Effect of Nano Alumina Loading on Functional Properties of Polypropylene Composites Made With Flax Fiber

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Abstract: Overcome drawback of adhesion and mechanical strength instead of using the polypropylene matrix and for recycling reasons. The flax fiber is used for strength and durability of various applications the current investigation on polypropylene composite composition of NaoH-treated flax fiber and Alumina nanoparticles by using injection molding by adding  10wt% Flax fiber with NaOH treated along with 0, 2.5, 5, and 7.5wt% Alumina Nanoparticles to enhancing behavior of mechanical strength the testing and evaluation of such as tensile strength of the composite, yield strength, flexural strength, Impact strength and SEM the PP matrix. the composite sample A1 does not add filler similarly composite sample A4 is  15wt% of flax fiber and 7.5wt%  of alumina nanoparticles due to improved bonding strength between matrix and fiber, increasing alumina filler up to 7.5wt% results show that maximum tensile strength and yield strength is 51.9 MPa and 43.5MPa correspondingly flexural strength, and Impact strength is 55MPa and 17.6J/mm2composite sample M4 is suitable for automotive application.

# Introduction

Enhancing polymer composite and thermal analysis of a flax fiber reinforced with phenol-formaldehyde resin hybridization with ramie fiber by using vacuum infusion process three stages of weight loss (%) by using thermo gravimetric analysis (TGA) max temperature at 6300c to increase thermal conductivity [1-4]. surface treatment of epoxy hybrid nano composites with the addition of two fillers such as Alumina and magnesia with particle size 50nm in weight proportion composite laminates were formed using the vacuum bagging technique to achieve better results of mechanical strength[5-9]. recycled textile waste and polypropylene non-woven fabrics further reinforced with short hemp fibers test standardized specimens by using injection molding To improve the quality of fiber and interaction of the reinforcing fibers with the recycled polymeric matrix [10-12].  use of recycled multi-materials from the treatment of multilayer packaging used in the food industry NS short fiber composites reinforced with flax fibers, up to 30 wt.% degradation temperatures higher than 3000C. reduce poor mechanical strength and stiffness [13-15] composing nano alumina and groundnut shell particles with volume percentages of 95:0:5, 95:2.5:2.5 and 95:5:0 of HDPE matrix. Specimens were tested as per standard to evaluate the compressive, shore hardness, and water intake characteristics of the composites to improve the quality of the Composite [16-18]. Flax fiber is most preferable in textiles for improving strength other than properties flax processing waste was used as reinforcement for polypropylene (PP) composites and separated into fibrous and non-fibrous fiber to improve the surface interaction and adhesion between reinforcement and matrix [19-20]. By using Nano-silica and nano-alumina at 0, 1%, and 2%, and with polypropylene fiber various ranges such as 0, 0.5%, and 1% were used in the production of Alkali-Activated Mortar tested compressive strength and flexural strength The addition of above two nanomaterials improved the mechanical properties and chemical resistance of composite [21-23] prepare photo luminescent nonwoven polypropylene fabrics by plasma-assisted screen-printing with earth doped strontium aluminates nano particles both of ultraviolet protection and antibacterial activity of the phosphor-printed nonwoven polypropylene fabrics are considered [8]. Reinforcement of flax fiber with biodegradable green composites based on poly lactic acid and polybutylene succinate matrix 10, 15, and 20% by weight addition of flax fibers from 4.4% to 1.9%  of the polymer matrix to achieve better strength and quality [9]. Surface modification using thin films onto flax fibers through plasma enhanced chemical vapor deposition and tetramethyl cyclone trisiloxane Mechanical tests of the PLA/flax fiber composites gradually improved in load transfer and interfacial bonding strength [24-26]. Thermoplastics matrix-based composites flax, recycled carbon fiber, polypropylene, and recycled PET via compression molding to improve flexural properties [27]. Hybrid composites consider two different natural fibers under the same matrix material other than synthetic fibers placing the filler materials (nano particles) in the composite materials to analyze mechanical strength and impact strength [28]. Compose ZnO and flax of epoxy resin matrix chopped form of fiber curing 900c at 7 hours to improve adhesive and bonding between matrix and fiber [29-32]. Basalt fiber-reinforced epoxy composites without nano-alumina composites containing 0.5, 1, 3, and 5 wt.% testing SEM after tensile and flexural tests adding 1 wt.% of nano alumina to improve tensile and flexural properties [33-35].

The present study developed NaOH-treated flax fiber with Alumina nano particles to overcome the drawback of quality and interracial bonding between matrices. To enrich polypropylene composite by addition of 15wt% flax fiber with alumina nano particles varies 0, 2.5, 5, and 7.5wt% via injection molding setup.

# Materials and Methods

Polypropylene consists of mechanical strength and greater stiffness  [1] polypropylene matrix is chosen for this study and is widely used in various engineering applications. Hence flax fiber is considered fiber material and Alumina nano particles (50nm) are taken as filler material for this study. Before the fabrication process, adding the 15wt% flax fiber NaOH treated at 5wt% of Polypropylene composite with no added filler to increase its adhesive behavior of composite Alumina nano particles marginally improved impact and mechanical strength reason are selected as 0, 2.5, 5, and 7.5wt% as filler material [36-38].

The polypropylene matrix adding 5wt% NaOH treated flax fiber compose and Alumina nano particles filler via injection molding setup. it consists of the control unit, hopper, Plunger, Die, and hydraulic assisted motor unit. Flax fiber is mixed with 15 wt% of the chopped form (3-5mm) of PP matrix and Alumina nano particles in various ranges of 0-7.5wt% blended by using a blending machine with 120 rpm stirrer speed With the aid of a control unit to monitor temperature difference from 20 to 230⁰C preheated at 110⁰C make composite sample 250mm x 200mm x 25mm mat for behavior study [39-45]. Load applied between upper plate to lower plate of the injection molding machine.

Testing of the composite samples with the help of a universal testing machine, evaluates the tensile strength, yield strength, flexural strength, Impact strength, and SEM followed by ASTM E8, ASTM D368, ASTM D790, and ASTM D6110 respectively [46-48].

# Results and Discussion

The polypropylene composite sample contains four sets of samples. The yield strength of composite sample 1 adding with the composition of 15wt% of flax fiber NaOH treated with no added filler reading noted that 32.1 MPa as shown in Fig 1. Corresponding the composite sample 2 by adding 2.5wt% of Alumina nanoparticles with 15wt% of flax fiber with NaOH treated 5wt% of yield strength of composite observed 32.6 MPa The increasing value of  Alumina nanoparticles 5wt% and 7.5wt% with 15wt% of flax fiber with NaOH treated 5wt% yield strength of composite sample 3&4  is noted 38.1 and 43.5 MParespectively.

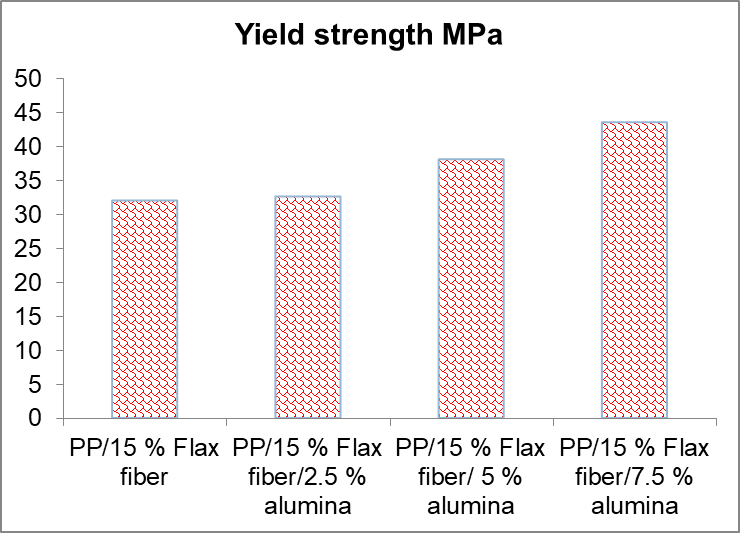


Fig. 1 Yield strength of composites

Alumina nanoparticles are used for increasing the yield strength of composite samples and the bonding strength of the matrix The polypropylene matrix of composite sample 4  is improved by 35.5% related to composite sample  1

The 5wt% of NaOH treated flax fiber along with alumina nanoparticles of polypropylene matrix tensile strength of composite as shown in Figure 2 It consisting sample 1-4 of composite samples of polypropylene matrix. Tensile strength Composite sample 1 is considered 15wt% of flax fiber 5wt% of NaOH treated without filler noted that  39.5 MPa  similarly tensile strength of composite sample 2 is adding with 2.5wt% of Alumina  nanoparticles with 15wt% of flax fiber note down the value of tensile strength is 43.1 MPa  the tensile strength of  sample 3 & 4 is Marginally increasing weight percentage range from 5wt% and 7.5wt% of Alumina nanoparticles  and 15wt% of flax fiber with NaOH treated at 5wt% observed the value of  composite sample is 45.6 and 51.9 MPa when compared 1 composite sample increasing tensile strength up to 31.5 % of 4 sample [47-50].

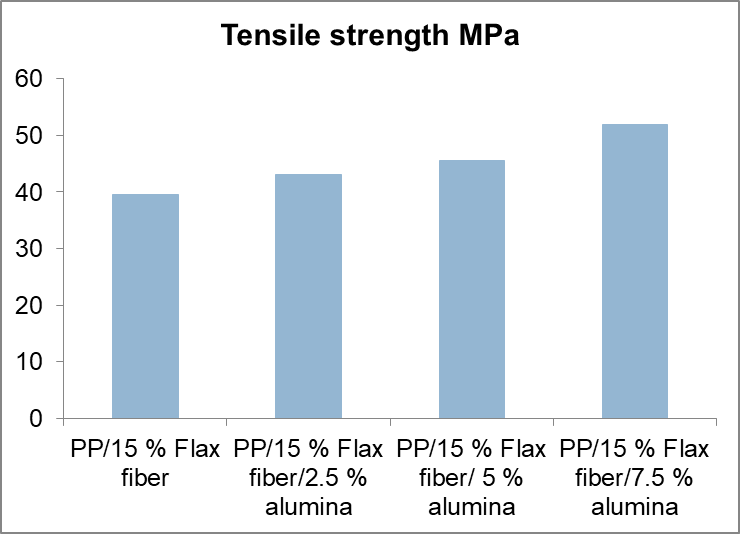


Fig. 2 Tensile strength of composites

Figure 3 shows the flexural strength of a composite sample of polypropylene matrix. Adding 15wt% of flax fiber with NaOH treated 5wt% bonded Alumina nano particles of varied weight percentages. The Polypropylene composite sample of flexural strength 1 is noted by 42.1MPa due to 15wt% of flax fiber NaOH treated at 5wt% without filler. The addition of 15wt% of flax fiber NaOH treated at 5wt% with 2.5wt% of Alumina nano particles of composite sample 2 is obtained in flexural strength 44.8 MPa, similarly, the flexural strength of composite sample 3 is 49.4MPa due to adding filler 5wt% of Alumina nano particles with 15wt% of flax fiber NaOH treated. The  composite sample 4 is noted at 55 MPa composing 7.5wt% of Alumina nano particles 15wt% of flax fiber NaOH treated the composite sample 4 is increased by 30.6% in flexural strength as compared to composite sample A1 without filler

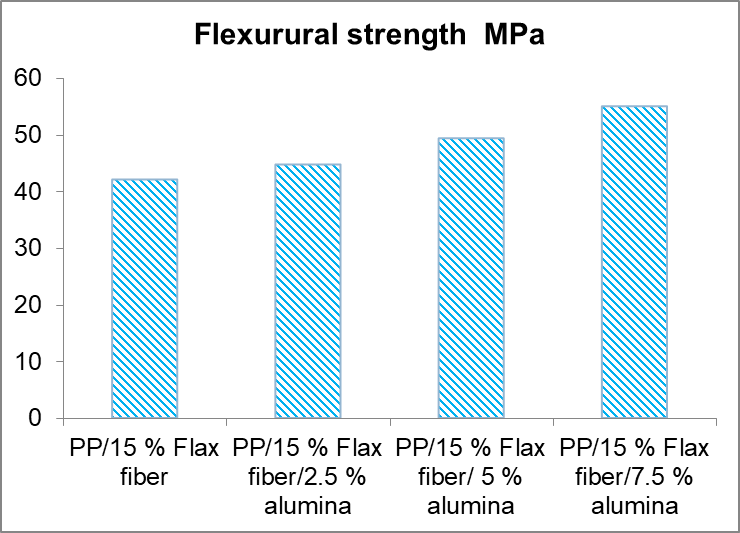


Fig.3 Flexural strength of composites

Adding 15wt% of flax fiber with NaOH treated 5wt% bonded Alumina nanoparticles of varied weight percentages. As shown in Fig 4. The Polypropylene composite sample of impact strength 1 is observed by 7.8J/mm2 prepare 15wt% of flax fiber NaOH treated at 5wt% without filler. The composing of 15wt% of flax fiber NaOH treated at 5wt% with 2.5wt% of Alumina nanoparticles of composite sample 2 is obtained in impact strength 14.5J/mm2, similarly, the impact strength of composite sample 3 is 16.4J/mm2 by adding filler 5wt% of Alumina nanoparticles with 15wt% of flax fiber NaoH treated. The composite sample 4 is noted at 17.6J/mm2.composing 7.5wt% of Alumina nano particles and 15wt% of flax fiber NaOH treated the composite sample A4 is increased by 125% in impact toughness as compared to composite sample A1 without filler

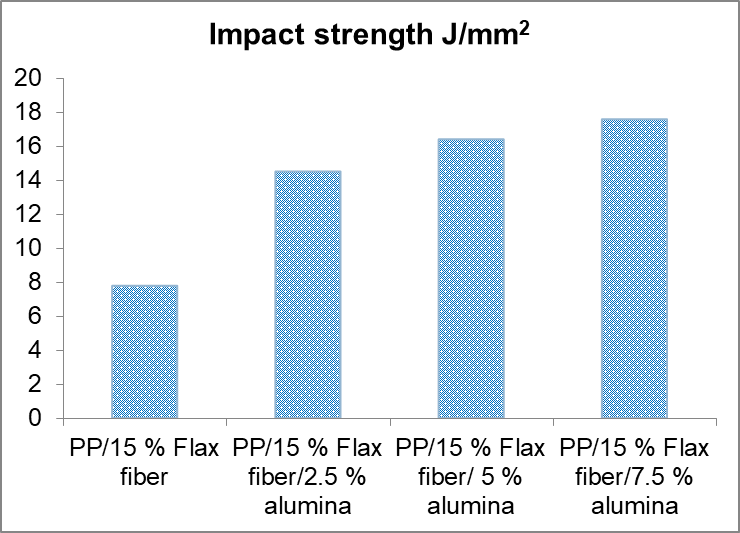
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Fig.4 Impact strength of composites

# Conclusion

With characteristics of polypropylene, composites are influenced by 15wt% flax fiber with NaOH treated at 5wt% bonded varies of 0, 2.5, 5, and 7.5wt% of Alumina nanoparticles by using injection molding setup. Testing and analysis of tensile strength, Yield strength, flexural strength, Impact strength, and SEM on the mechanical behavior of composites were studied via ASTM standard and results are summarized below. The composition sample 1 prepared 15wt% flax fiber NaOH treated at 5wt%  without added filler similar A4 composite sample since the fiber value is constant only increasing 7.5wt% of Alumina nanoparticles commonly using this composite combination used. According to outcome results, the sample 4 tensile, flexural, and impact toughness was enhanced by 31.5, 30.5, and 125 % better than the sample 1.

# References

1. Durvasulu Rajesh et al. Enhancement of Thermal Behaviour of Flax with a Ramie Fibre-Reinforced Polymer Composite, Polymers 2023, 15, 350. https://doi.org/10.3390/polym15020350.
2. Adnan Amjad et al. Effect of Fibre Surface Treatment and Nano Filler Addition on the Mechanical Properties of Flax/PLA Fibre Reinforced Epoxy Hybrid Nanocomposite, Polymers 2021, 13, 3842. https://doi.org/10.3390/polym13213842.
3. M. Krishnaraj et al. (2019). Fabrication and Wear Characteristics Basalt Fiber Reinforced Polypropylene Matrix Composites. In SAE Technical Papers. SAE International. <https://doi.org/10.4271/2019-28-2570>
4. Francisco Burgada et al. Upgrading Recycled Polypropylene from Textile Wastes in Wood Plastic Composites with Short Hemp Fiber, Polymers 2021, 13, 1248. https://doi.org/10.3390/polym13081248 https://www.mdpi.com/journal/polymers
5. Irene Bavasso et al. Recycled Multi-Material Packaging Reinforced with Flax Fibres: Thermal and Mechanical Behaviour, Polymers 2022, 14, 4423. https://doi.org/10.3390/polym14204423
6. R. Girimurugan et al. An experimental study on compressive properties of high-density polyethylene-nano alumina-groundnut shell hybrid composites, Materials Today: Proceedings, V68,(6) 2022
7. Meshram et al., (2024). Investigation of Mechanical and Thermal Properties of Bamboo Fiber Reinforced with Epoxidized Soybean Oil for Automotive Seat Bases (No. 2024-01-5009). SAE Technical Paper. <https://doi.org/10.4271/2024-01-5009>
8. Munirathnam, Rajesh, Rohit P. Jadhav, Nilesh M. Mahajan, Amit Barve, and ME Shashi Kumar. Electric Vehicle Charging Demand Prediction using Multiresolution Sinusoidal Neural Network Optimized with Addax Optimization. In 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), pp. 604-609. IEEE, 2025.
9. Supriya et al., (2024). Securing loT Systems with AI-Infused Software and Virtual Replica Models. In 2024 International Conference on Integrated Intelligence and Communication Systems (ICIICS) (pp. 1-6). IEEE. https://doi.org/10.1109/ICIICS63763.2024.10860178
10. Jain, Akshay, et al. Conversion of water hyacinth biomass to biofuel with TiO2 nanoparticle blending: Exergy and statistical analysis. Case Studies in Thermal Engineering 67 (2025): 105771.
11. Chaudhary et al., (2024). AI-Driven Digital Mirror Technology for Securing IoT-Enabled Smart Infrastructures. In 2024 International Conference on Integrated Intelligence and Communication Systems (ICIICS) (pp. 01-08). IEEE. https://doi.org/10.1109/ICIICS63763.2024.10859436
12. Nikaljeet al., (2024). Detecting Cancer through Analysis of Histopathological Images. In 2024 International Conference on Expert Clouds and Applications (ICOECA) (pp. 579-585). IEEE. https://doi.org/10.1109/ICOECA62351.2024.00107
13. R.K. Singh et al. Exposure of Cu on microstructural and functional performance of Cadmium telluride solar cell. Opt Quant Electron 57, 112 (2025). <https://doi.org/10.1007/s11082-024-08027-6>
14. Lakshmaiya, N. (2024). Perovskite photovoltaic cells with freezone zone carbon-based instruments: state of review. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 351-358). SPIE. <https://doi.org/10.1117/12.3030837>
15. Almatrafiet al., (2024). Reducing metastasis ability of gastric cancer cell line by targeting MMP16 using miR-193a-5p and 5-FU. Advances in Medical Sciences, 69(2), 463-473. <https://doi.org/10.1016/j.advms.2024.09.008>
16. V. Mohanvel et al. Ferric oxide nanofluid on functional properties of parabolic trough solar collector under different flow rate, Applied Thermal Engineering (2025). Volume 265, 2025,125608, <https://doi.org/10.1016/j.applthermaleng.2025.125608R>.
17. R.P. Singh et al. Alumina-silicon dioxide hybrid nanofluid action on functional characteristics of photovoltaic thermal collector featured with spiral coil. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-024-13973-0>
18. Udhayakumar et al., (2025). Multi-functional natural fiber composites using flaxseed and cotton: tailoring acoustic, mechanical, and thermal properties for eco-friendly applications. Discover Applied Sciences, 7(8), 906.
19. Singh et al. Natural fiber-ceramic filler configured polypropylene hybrid composite made via hot compression technique: Characteristics evaluation. J Mech Sci Technol. 39(1), 2025. <https://doi.org/10.1007/s12206-024-1216-4>
20. R. Venkatesh Fabrication and Functional Behavior Studies of Polypropylene Composite Containing Hybrid Reinforcements, SAE Int. J. Mater. Manf. 18(2), 2025, <https://doi.org/10.4271/05-18-02-0015>.
21. G. Deepana et al. (2025). Synthesis and machining characteristics study of agro-waste coconut shell powder incorporated aluminium alloy composite via the squeeze cast technique. International Journal of Cast Metals Research, 1–11. <https://doi.org/10.1080/13640461.2024.2447101>
22. K. Logesh et al. Injection mould processing and characteristics measures of hybrid epoxy composites with jute fiber/boron nitride. J Mech Sci Technol. 39(1), 2025. <https://doi.org/10.1007/s12206-024-1219-1>
23. S. Prabagaran et al. Texturing of silicon nitride passivation layers on functional behaviour study of polycrystalline silicon (p-Si) made with plasma enhanced chemical vapour deposition. J Mater Sci: Mater Electron 36, 73 (2025). <https://doi.org/10.1007/s10854-024-14135-6>
24. Venkatesh, R., "Synthesis and Machining Characteristics Evaluation of Silicon Nitride Made Magnesium Alloy Composites," SAE Int. J. Mater. Manf. 18(3), 2025, <https://doi.org/10.4271/05-18-03-0017>.
25. Melvin Victor De Poures et al., Processing and Characteristics Study of Hydrogen from Sewage and Waste Municipal Water via Gasification Process" SAE Technical Paper 2024-01-5257, 2024, <https://doi.org/10.4271/2024-01-5257>
26. Ravindra Pratap Singh et al. Enhancement and thermal performance evaluation of parabolic trough solar collector with the integration of innovative snail porous material. ASME. J. Thermal Sci. Eng. Appl. (2025) 1-23. <https://doi.org/10.1115/1.4067588>
27. Vinodh et al., (2024). Experimental analysis on surface hardness of AA5083 with SiC/eggshell powder reinforced novel metal matrix composite. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 368-377). SPIE. <https://doi.org/10.1117/12.3030842>
28. M.E.M. Soudagar et al. Integration and heat performance evaluation of NaNO3–KNO3 PCM and hybrid nanofluid configured solar thermal heat exchanger. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-024-13970-3>
29. Lakshmaiya, N. (2024). Short review of partial flow dilution systems for very low PM mass measurements. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 359-367). SPIE. https://doi.org/10.1117/12.3030836
30. Kumar et al., (2024). Cognitive Digital Twin Systems for Predictive Security in AI-Enhanced IoT Environments. In 2024 First International Conference on Software, Systems and Information Technology (SSITCON) (pp. 1-6). IEEE. https://doi.org/10.1109/SSITCON62437.2024.10796449
31. Neelakandan Aagashram et al., Computational design exploration of rocket nozzle using deep reinforcement learning. Results in Engineering 25 (2025): 104439.
32. Prasad et al., (2024). Deep Learning based Channel Assignment with Load Balancing in MANET for Improved Performance. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1172-1177). IEEE. https://doi.org/10.1109/ICICT60155.2024.10544447
33. Melvin Victor De Poures et al. Effect of Gasification Temperature on Biohydrogen Derived from Waste Agro Products for Alternative Fuel Application " SAE Technical Paper 2024-01-5260, 2024, <https://doi.org/10.4271/2024-01-5260>
34. Alamanda et al., (2024). Machine Learning-Based Fault Diagnosis for Rotating Machinery in Industrial Settings. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568891
35. Aslam et al., (2024). Smart Multiphase Power Converter in the Fault-Tolerant Machine Development for Aerospace Applications. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568598
36. Selvi et al., (2024). Transfer Learning Approaches for Improved Thyroid Detection. In 2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC) (pp. 1311-1317). IEEE. <https://doi.org/10.1109/ICESC60852.2024.10689771>
37. Baruah et al., (2024). Artificial Intelligence Influence on Leadership Styles in Human Resource Management for Employee Engagement. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568819
38. Saadh et al., (2024). Natural killer cell-mediated immune surveillance in cancer: Role of tumor microenvironment. Pathology-Research and Practice, 254, 155120. <https://doi.org/10.1016/j.prp.2024.155120>
39. Logesh, K., Vinayagam, M., Kumar, A., Chaturvedi, R., Prabagaran, S., Soudagar, M. E. M., Salmen, S. H., and Al Obaid, S. (2025). "Solar collector featured dryer performance enriched by the adaptations of phase change material embedded with fin collector absorber." ASME. J. Thermal Sci. Eng. Appl. doi: <https://doi.org/10.1115/1.4067631>
40. Mohan et al., (2024). Image Quality Enhancement using Deep Convolutional Network. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1272-1277). IEEE. https://doi.org/10.1109/ICICT60155.2024.10544980
41. R. Venkatesh Effects of ramie fiber/boron nitride exposure on the mechanical characteristics of injection-moulded polypropylene composites for automated structural applications. International Journal of Automotive Science and Technology. 2024; 8 (4): 451-456. <http://dx.doi.org/10.29228/ijastech..1528281>
42. V. Mohanavel et al. Investigation of Al/Mg composite behaviour by the adaptation of SiC and Al2O3 nanoparticle via electromagnetic stir cast route. Materials Science and Technology. 2025;0(0). doi:10.1177/02670836241306686
43. R.P. Singh et al. Influence of a Copper Layer on the Functional Behaviour of a Cadmium Telluride Solar Cell Processed via Thermal Evaporation. J. Electron. Mater. (2024). <https://doi.org/10.1007/s11664-024-11669-7>
44. Melvin Victor De Poures et al. Influences of Zinc Oxide Doping on Functional Characteristics Study of Thin Film Solar Cell for Hybrid Solar Electric Vehicle Utilization" SAE Technical Paper 2024-01-5256, 2024, <https://doi.org/10.4271/2024-01-5256>
45. Venkatesh, R., Chaturvedi, R., Umamaheswari, D. et al. Featuring of Fiber-Ceramic Combination on Behavior Studies of High Density Polyethylene Composite: Hot Compression Mould. Mech Compos Mater (2025). <https://doi.org/10.1007/s11029-025-10305-7>
46. R. Venkatasubramanian et al. Thermal characteristics and dryer performance analysis of double pass solar collector powered by copper and iron oxide. J. Thermal Sci. Eng. Appl. (2025) 1-20. <https://doi.org/10.1115/1.4067258>
47. Saravanakumar, A., Murali, J. G., Kuila, A., Karthikeyan, S., Ganesan, S., & Gowrishankar, A. (2025). Biodegradable bast fiber made polypropylene composite via hot compression: Characteristics study. In AIP Conference Proceedings (Vol. 3267, No. 1, p. 020291). AIP Publishing LLC.
48. Saravanan, N., Karthikeyan, S., Marimuthu, S., Murali, J. G., Prasath, M., & Gowrishankar, A. (2025). Effect of surface treatment on characteristics of bast fiber incorporated polyethylene composite: Behavior study. In AIP Conference Proceedings (Vol. 3267, No. 1, p. 020295). AIP Publishing LLC.
49. Muthugounder, P., Kumar, R. D., Ganesan, S., Gowrishankar, A., Karthikeyan, S., & Jebasingh, B. E. (2025). Featuring of boron nitride on high density polyethylene/sisal fiber composite: Characteristics evaluation. In AIP Conference Proceedings (Vol. 3267, No. 1, p. 020246). AIP Publishing LLC.
50. Karthikeyan, S., Manivannan, S., Venkatesh, R., Karthikeyan, S., Kuila, A., & Lakshmanan, S. (2024). Impact of binder selection on functional properties of polymer nanocomposite featured with metal oxide nanoparticle. Journal of Environmental Nanotechnology, 13(3), 262–270.