Effect and Contribution of Aluminium Nitride on Tribo-Mechanical Behaviour of Aluminium Alloy (Al6061) Composites

S Vinoth Kumar1, S Baskaran2, R Ashok kumar3, G Sankaraiah 4, M Saravanan 5, Jonnala Subba Reddy6, Gobikrishnan Udhayakumar7, S Karthikeyan8,a), Mohanavel Vinayagam9

1Department of Mechanical Engineering, Vel Tech Multi Tech Dr.RangarajanDr.Sakunthala Engineering College, Avadi, Chennai, 600062, Tamil Nadu, India.

2Department of Mechatronics Engineering, Rathinam Technical Campus, Coimbatore, 641021, Tamil Nadu, India.

3Department of Safety and fire Engineering, K.S.R College of Engineering, Tiruchengode637215, Tamil Nadu, India.

4 Department of Mechanical Engineering, G.Pulla Reddy Engineering College, Kurnool, 518007, Andhrapradesh, India

5Department of Electrical and Electronics Engineering, Holymary Institute of Technology and Science, Bogaram, 501301, Telangana, India.

6Department of Mechanical Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Andhra Pradesh, 521230, India

7Department of Mechanical Engineering, Sona College of Technology, Salem, 636005, Tamil Nadu, India.

8 Department of Mechanical Engineering, Erode Sengunthar Engineering College, Thuduppathi, 638057, Tamil Nadu, India.

9 Centre for Sustainable Materials Research, Department of Mechanical Engineering, Academy of Maritime Education and Training (AMET) Deemed to be University,Kanathur, Chennai 603112, Tamil Nadu, India.

**Corresponding author:** a)[karthiksamynathan@gmail.com](mailto:karthiksamynathan@gmail.com)

Abstract: This work examines how the mechanical and tribological performance of Al6061 aluminum alloy composites made via powder metallurgy is affected by nanoscale aluminum nitride reinforcements and were tested for Vickers hardness, wear rate and coefficient of friction under a range of typical loads after AlN nanoparticles were added at weight percentages of 3, 6 and 9. Because of the increased load-bearing capacity and decreased matrix deformation the results showed a constant improvement in surface hardness and wear resistance as the AlN content increased. These results support AlN-reinforced Al6061 potential for high performance automotive braking systems, where longevity and frictional stability are crucial.

# Introduction

Aluminium alloy Al6061 is extensively used in structural and automotive applications due to its good strength-to-weight ratio, corrosion resistance, and formability. However, its tribological properties are insufficient for high-friction environments like brake disc systems [1-3]. Incorporating ceramic nanoparticles like aluminium nitride (AlN), known for its high thermal conductivity and mechanical strength, can improve these functional characteristics. It is known that certain reinforcing methods can make aluminum-based nanocomposites work much better in terms of tribological and mechanical performance [4-8]. Al/nano and Mg/AlN composites made using liquid metallurgy. They found that the hardness and wear resistance of the material improved a lot and verified these benefits by showing that adding nano-AlN to aluminum reduced wear loss in dry environments [9]. It say that using FSP to add hybrid boron nitride and vanadium carbide to AA6061 made it much harder, wore down faster, and made the structure more consistent [10-12]. They stressed that the right processing pathways are critical for making the right tribological features, especially when dry sliding is involved [13-14]. Research [15] found that adding particles made things last longer and could hold more weight and they used Taguchi analysis to find the best values for the parameters of ceramic-reinforced AA6061 composites. It looked explored hybrid self lubricating aluminum composites. Their results revealed that the composites were less likely to wear out and that the friction coefficients stayed the same [16-20]. At Al–Si–N coated steel and discovered that it was better at resisting corrosion and dry sliding wear. This discovery shows how useful it could be on protective surfaces [21-25] and reviewed the literature and described how several types of reinforcement, such as graphene, carbon nanotubes and ceramics affect the mechanical and tribological properties of aluminum alloys [26-30]. Aluminum-silicon composites for use in brake rotors and focused on how the composites wear down and how stable they are when they are under stress from braking [31-33]. An overview of the pros and cons of employing nanoceramic-reinforced aluminum in engineering applications, focusing on its wear resistance and mechanical strength [34-36]. Researcher [37-39] found that FSW joints made of AA6061/AlN composites were better at bonding and resisting wear than those that weren't reinforced and researchers looked at adding nano hexagonal boron nitride to aluminum alloys and found that these additions made the surface much harder and the area of wear much larger [40-43]. By creating a hybrid aluminum nanocomposite that wears down flawlessly, demonstrated how helpful synergistic reinforcement approaches may be in the future [44-45]. The researchers [46] studied composites constructed of AA6061–Si₃N₄ and discovered that these composites consistently increased their mechanical strength and lowered their wear. After focusing their attention on the densification of Al–SiC powder compacts, the researchers Moazami-Goudarzi and Akhlaghi [15] made the discovery that the incorporation of nanoparticles leads to an increase in density as well as improved consolidation. The production of Al/MWCNT nanocomposites was accomplished through the utilization of powder metallurgy method [47-49] and In order to achieve the best possible results in terms of the nanocomposites' resistance to wear they employed a design of experiment technique. At the dual effect that ZnO nanorods and Y2O2 nanoparticles have on aluminum. The researchers arrived at the conclusion that the combined reinforcement significantly improved the microstructure of the material, in addition to increasing its tensile strength and hardness [50-53]. This research investigates how different AlN concentrations influence tribo-mechanical behavior using powder metallurgy processing.

# Materials and Methods

## Materials

Due to the balanced mechanical strength, corrosion resistance and thermal stability of Al6061 alloy powder with an average particle size of around 50 μm was used as the matrix material with a mean size of 30 nm aluminum nitride nanoparticles as the reinforcing phase for their higher hardness, high heat conductivity and chemical compatibility with aluminum. The powder metallurgy process guarantees improved particle dispersion and refined microstructures was used to create the composite specimens. To create a homogenous mixture the Al6061 and AlN particles were first mechanically combined to create green compacts with sufficient mechanical integrity and then cold compaction was carried out at a uniaxial pressure of 400 MPa. Then the compacts were sintered in an inert argon environment at 580°C to improve particle bonding, decrease porosity and stop oxidation. For achieving homogeneous dispersion of nanoparticles in the aluminum matrix and minimize thermal degradation, this process is good.

## Composite Formulations

**TABLE 1.** Composite Configurations Table

|  |  |
| --- | --- |
| **Sample ID** | **Composition** |
| Sample 1 | Al6061 (Unreinforced) |
| Sample 2 | Al6061 + 3 wt% AlN |
| Sample 3 | Al6061 + 6 wt% AlN |
| Sample 4 | Al6061 + 9 wt% AlN |

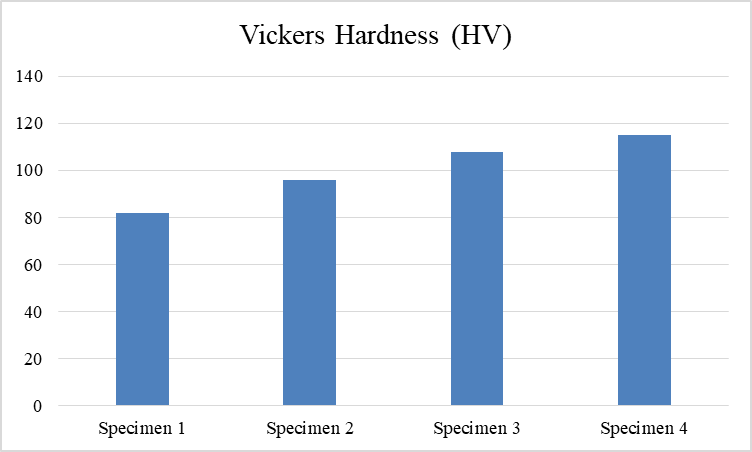
# Results and Discussion

## Microhardness

The incorporation of nano AlN particles resulted in a significant increase in the microhardness of Al6061 composites. This increase was driven by the increased load-bearing capability of the ceramic phase and the dislocation hindrance that ceramic phase provides. It can be observed in Table 2 that the Vickers hardness increased gradually from 82 HV (unreinforced) to 115 HV at 9 wt% AlN demonstrating the reinforcing impact that AlN has in terms of preventing surface deformation.

**TABLE 2**Microhardness

|  |  |
| --- | --- |
| Specimen | Vickers Hardness (HV) |
| Specimen 1 | 82 |
| Specimen 2 | 96 |
| Specimen 3 | 108 |
| Specimen 4 | 115 |



**Figure 1.** Microhardness

## Wear Rate

Table 3 summarizes the findings of an evaluation of the wear performance of Al6061with AlN composites under typical loads of 10 N, 30 N and 50 N. When AlN reinforcement increased there is steady decrease in wear rate that shows the use of ceramic nanoparticles in preventing material loss.

Under all load circumstances, Specimen 4 (9 weight % AlN) showed the least amount of wear but the unreinforced Al6061 showed the highest rates. The main causes of this improvement are the nano AlN particles' enhanced surface hardness, better load distribution and barrier effect preventing adhesive and abrasive wear mechanisms. The wear rate of AlN reinforced composites remained noticeably lower even under high loads (50 N) suggesting greater tribological endurance. These results confirm that AlN nanoparticles are efficient wear-resistant reinforcements, which makes the composites perfect for high load, friction intensive applications like aerospace parts and car brake systems.

**TABLE 3.** Compressive Strength

|  |  |  |  |
| --- | --- | --- | --- |
| **Specimen** | **Wear Rate (mm³/N·m) @10N** | **@30N** | **@50N** |
| Specimen 1 | 5.3 × 10⁻⁴ | 7.9 × 10⁻⁴ | 1.15 × 10⁻³ |
| Specimen 2 | 4.1 × 10⁻⁴ | 6.6 × 10⁻⁴ | 9.2 × 10⁻⁴ |
| Specimen 3 | 3.5 × 10⁻⁴ | 5.3 × 10⁻⁴ | 7.8 × 10⁻⁴ |
| Specimen 4 | 2.8 × 10⁻⁴ | 4.6 × 10⁻⁴ | 6.9 × 10⁻⁴ |

## Coefficient of Friction (COF)

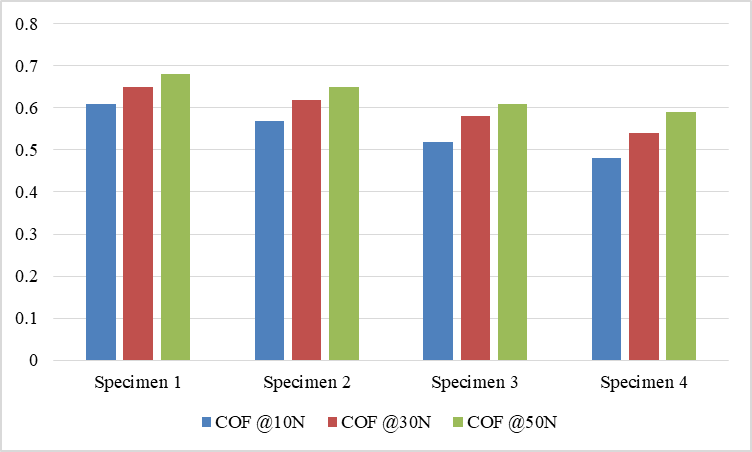
Table 4 showed that the coefficient of friction reduced when the AlN concentration increased, no matter what loads were applied and it shows that adding AlN nanoparticles to the Al6061 matrix is good for tribology.

AlN's natural lubricating capabilities and its ability to make a protective tribolayer when sliding are the main reasons in reduction of COF and to cut down on adhesive wear and surface plowing the nanoparticles do a good job of filling up micro asperities, lowering metal to metal contact and spreading out contact stress more evenly.

Specimen 4 was reinforced with 9 weight % AlN showed better interfacial stability and less wear under high stress conditions. It also exhibited the lowest COF values across all test loads and these results show that AlN can do two things: make things smoother and more resistant to wear. This means that the composite could be useful in applications where friction is important, such sliding parts, disc brakes, and airplane parts.

**TABLE 4.** Wear Resistance

|  |  |  |  |
| --- | --- | --- | --- |
| **Specimen** | **COF @10N** | **COF @30N** | **COF @50N** |
| Specimen 1 | 0.61 | 0.65 | 0.68 |
| Specimen 2 | 0.57 | 0.62 | 0.65 |
| Specimen 3 | 0.52 | 0.58 | 0.61 |
| Specimen 4 | 0.48 | 0.54 | 0.59 |



**Figure 3.**Wear Resistance

# Application in Brake Disc Systems

Brake disc systems require materials that can withstand high temperatures and contact stress exhibit consistent frictional behavior and rapidly dissipate heat. These requirements are satisfied by the Al6061/AlN composites that were created. In comparison to the unreinforced alloy, specimen 4 (9 weight % AlN) demonstrated a ~46% reduction in wear rate and a ~20% reduction in coefficient of friction under a 50 N load.

The ceramic reinforcement can hold more weight, has a harder surface, and helps make a thermally stable and low friction tribolayer. These are the reasons for the improvements. Because of this the composite has steady braking performance with a longer service life and less thermal fatigue making it a great choice for lightweight, high performance brake systems in cars, motorcycles and motorsports.

# Conclusion

Powder metallurgy is an effective method for incorporating nano sized aluminum nitride into the matrix of the Al6061 alloy. This has resulted in an increase in the composite hardness, wear resistance and frictional stability. Specimen 4 contained nine weight % of aluminum nitrogen was found to be the most effective arrangement that resulted in the most balanced improvement across all of the tribological and mechanical characteristics that were examined.

These findings demonstrate that Al6061/AlN nanocomposites are potentially useful materials for the next generation of brake disc systems and these nanocomposites offer a mix of durability, thermal resilience and minimal maintenance requirements in situations that are demanding in terms of their operational requirements.

# References

1. Srinivasan, D., M. Meignanamoorthy, Amel Gacem, Mohanavel Vinayagam, Thanakodi Sathish, M. Ravichandran, Suresh Kumar Srinivasan, Magda H. Abdellattif, and Haiter Lenin Allasi. "Tribological behavior of Al/Nanomagnesium/Aluminum nitride composite synthesized through liquid metallurgy technique." Journal of Nanomaterials 2022, no. 1 (2022): 7840939.
2. Rizwi, Md Imran, Durbadal Mandal, and Bijay Kumar Show. "Development of Wear Resistant Aluminum Based Nano-Composite Reinforced With Nano-AlN." Journal of Tribology 145, no. 2 (2023): 021702.
3. Milyani, Ahmad H., Ahmed O. Mosleh, and Essam B. Moustafa. "Effect of Hybrid Addition of Boron Nitride and Vanadium Carbide on Microstructure, Tribological, and Mechanical Properties of the AA6061 Al-Based Composites Fabricated by FSP." Journal of Composites Science 8, no. 12 (2024): 500.
4. Akilan, T., and M. Mahendiran. "and Tribological Characteristics." Advances in Materials Processing and Manufacturing Applications: Proceedings of iCADMA 2020 (2021): 113.
5. Yadav, Ramkumar, Anoj Meena, Seul-Yi Lee, and Soo-Jin Park. "Experimental tribological and mechanical behavior of aluminium alloy 6061 composites incorporated ceramic particulates using Taguchi analysis." Tribology International 192 (2024): 109243.
6. Srivyas, Pranav Dev, and M. S. Charoo. "Tribological behavior of hybrid aluminum self-lubricating composites under dry sliding conditions at elevated temperature." Tribology-Materials, Surfaces & Interfaces 16, no. 2 (2022): 153-167.
7. Bose, A., K. Singh, P. Dubey, and S. K. Mishra. "Study of dry sliding wear and corrosion behavior of nanocomposite Al-Si-N coated steel." Surface and Coatings Technology 441 (2022): 128543.
8. Singh, Ranveer, and Ashok Kumar. "A literature survey on effect of various types of reinforcement particles on the mechanical and tribological properties of aluminium alloy matrix hybrid nano composite." Materials Today: Proceedings 56 (2022): 200-208.
9. T.T.M. Kannan et al. (2020). Effect of silicon carbide and silicon carbide/alumina reinforced aluminum alloy (AA6061) metal matrix composite. In Materials Today: Proceedings (Vol. 45, pp. 7147–7150). Elsevier Ltd. https://doi.org/10.1016/j.matpr.2021.02.143
10. Kumar, PK Dinesh, and S. Darius Gnanaraj. "Aluminium-silicon based metal matrix composites for brake rotor applications: a review." Engineering Research Express 5, no. 2 (2023): 022002.
11. Ogbonna, Victor Ekene, Patricia Popoola, and Olawale Popoola. "Mechanical and tribological properties of nanoceramic reinforced aluminium-based nanocomposites for engineering applications, challenges and recommendations for future improvement: A review." Journal of Composite Materials 58, no. 28 (2024): 2993-3025.
12. Kumar, B. Ashok, I. Dinaharan, and N. Murugan. "Microstructural, mechanical and wear properties of friction stir welded AA6061/AlNp composite joints." Journal of Materials Engineering and Performance 31, no. 1 (2022): 651-666.
13. 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
14. 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
15. V. Mohanavel et al. Exploration of photovoltaic thermal collector performance enhancement by the accumulations of hybrid nanofluid and phase change material. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-025-14427-x>
16. A. Sharma et al. Featuring of Formamidinium lead halide and enrichment of optoelectronic behaviour of SnO2/FAPbI3/NiOx with PCBM layer. J Mater Sci: Mater Electron 36, 1124 (2025). <https://doi.org/10.1007/s10854-025-15203-1>
17. M.E.M. Soudagar et al. Exploration and thermal characteristics analysis of hybrid TiO2/SiO2 nanofluids passing through heavy-duty automotive radiators for intensive cooling system. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-025-14305-6>
18. Niveditha, V. R., Nadh, V. S., Srinivas, C., Dhanraj, J. A., & Saravanan, A. (2024). Application of response surface and artificial neural network optimization approaches for exploring methylene blue adsorption using luffa fiber treated with sodium chlorite. Journal of Water Process Engineering, 58, 104778.<https://doi.org/10.1016/j.jwpe.2024.104778>
19. Anita et al., (2024). Energy Trading and Optimum Scheduling for Microgrids Using Multiple Agents Based DL Approach. Electric Power Components and Systems, 1-19. <https://doi.org/10.1080/15325008.2023.2300329>
20. Chhaparwal et al., (2024). Numerical and experimental investigation of a solar air heater duct with circular detached ribs to improve its efficiency. Case Studies in Thermal Engineering, 60, 104780. <https://doi.org/10.1016/j.csite.2024.104780>
21. Rajendran et al., (2024). Development of Intelligent Power Quality Management in Renewable Energy System in Smart Grid using Deep Learning. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1178-1182). IEEE. <https://doi.org/10.1109/ICICT60155.2024.10544835>
22. Tuluwengjiang et al., (2024). Dendritic cell-derived exosomes (Dex): Underlying the role of exosomes derived from diverse DC subtypes in cancer pathogenesis. Pathology-Research and Practice, 254, 155097. <https://doi.org/10.1016/j.prp.2024.155097>
23. Senthilkumar et al., (2024). Maximizing Power Utilization through Machine Learning and IoT based Power Flow Strategies in DC Micro Grids with Renewable Energy Resources. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1166-1171). IEEE.  https://doi.org/10.1109/ICICT60155.2024.10544791
24. Kamal, M. R., Manivannan, K. K., & Sunil, G. (2024, January). Machine Learning and Data Mining Approaches for Infectious Disease Surveillance and Outbreak Management in Healthcare. In 2024 International Conference on Advancements in Smart, Secure and Intelligent Computing (ASSIC) (pp. 1-7). IEEE. <https://doi.org/10.1109/ASSIC60049.2024.10507990>
25. Raskar, Sandeep, Gulshan Dhasmana, M. Lakshminarayana, and Harshal Patil. Enhancing Energy Efficiency in Wireless Sensor Networks using Deep Learning. In 2025 International Conference on Multi-Agent Systems for Collaborative Intelligence (ICMSCI), pp. 1515-1520. IEEE, 2025.
26. Chaturvedi, Abhay, S. Suhas, JL Divya Shivani, Ch Raja, Umang Soni. Enhancing IoT Network Security: A Double Decker Convolutional Neural Network with Brown-Bear Optimization for Intrusion Detection. In 2025 International Conference on Inventive Computation Technologies (ICICT), pp. 1903-1908. IEEE, 2025.
27. Murthy, HS Niranjana, Shirish Kulkarni, Syed Mohd Uzair Iqbal, and Umang Pancha. Enhancing Video Captioning: A Bayesian Normalized Attention-based Multi-Dimensional Graph Network with Moss Growth Optimization. In 2025 5th International Conference on Pervasive Computing and Social Networking (ICPCSN), pp. 1688-1694. IEEE, 2025.
28. 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>
29. 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>
30. 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>
31. 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>
32. S. Ravi et al. Processing and SiC content on functional behaviour of aluminium alloy composite. J Mech Sci Technol (2025). <https://doi.org/10.1007/s12206-025-0723-2>
33. A. Sharma et al. Semisolid stir casting and effect of hybrid fillers on functional properties of aluminium alloy composites. J Mech Sci Technol (2025). <https://doi.org/10.1007/s12206-025-0620-8>
34. V. V. Upadhyay et al. Hexachloroethane fluxing mechanism and actions of hybrid fillers on functional behaviour of AZ31B alloy composites. J Mech Sci Technol (2025). <https://doi.org/10.1007/s12206-025-0622-6>
35. N. Basavegowda et al. Influence of Silver Nanowire Concentration on Electrical and Optical Properties of Polyaniline for Transparent Conductive Sensors. J. Electron. Mater. (2025). <https://doi.org/10.1007/s11664-025-12174-1>
36. Kaushal et al., (2024). Fault prediction and awareness for power distribution in grid connected res using hybrid machine learning. Electric Power Components and Systems, 1-22. <https://doi.org/10.1080/15325008.2024.2337217>
37. Natarajan, Gobu, et al. Influence of heat treated Manihot Esculenta Biosilica on friction stir welded AA 6065-Al2O3 metal matrix composite and microstructural, mechanical, and fatigue analysis. Materials Research 28 (2025): e20240473.
38. Sreethar et al., (2024). Implementation of cross layer design with localization techniques in wireless sensor networks using deep learning. In 2024 International Conference on Expert Clouds and Applications (ICOECA) (pp. 607-613). IEEE.<https://doi.org/10.1109/ICOECA62351.2024.00111>
39. Kaushal et al,. (2024). Navigating Independence: The Smart Walking Stick for the Visually Impaired. In 2024 5th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI) (pp. 103-108). IEEE. https://doi.org/10.1109/ICMCSI61536.2024.00022
40. 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>
41. 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>
42. 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>
43. 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>.
44. M. A. Babu et al. Effect of Surfactants and Hybrid Filler on Microstructural and Mechanical Properties of Al7075/TiC/Graphene Alloy Composite via Additive Manufacturing. J. of Materi Eng and Perform (2025). <https://doi.org/10.1007/s11665-025-11873-4>
45. V. Rathinavelu et al. Optimal performance of poly-hybrid nanocomposites promoted with carbon fibers and nano silicon carbide particles via compression associated with hot pressing: characterization study. International Polymer Processing, 2025. <https://doi.org/10.1515/ipp-2024-0152>
46. K. K. Ilavenil et al. Enrichment of monolithic aluminium alloy characteristics by nano ceramic: Solid state process. J Mech Sci Technol (2025). <https://doi.org/10.1007/s12206-025-0513-x>
47. Kaliappan S et al., (2024). Impact of Kenaf Fiber and Inorganic Nanofillers on Mechanical Properties of Epoxy-Based Nanocomposites for Sustainable Automotive Applications (No. 2023-01-5115). SAE Technical Paper.<https://doi.org/10.4271/2023-01-5115>
48. Yuvaraj, K. P., Reddy, V. K., & Ali, H. M. (2024). Evaluating the Wear and Mechanical Properties of Cotton Fabrics for Women’s Summer Clothing. Engineering Proceedings, 61(1), 15. <https://doi.org/10.3390/engproc2024061015>
49. Masannan et al., (2024). Experimental investigation on the drilling characteristics of kenaf/PLA-based laminates. Engineering Proceedings, 61(1), 9. <https://doi.org/10.3390/engproc2024061009>
50. Kumar et al., (2024). Optimized forecasting approach for scheduling wind generation plants and maximizing renewable energy utilization. Electric Power Components and Systems, 1-17. <https://doi.org/10.1080/15325008.2024.2337218>
51. Kaliappan et al., (2024). Thermal and Mechanical Properties of Abutilon indicum Fiber-Based Polyester Composites under Alkali Treatment for Automotive Sector (No. 2024-01-5031). SAE Technical Paper.<https://doi.org/10.4271/2024-01-5031>
52. Parashar et al., (2024). Time series analysis and random forest techniques for prediction of sales for retail grocery. In 2024 IEEE International Conference on Computing, Power and Communication Technologies (IC2PCT) (Vol. 5, pp. 531-535). IEEE. <https://doi.org/10.1109/IC2PCT60090.2024.10486802>
53. Manivannan, S., Venkatesh, R., Kaliyaperumal, G., Karthikeyan, S., Mohanavel, V., Soudagar, M. E. M., & Karthikeyan, N. (2024). Magnesium alloy hybrid composite properties are featured with boron carbide particle for automotive seat frame usage (SAE Technical Paper).