer performance by Gallium–Copper–Zinc tri-layer thin films structure via plasma featured chemical vapour deposition route. J Mater Sci: Mater Electron 36, 243 (2025). <https://doi.org/10.1007/s10854-025-14326-9>
23. N. Nagabhooshanam et al. Influences of Potassium Fluoride and Ultrasonic Vibration on Functional Performance of AZ91 Alloy Hybrid Nanocomposite with Nano-SiC/TiO2. Inter Metalcast (2025). <https://doi.org/10.1007/s40962-025-01552-4>
24. I. Hossain et al. (2025). Enriching performance of Al-Mg composites by incorporating nano-alumina and SiC via semi-solid stir processing. International Journal of Cast Metals Research, 1–11. <https://doi.org/10.1080/13640461.2025.2476826>
25. V. Mohanavel et al. Tribological characteristics and optimization of ZrB2 configured magnesium alloy composite via squeeze casting technique. J Mech Sci Technol. 39(5), 2025. <https://doi.org/10.1007/s12206-025-0425-9>
26. Manzoore Elahi M. Soudagar, Ravindra Pratap Singh, Nagabhooshanam Nagarajan. et al. Featuring of in-situ carbon capturing and functional performance study of hydrogen from aquaculture wastewater algae biomass via supercritical steam gasification route, Chemical Engineering Science 313 (2025) 121704. <https://doi.org/10.1016/j.ces.2025.121704>
27. P. K. Singh et al. Integration of phase change material for enriching the solar collector featured with dryer configuration enhanced via alumina/titanium dioxide nanoparticle: performance study. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-025-14302-9>
28. A. Sharma et al. Structural Modification and Enhancement of Optoelectronic Behaviour of ZnO Nanofilms Featuring Cu and Ti Particles. J. Electron. Mater. (2025). <https://doi.org/10.1007/s11664-025-11951-2>
29. N. Nagarajan et al. Hybrid Stir Cast Featured with Wettability Agent and Ultrasonic Action of Magnesium Alloy Composite Composed with Nanofiller: Study Characteristics. Inter Metalcast (2025). <https://doi.org/10.1007/s40962-025-01603-w>
30. N. Nagarajan. et al. Thermal performance assessment of dish collector-integrated cooking application using TiO2/SiO2 hybrid nano-enhanced coated receiver. J Braz. Soc. Mech. Sci. Eng. 47, 148 (2025). <https://doi.org/10.1007/s40430-025-05454-8>
31. Soudagar, M. Manzoore Elahi et al. Effect of electron transport layer thickness and characteristics behaviour of hybrid copper indium gallium selenide thin film solar cells, Journal of Power Sources (2025). Volume 639, 2025,236657, <https://doi.org/10.1016/j.jpowsour.2025.236657>
32. M. Aruna et al. Integration of Magnesium Fluoride and Nano Alumina–Silicon Carbide Actions on Properties of AZ91 Alloy Hybrid Nanocomposites. Inter Metalcast (2025). <https://doi.org/10.1007/s40962-025-01617-4>
33. P. Sharma et al. Effect of paraffin with salt hydrates PCM and hybrid Al2O3/Tio2 nanofluid on thermal and energy storage characteristics of solar thermal heat exchanger. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-025-14224-6>
34. Manzoore Elahi M. Soudagar et al. Higher performance solar air dryer functioned with palmitic acid phase change material and hybrid nanofluid: Thermal performance evaluation, Applied Thermal Engineering (2025). Volume 272, 2025,126413, <https://doi.org/10.1016/j.applthermaleng.2025.126413>
35. Kalam, S. A., Sheela, S., Paramasivam, P., & Shanmugam, K. (2024). Bio-synthesis of nano-zero-valent iron using barberry leaf extract: classification and utilization in the processing of methylene blue-polluted water. Discover Applied Sciences, 6(12), 1-15. https://doi.org/10.1007/s42452-024-06327-w
36. Lakshmaiya, N. (2024). Detection and impact of stochastic anomalies in investigations of urban pollution. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 269-277). SPIE. <https://doi.org/10.1117/12.3030839>
37. Agrawal et al., (2024). Deep Learning Methods for Detecting ImageBased Defects in Manufacturing Processes. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568644
38. Lakshmaiya, N. (2024). Influence of small non-capillary washing activity on flow boiling essential heat transfer. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 224-231). SPIE.  https://doi.org/10.1117/12.3030838
39. Chakrapani et al., (2024). Optimizing sample length for fault diagnosis of clutch systems using deep learning and vibration analysis. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 09544089241272791. https://doi.org/10.1177/095440892412727
40. Deepthi et al., (2024). Deep Learning-Enabled Human Resource Analytics in Predicting Employee Performance. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). EEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568716
41. Selvan et al., (2024). Investigation of the Use of Renewable Energy in Microgrid Applications. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE . https://doi.org/10.1109/ICONSTEM60960.2024.10568631
42. Vinodh, D et al., (2024). Experimental investigation on tensile strength of novel metal matrix composite of aluminium alloy 5083 with SiC and eggshell powder reinforcement. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 297-306). SPIE.  https://doi.org/10.1117/12.3030843
43. Kaushal et al., (2024). Evaluation of Deep Learning Approaches for Air Quality Analysis using an Image Dataset. In 2024 Second International Conference on Intelligent Cyber Physical Systems and Internet of Things (ICoICI) (pp. 1378-1383). IEEE. https://doi.org/[10.1109/ICoICI62503.2024.10696429](https://doi.org/10.1109/ICoICI62503.2024.10696429)
44. Babu et al., (2024). Enhancing Security with Machine Learning-based Finger-Vein Biometric Authentication System. In 2024 5th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI)(pp. 797-802). IEEE. https://doi.org/[10.1109/ICMCSI61536.2024.00123](https://doi.org/10.1109/ICMCSI61536.2024.00123)
45. Ahmad et al., (2024). IoT-Enabled Smart E-Healthcare System with Predictive Prescription Algorithm for Automatic Patient Monitoring and Treatment. In 2024 4th International Conference on Pervasive Computing and Social Networking (ICPCSN) (pp. 1076-1081). IEEE. https://doi.org/[10.1109/ICPCSN62568.2024.00179](https://doi.org/10.1109/ICPCSN62568.2024.00179)
46. Jothi Arunachalam et al. Integration of nanographene and action of fiber sequences on functional behaviour of composite laminates" International Polymer Processing, 2025. <https://doi.org/10.1515/ipp-2024-0149>
47. P. P. Singh et al. Hybrid Thin Film Coating Performance and Functional Characteristics of Silicon Nitride (SiNx) Layer for Solar Cell Application. J. Electron. Mater. (2025). <https://doi.org/10.1007/s11664-025-11888-6>
48. Murali, J. G., Marimuthu, S., Vignesh, P., Prakash, P., Kaliyannan, G. V., & Karthikeyan, S. (2025). Influences of silicon carbide particles on tensile performance and hardness behavior of polyethylene composites made via injection mold. In *AIP Conference Proceedings* (Vol. 3267, No. 1, p. 020292). AIP Publishing LLC.
49. Marimuthu, S., Ashokkumar, R., Karthick, S., Karthikeyan, A., Karthikeyan, S., & Gunasekaran, R. (2025). Synthetic fiber featured epoxy composite for light weight application: Performance measures. In *AIP Conference Proceedings* (Vol. 3267, No. 1, p. 020293). AIP Publishing LLC.
50. Karthikeyan, S., Ganesan, S., Suresh, A., Muruganandhan, P., Jebasingh, B. E., & Manogar, K. (2025). Impact of E glass fiber on functional properties of low density polyethylene composite made via compression mold. In *AIP Conference Proceedings* (Vol. 3267, No. 1, p. 020243). AIP Publishing LLC.