Hybrid Reinforcements and Processing Actions on Mechanical and Wear Behaviour of Magnesium Alloy Composites: Stir Cast Route

S Vinoth Kumar1, M Jegadeeswaran2, S Karthikeyan3,a), S Surrya Prakash DilliBabu4, S Dineshkumar5, S Kalaiarasan6, B N Deepak Kumar7,A Thanikasalam8, Manzoore Elahi M. Soudagar9

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

2 Department of Agricultural Engineering, Rathinam Technical Campus, Coimbatore Tamilnadu 641021, India.

3Department of Mechanical Engineering, Erode Sengunthar Engineering College, Thuduppathi, 638057, Tamil Nadu, India.

4Department of Mechanical Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai,600062, Tamil Nadu, India

5Department of Civil Engineering, K.S.R College of Engineering, Tiruchengode, 637215, Tamil Nadu, India.

6 Department of Chemistry, Sona College of Technology, Salem, 636005, Tamil Nadu, India.

7Department of Mechanical Engineering, Dayananda Sagar Academy of Technology and Management, Bengaluru, 560082, Karnataka, India.

8Department of Marine Engineering Academy of Maritime Education and Training (AMET) Deemed to be University 135, East Coast Road, Kanathur, Chennai – 603112, India.

9Department of Mechanical Engineering and University Centre for Research & Development, Chandigarh University, Mohali-140413, Punjab, India

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

**Abstract:** The combined impacts of squeeze stir casting and hybrid nanoparticle reinforcements on the mechanical and tribological performance of composites made of magnesium alloy AZ31 are thoroughly investigated in this work. Five different composite formulations were created by including boron nitride and titanium diboride at specified weight fractions. To guarantee better matrix integrity and particle dispersion the squeeze stir casting method was used. Microhardness, wear rate and coefficient of friction were all thoroughly evaluated under varying loading scenarios (10, 30 and 50 N). The findings showed that hybrid reinforcement significantly improved hardness and wear resistance, especially at the ideal TiB₂ BN ratios. The improvement is ascribed to the even dispersion of hard TiB₂ particles and the solid lubricating action of BN both of which lessen friction and material removal during sliding. These results demonstrate that these hybrid nanocomposites are appropriate for high performance tribological applications particularly in lightweight brake disc systems where heat stability and longevity are crucial.

# Introduction

Because of its well-known low density, high specific strength and superior machinability, the magnesium alloy AZ31 is a desirable option for lightweight structural applications. However its intrinsic low hardness and poor wear resistance severely restrict its use in high load, high friction situations, especially in automotive and aerospace parts where tribological stability is crucial including clutches and brake systems [1-4].

The use of nanoparticle reinforcements has become a practical way to get around these problems. Boron nitride has a high thermal conductivity, low friction and chemical inertness which makes it ideal for lowering wear and dissipating heat in sliding contact situations [5-9].

Recent developments in hybrid composites based on magnesium and aluminium have demonstrated that new processing techniques and targeted reinforcement can significantly improve the mechanical, tribological and corrosion qualities. Friction stir processing of AZ31 magnesium alloy with particle reinforcements improved wear behavior and corrosion resistance [10-12]. They provided analysis of hybrid magnesium matrix composites emphasizing the ways in which processing and reinforcement choice impact mechanical and tribological results [13-15]. Researches [16-19] worked on stir cast Al7050 hybrid composites they saw improved hardness and resistance to dry sliding wear, which they attributed to efficient particle-matrix bonding.

A key component of improving properties has been the application of ceramic nanoparticles. SiC nanoparticles in AZ31 resulted in grain refinement and strength increases [20-23]. TiC reinforced AZ31, which was produced using FSP and optimized using Response Surface Methodology was the subject of Researches [24-26] study. and demonstrated exceptional wear resistance because of its well-structured surface and refined microstructure. In a different study, Khatkar [6] emphasized the significance of customized reinforcement techniques for hybrid magnesium composites. The effects of reinforcement on magnesium based composites was presented [27] found that appropriate dispersion and interface bonding consistently improved mechanical and wear behavior.

AZ31/TiB₂ composites were created by Venugopal and Mannayee [8] using ultrasonic assisted squeeze casting and they reported increases in mechanical strength and porosity control as a result of improved wetting and dispersion. Blue dual phase zirconia ceramics were created [28] and have exceptional mechanical qualities. Their reinforcement processes can also be applied to the creation of hybrid composites. Chourasiya and Krishna [10] evaluated Al composites supplemented with TiO₂ and BN in an aluminum based investigation showing exceptional dry sliding wear resistance because of the complementary effects of the hard and lubricating phases.

Using the Taguchi approach, Researches [29-30] reduced wear in a range of loads and speeds by optimizing the friction and wear behavior of AZ31 and SiC/graphite hybrid composites Researches [31-32] emphasized the volume percentage and kind of reinforcement have a major impact on the tribo mechanical balance of magnesium composites.Ammisetti and Kruthiventi [13] used machine learning and discovered that data driven methods improve the forecasting of performance trends under various circumstances.

Using stir casting, Agrawal and Srivastava [14] created Al/Zn/Mg alloy composites reinforced with Si₃N₄ and TiB₂ and reported enhanced wear resistance and increased tensile strength as a consequence of the dense matrix-reinforcement contacts and Researches [33] investigated the impact of TiB₂/graphite reinforcement in Al7075 and employed RSM to optimize wear parameters. Novel method for creating high performance Al composites that greatly improve hardness and surface quality by combining micro TiO₂ with friction stir processing and Grey Taguchi optimization [34-39]. This study determines an ideal composite formulation appropriate for high performance, wear resistant lightweight components by means of thorough characterization including microhardness and wear testing under varied loads.

# Materials and Methods

## Base Alloy and Reinforcements

AZ31 magnesium alloy was selected as the matrix material due to its advantageous strength to weight ratio and simplicity of casting. The reinforcement materials comprised nanoscale titanium diboride and boron nitride each with an average particle size of 50 nm. Before integration the reinforcements were warmed to 250 °C to remove moisture and enhance wettability with the molten matrix [40-42].

## Fabrication Process

The hybrid nanocomposites were produced via the squeeze stir casting technique, which efficiently improves particle dispersion and minimizes porosity by applying external pressure during solidification. The AZ31 alloy was melted in a graphite crucible at a temperature of 720 °C utilizing an electric resistance furnace and as the temperature reached around 630 °C, the warmed TiB₂ and BN nanoparticles were introduced into the molten alloy. To confirm uniform dispersion of the reinforcements mechanical agitation was carried out at 500 rpm for 10 minutes using a stainless and steel impeller. The slurry was then put onto a heated steel die that was kept at 300 °C. In order to enhance matrix densification and reduce casting defects a pressure of 70 MPa was applied during solidification. As shown in Table 1 five different samples with varying reinforcement contents were produced.

**TABLE 1.** Mechanical Composite Formulations Table

|  |  |
| --- | --- |
| **Sample** | **Description** |
| S1 | AZ31 alloy (Unreinforced) |
| S2 | AZ31 + 1 wt% TiB₂ |
| S3 | AZ31 + 1 wt% TiB₂ + 2 wt% BN |
| S4 | AZ31 + 1 wt% TiB₂ + 4 wt% BN |
| S5 | AZ31 + 1 wt% TiB₂ + 6 wt% BN |

## Testing Methods

A Vickers hardness tester was employed to evaluate microhardness using a 100 gram force and a 10 second dwell period. A pin on disc tribometer was used to conduct dry sliding wear tests for tribological investigation trials were carried out under three load settings with a constant sliding velocity of 1 m/s and each composite sample yielded cylindrical pin specimens measuring 10 mm in diameter and 20 mm in height and the coefficient of friction and wear rate (mm³/m) were noted to evaluate wear resistance and frictional behaviour [43-45].

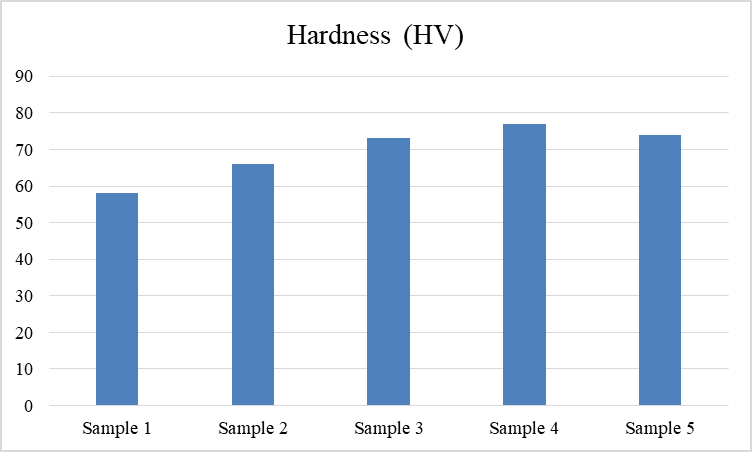
# Results and Discussion

## Microhardness

Adding TiB₂ and BN nanoparticles to the AZ31 alloy significantly enhances microhardness and from Sample 1 to Sample 4 the hardness gradually rose, with Sample 4 having the highest value at 77 HV. This improvement is due to the even distribution of BN a hard secondary phase that resists plastic deformation and TiB₂, which provides structural support. Sample 5's minor drop in hardness raises that too much BN will produce particle agglomeration leading in localized stress zones that restrict efficient load transfer.

**TABLE 2.** Microhardness

|  |  |
| --- | --- |
| **Sample** | Hardness (HV) |
| S1 | 58 |
| S2 | 66 |
| S3 | 73 |
| S4 | 77 |
| S5 | 74 |

  
**Figure 1.** Microhardness

Adding TiB₂ and BN nanoparticles to the AZ31 alloy significantly enhanced its microhardness. From Sample 1 to Sample 4 the hardness gradually increases with Sample 4 having the highest value at 77 HV. This improvement is due to the even distribution of BN, a hard secondary phase that resists plastic deformation and TiB provides structural support. Sample 5's minor drop in hardness raises that too much BN will produce particle agglomeration leading in localized stress zones that restrict efficient load transfer.

## Wear Rate

The addition of hybrid reinforcements significantly increased the wear resistance. Sample 4 consistently showed the lowest wear rate across all applied loads, a result of the synergistic effect of BN's lubricating action and TiB₂'s hardness which reduce material removal and surface degradation. Sample 5's small increase in wear with increased BN content suggests that particle clustering may weaken the tribological contact, resulting in less effective wear protection [46-48].

**TABLE 3.** Wear Rate

|  |  |  |  |
| --- | --- | --- | --- |
| **Sample** | **10 N** | **30 N** | **50 N** |
| S1 | 3.2×10⁻³ | 4.9×10⁻³ | 6.8×10⁻³ |
| S2 | 2.6×10⁻³ | 4.2×10⁻³ | 6.1×10⁻³ |
| S3 | 1.9×10⁻³ | 3.3×10⁻³ | 5.1×10⁻³ |
| S4 | 1.4×10⁻³ | 2.5×10⁻³ | 4.2×10⁻³ |
| S5 | 1.7×10⁻³ | 2.8×10⁻³ | 4.6×10⁻³ |

The baseline tensile strength of the unreinforced AZ91 alloy was 165 MPa. This was increased to 180 MPa by adding 3 weight percent AlO₃ and 2.5-5 weight percent SiC for effective dispersion strengthening and grain refinement. Sample 4 had the maximum strength (204 MPa), indicating that AlO₃ and SiC function well together. However, a little decrease was detected in Sample 5, which could have been caused by localized stress accumulation, insufficient filler dispersion, and particle agglomeration all of which serve as locations for the beginning of cracks under tensile loading [49-50].

## Coefficient of Friction (COF)

When BN was introduced, the coefficient of friction continuously decreased, with Sample 4 showing the greatest reduction. By producing a protective tribofilm at the contact interface, BN's solid lubricating qualities minimized frictional heating and adhesive wear. Sample 5's performance dipped slightly demonstrating that too much BN can impair optimal particle distribution and tribofilm continuity during dynamic loading.

**TABLE 4.** Coefficient of Friction (COF)

|  |  |  |  |
| --- | --- | --- | --- |
| **Sample** | 10 N | 30 N | 50 N |
| S1 | 0.54 | 0.61 | 0.68 |
| S2 | 0.48 | 0.55 | 0.63 |
| S3 | 0.42 | 0.51 | 0.59 |
| S4 | 0.38 | 0.47 | 0.54 |
| S5 | 0.4 | 0.49 | 0.56 |

# Application in Automotive Interior Trims

Materials used in contemporary car braking systems are exposed to strong frictional forces, cyclic stress and high temperatures. There is an urgent need for lightweight materials with improved wear resistance, thermal stability and consistent frictional response. Sample 4 reinforced with 1 weight % TiB₂ and 4 weight % BN and showed the best mechanical and tribological performance among the produced composites. Even under high loads solid lubricating properties and TiB₂'s ceramic reinforcing worked in concert to reduce wear rate and coefficient of friction (COF). With improved durability, heat resistance and operational dependability this hybrid nanocomposite is a viable option for next-generation lightweight brake disc applications due to its reduced COF (0.38), increased hardness (77 HV) and minimal wear (1.4×10⁻³ mm³/N•m).

# Conclusion

The impact of TiB₂ and BN hybrid nanoparticle reinforcements on the mechanical and tribological properties of AZ31 magnesium alloy composites which were squeeze stir cast was methodically assessed in this work with 5 different composites were created and tested with different loads. The composite containing 1 weight % TiB₂ and 4 weight % BN (Sample 4) had the best balance of characteristics among them

* Hardness: 77 HV
* At 10 N stress, the wear rate is 1.4×10⁻³ mm³/N•m.
* Friction coefficient: 0.38

The findings verify that without sacrificing lightweight properties the ideal hybrid reinforcement levels can greatly improve wear resistance and frictional stability. These results establish AZ31/TiB₂/BN hybrid composites as competitive substitutes for traditional materials in automobile brake disc systems especially for lightweight and electric vehicles where durability and material efficiency are crucial.

# References

1. Kumar, Dinesh, Satnam Singh and Surjit Angra. "Effect of reinforcements on mechanical and tribological behavior of magnesium-based composites: a review." Mater. Phys. Mech 50, no. 3 (2022): 439-458.
2. A. A. Alqahtani et al. (2025). Influences of myristic acid and magnetic hybrid nanofluid embedded with heat recovery system latent heat and thermal performance of solar based HVAC. Applied Thermal Engineering, 279(127568), 127568. https://doi.org/10.1016/j.applthermaleng.2025.127568
3. Venugopal, Jayakumar and Giriraj Mannayee. "Enhanced the Microstructure, Mechanical Properties and Porosity Analysis of AZ31/TiB2 Magnesium Alloy Metal Matrix Composite Through Ultrasonic Assisted Squeeze Casting Process." International Journal of Metalcasting (2025): 1-15.
4. Zhao, Hengbin, Yonghe Zhang, Yuwei Ma, Weixiang Shang, Hongxia Li, Gaofei Pan, Fei Ruan, Qingchun Wang andJinxiao Bao. "Design and reinforcement mechanisms of the blue dual-phase zirconia ceramics with excellent mechanical properties." Journal of Alloys and Compounds 1013 (2025): 178560.
5. Chourasiya, Anil and C. M. Krishna. "Dry sliding and mechanical characteristics of aerospace grade aluminium composite reinforced with TiO2/BN particle." Materials Chemistry and Physics 337 (2025): 130577.
6. Veeranjaneyulu, Itha, V. Haripriya, Rajasekaran Saminathan, B. Vishnu Vardhana Naidu, J. Justin Maria Hillary, Adina Srinivasa Vara Prasad, P. Satishkumar, B. Ch Nookaraju and Ram Subbiah. "Friction and wear optimization of SiC/graphite reinforced AZ31 hybrid composite using Taguchi method." International Journal on Interactive Design and Manufacturing (IJIDeM) 18, no. 3 (2024): 1373-1386.
7. Kumar, Dinesh, Satnam Singh and Surjit Angra. "Effect of reinforcements on mechanical and tribological behavior of magnesium-based composites: a review." Mater. Phys. Mech 50, no. 3 (2022): 439-458.
8. Matharu et al., (2024). Developing an AI-Driven Personalization Engine for Real-Time Content Marketing in E-commerce Platforms. In 2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT) (pp. 1-6). IEEE.https://doi.org/10.1109/ICCCNT61001.2024.10725400
9. Ashok et al., (2024). Effect of Stacking Sequence on Mechanical Properties of Bamboo/Bagasse Composite Fiber for Automobile Seat Cushions and Upholstery Application (No. 2024-01-5013). SAE Technical Paper.<https://doi.org/10.4271/2024-01-5013>
10. Malladi et al., (2024). Effectiveness of thermal and mechanical properties of jute fibers under different chemical treatment for automotive interior trim (No. 2024-01-5008). SAE Technical Paper.<https://doi.org/10.4271/2024-01-5008>
11. Anitha, Cuddapah, G. Vipashi Kansal, Swapnil Uttamrao Deokar, Kamal Sutaria, and Ravi Kumar. Bi-Directional Power Control in Grid-Connected Electric Vehicle On-Board Chargers using Spider Wasp Optimization. In 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), pp. 517-522. IEEE, 2025.
12. 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>
13. 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>
14. 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>
15. 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>
16. 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>
17. 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>
18. 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>
19. 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>
20. 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>
21. 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>
22. 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>
23. 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>
24. 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>
25. 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>
26. Karthick, M., Bhaskar, K., Chukka, N. D. K. R. (2025). Development of eco friendly hybrid nanocomposites with improved antibacterial and mechanical properties through NaOH treated natural fibers. Results in Engineering, 104996.
27. Balaji, N., & Mahesh, V. (2024). Dynamic Mechanical and Thermal Properties of Polymer-Coated Jute Fibers for Enhanced Automotive Parts (No. 2024-01-5019). SAE Technical Paper. <https://doi.org/10.4271/2024-01-5019>
28. Surakasi, R., Muthu, G., Paramasivam, P., & Shanmugam, K. (2024). Effectiveness of natural dye adsorption on ILSS and optical properties of bio synthesised TiO2 nano particles and reinforced with flax seed fiber/epoxy based hybrid composites. Discover Applied Sciences, 6(3), 125. <https://doi.org/10.1007/s42452-024-05758-9>
29. 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>
30. Prasad, P. Venkata, and Chrispin Jiji. Spiking Deep Residual Network Optimized Using Pied Kingfisher Optimizer for Renewable Energy Forecasting in Microgrids. In 2025 International Conference on Inventive Computation Technologies (ICICT), pp. 1-7. IEEE, 2025.
31. Mariya Louis et al., Multiresponse optimization and network-based prediction modelling for the WEDM of AM60B biomedical material. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 238(20), 10045-10066. [https://doi.org/10.1177/09544062241264](https://doi.org/10.1177/09544062241264939)
32. Muda et al., (2024). Innovative Blockchain Protocol for Enhancing Transaction Security and Integrity in Decentralized Financial Ecosystems. In 2024 International Conference on Data Science and Network Security (ICDSNS)(pp. 1-6). IEEE. **https://doi.org/10.1109/ICDSNS62112.2024.10691288**
33. Lakshmaiya et al., (2024). Mechanical and thermal characteristics of coir powder-filled epoxy composites for industrial application. Engineering Proceedings, 61(1), 13. <https://doi.org/10.3390/engproc2024061013>
34. Stalin et al., (2024). Innovative cinque rib-roughened stimulators on performance improvement in triangular channel solar air heater. International Journal of Low-Carbon Technologies, 19, 227-235. <https://doi.org/10.1093/ijlct/ctae002>
35. Anand et al., (2024). A comprehensive analysis of small-scale building integrated photovoltaic system for residential buildings: Techno-economic benefits and greenhouse gas mitigation potential. Journal of Building Engineering, 82, 108232. <https://doi.org/10.1016/j.jobe.2023.108232>
36. Mehta et al., (2024). Twisted tape inserts in parabolic trough solar collectors: Assessment of Energy, Exergy, and Environmental impacts. Applied Thermal Engineering, 250, 123566. <https://doi.org/10.1016/j.applthermaleng.2024.123566>
37. Dutt, Sudershan, et al. Emerging EM wave sensors for non-invasive glucose monitoring: review, techniques and developments. Sensors and Actuators Reports 9 (2025): 100282.
38. 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>
39. 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>.
40. 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>
41. 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>
42. 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>.
43. Kaliappan et al., (2024). Polypropylene Composite Materials with Natural Fiber Reinforcement: An Acoustic and Mechanical Analysis for Automotive Implementations (No. 2023-01-5130). SAE Technical Paper. <https://doi.org/10.4271/2023-01-5130>
44. Chaturvedi, Abhay, Mudit Mittal, Swapnil Uttamrao Deokar, Rachit Adhvaryu, and G. Satish. Dual Active Bridge Converter Output Current Ripple Prediction in EV Battery Chargers Through Multimodal Adaptive Spatio-Temporal Graph Neural Network. In 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), pp. 32-37. IEEE, 2025.
45. Seeniappan et al., (2024). Surface Modification of Henequen Fibers with Catalyst for Improving Mechanical and Thermal Properties in Phenolic Composites for Automotive Uses (No. 2024-01-5029). SAE Technical Paper.<https://doi.org/10.4271/2024-01-5029>
46. Al-Safi, JehanKadhim Shareef, Tanusha Mittal, Najmuddin Aamer, and Harshal Patil. Smart Grids: AI-Enabled Energy Management and Demand Forecasting. In 2025 International Conference on Frontier Technologies and Solutions (ICFTS), pp. 1-6. IEEE, 2025.
47. Chaturvedi, Abhay, Mudit Mittal, Swapnil Uttamrao Deokar, Rachit Adhvaryu, and G. Satish. Dual Active Bridge Converter Output Current Ripple Prediction in EV Battery Chargers Through Multimodal Adaptive Spatio-Temporal Graph Neural Network. In 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), pp. 32-37. IEEE, 2025.
48. Pandian et al., (2024). Analyzing the Moisture and Chemical Retention Behavior of Flax Fiber–Ceramic Hybrid Composites for Automotive Underbody Shields (No. 2024-01-5006). SAE Technical Paper.<https://doi.org/10.4271/2024-01-5006>
49. 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).
50. Venkatesh, R., Kaliyaperumal, G., Manivannan, S., Karthikeyan, S., Aravindan, N., Mohanavel, V., Soudagar, M. E. M., & Karthikeyan, N. (2024). Effect of silicon carbide addition and jute fiber surface treatment on functional qualities of low-density polyethylene composites. *SAE Technical Papers*, 2024-01-5238.