Squeeze Casting Process and Hybrid Reinforcements Action on Thermal and Wear Behaviour of Az91 Alloy Composites

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Abstract: Using a squeeze stir casting technique this work investigates the addition of nanoscale molybdenum disulphide and alumina can advance the mechanical and thermal properties of AZ91 magnesium alloy composites. To understand its effect Al₂O₃ (30 nm) was gradually changed from 0 to 15 wt%, while MoS₂ (30 nm) was kept constant at 1 wt%. Vickers microhardness, heat resistance and tensile stress strain behaviour were among the important performance metrics that were the focus of the inquiry. The hybrid composite reinforced with 1 weight % MoS₂ and 10 weight percent Al₂O₃ showed the best balance between strength, hardness and heat resistance among the compositions evaluated. This is explained by the hybrid fillers enhanced load transfer, fine tuned grain structure and heat barrier effects. These findings support the technological feasibility of MoS₂ and Al₂O₃ reinforced AZ91 composites for demanding lightweight structural applications where thermal endurance and mechanical robustness are crucial such as electronics housing, automotive and aerospace.

# Introduction

Magnesium alloys, especially AZ91, are lightweight materials extensively applied in the transport and structural sectors due to their excellent strength-to-weight ratio. Limitations in wear resistance, thermal stability, and ductility restrict their application in high-load or high-temperature conditions. Nano-reinforcement using ceramics such as alumina and solid lubricants like MoS₂ has emerged as a promising strategy to overcome these drawbacks. Recent advances in magnesium matrix composites have focused on hybrid reinforcement strategies to progress the mechanical and tribological properties of the materials [1-2]. It was studied the lubricating characteristics of MoS₂ made AZ91 magnesium alloy harder and more resistant to wear when it was produced by powder metallurgy with AlO₃ and MoS₂ [3-5]. According to [6-9], adding nano sized AlO₃ and MoS₂ reinforcements improved mechanical performance and made the grains finer. It was looked at the design ideas behind tribological hybrid materials as part of the larger field of hybrid material research and showed the importance of reinforcing synergy to make materials that wear well [10-12]. It was made Al–Zn–Mg alloys reinforced with SiC and BN and found that Strong bonding at the interface made the material much harder and stronger in tension [13-15]. Hybrid Al composites that were created using GFRA and had MoS₂ and AlO₃ added to them and found that these composites had low friction coefficients and high dry slide wear resistance [16] and gave a thorough evaluation of stir cast AZ91D hybrid composites and showed the process management affects the final attributes of the composite [17]. It was found that AZ91 reinforced with MoS₂ improves in tribological efficiency and mechanical strength when tested with different loads and speeds [18] and looked into how hybrid fillers affected AZ61 nanocomposites and found that dual phase reinforcements made them stronger and more stable at high temperatures made them work better [19]. the tribological role of MoS₂ particles in magnesium composites and found that MoS₂ works as a good solid lubricant reducing wear and friction while keeping the structure intact [20-22]. Eleectroless Ni–P-coated Al₂O₃ reinforcements in recycled Al alloys and found that the uniform distribution of particles made them more resistant to wear and made them stronger [23-25]. Which was confirmed their earlier research on AZ91D/AlO₃/SiC composites by adopting friction stir processing to change the microstructure and tribological performance [26-28]. How carbon fibers and multi walled carbon nanotubes worked together to make Mg AZ91D nanocomposites stronger and more resistant to wear, they found that they made a big difference [29]. Self lubricating MMCs from a sustainability point of view and showed that hybridization is necessary for long term durability and environmental compatibility [30-32].

In this study, the squeeze stir casting technique was employed to synthesize AZ91-based composites with varying alumina content while maintaining MoS₂ at a constant level. The synergy between MoS₂ and Al₂O₃ aimed to improve tribological and thermal properties, enabling the composites' application in structural systems where weight, wear, and thermal endurance are critical.

# Materials and Methods

## Materials

Due to its advantageous strength to weight rati, the commercially available magnesium alloy AZ91 was selected as the matrix. As reinforcements, nanoparticles of alumina and molybdenum disulphide with an average size of around 30 nm were employed. Both nanopowders were warmed to 200°C before inclusion in order to remove surface moisture and enhance wettability. To improve reinforcement incorporation, the AZ91 alloy was heated and then partially cooled to a semi solid condition (around 600°C). To ensure even dispersion the nano reinforcements were added gradually while being mechanically stirred for ten minutes at 500 rpm. To ensure dense and flawless solidification the resultant composite slurry was subsequently squeeze cast into steel moulds that had been heated to 75 MPa [33-35].

Five composite formulations were created by keeping MoS₂ at 1 weight % and differing only in the amount of AlO₃. A methodical assessment of the effects of hybrid nano reinforcements is made possible by the presentation of the particular compositions in Table 1.

## Composite Formulations

**TABLE 1.** Mechanical Composite Formulations Table

|  |  |
| --- | --- |
| **Sample ID** | **Composition** |
| Sample 1 | AZ91 (Unreinforced) |
| Sample 2 | AZ91 + 1 wt% MoS₂ |
| Sample 3 | AZ91 + 1 wt% MoS₂ + 5 wt% Al₂O₃ |
| Sample 4 | AZ91 + 1 wt% MoS₂ + 10 wt% Al₂O₃ |
| Sample 5 | AZ91 + 1 wt% MoS₂ + 15 wt% Al₂O₃ |

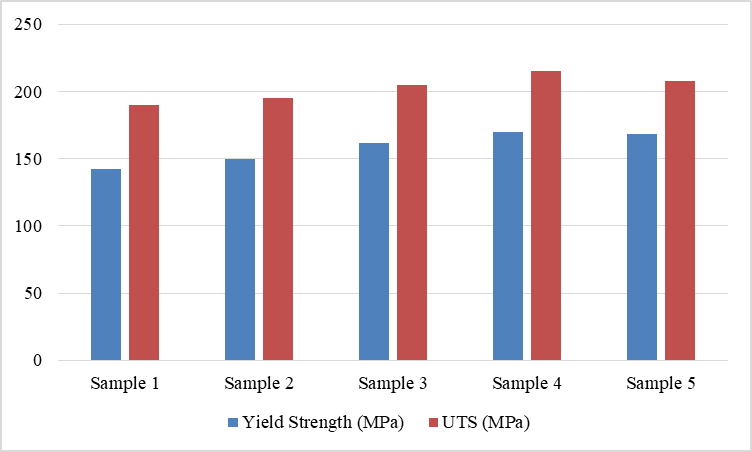
# Results and Discussion

## Tensile Stress-Strain Behaviour

Mechanical performance was significantly improved by adding nanoscale MoS₂ and AlO₃ to the AZ91 matrix. During deformation MoS₂ acts as a solid lubricant that promotes dislocation motion, which increased ductility. The ceramic AlO₃ phase high stiffness and load-bearing capacity greatly increased yield strength and ultimate tensile strength [36-39]. Sample 4 had the greatest UTS of 215 MPa and elongation of 7.2% among the composites demonstrating a well balanced microstructure with ideal dispersion and reinforcement synergy. Sample 5 included 15 weight % AlO₃, on the other hand showed a little decrease in ductility (6.0%). This is probably because ceramic particles agglomerate at higher loadings which might prevent plastic deformation and generate stress concentration zones.

**TABLE 2**Tensile Stress-Strain Behaviour

|  |  |  |  |
| --- | --- | --- | --- |
| **Sample** | **Yield Strength (MPa)** | **UTS (MPa)** | **Elongation (%)** |
| Sample 1 | 142 | 190 | 5.8 |
| Sample 2 | 150 | 195 | 6.5 |
| Sample 3 | 162 | 205 | 6.8 |
| Sample 4 | 170 | 215 | 7.2 |
| Sample 5 | 168 | 208 | 6 |



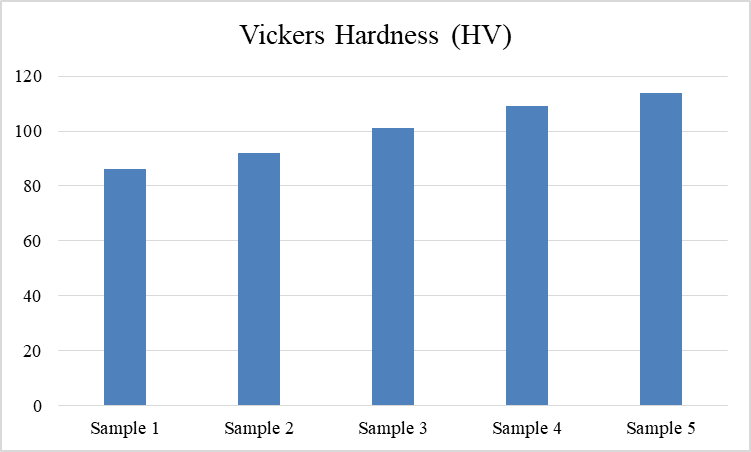
**Figure 1.** Tensile Stress-Strain Behaviour

## Vickers Hardness

With the inclusion of AlO₃ nanoparticles the Vickers microhardness of the AZ91 based composites increased gradually and explained by the ceramic reinforcement's enhanced load transmission capacities and grain refinement effect [40-43]. These particles increase the alloy resistance to localized plastic deformation by acting as barriers to dislocation motion. The ceramic phase effectively contributed to surface strengthening as seen by Sample 5 had the maximum hardness value of 114 HV and contained 15 weight percent AlO₃. Wear rate tests further showed across applied loads of 10 N, 20 N and 30 N, material loss decreased gradually as the AlO₃ content increased. Sample 5 had the lowest wear rate (2.28 mm³/N·m at 10 N) indicating the greater wear resistance that results from homogeneous reinforcement distribution and higher surface hardness. These hybrid composites enhanced hardness wear makes them suitable for surface durability in abrasive or frictional environments [44-46].

**TABLE 3.** Vickers Hardness

|  |  |  |  |
| --- | --- | --- | --- |
| **Load (N)** | **10 N** | **20 N** | **30 N** |
| S1 | 4.32 | 5.89 | 6.78 |
| S2 | 3.2 | 4.62 | 5.3 |
| S3 | 2.76 | 3.85 | 4.69 |
| S4 | 2.42 | 3.41 | 4.1 |
| S5 | 2.28 | 3.22 | 3.91 |



**Figure 2.** Vickers Hardness

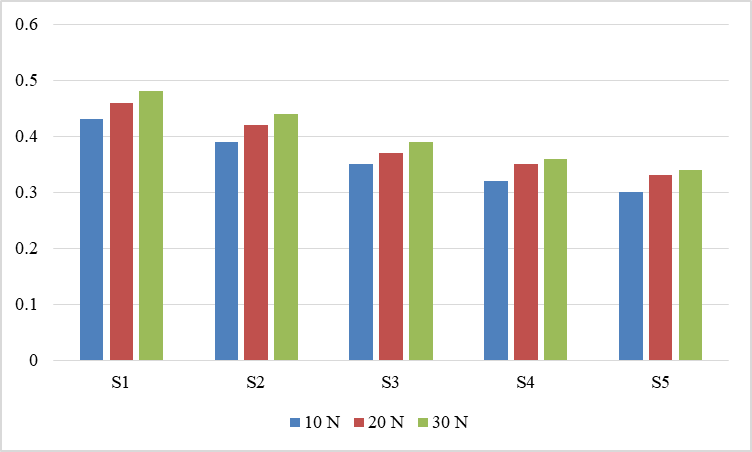
## Thermal Stability

TGA showed the thermal stability of AZ91 composites was significantly increased by the addition of nano AlO₃ particles. Sample 4 had 1 weight % MoS₂ and 10 weight % AlO₃ lasted up to 430°C while Sample 1 is at 385°C. This is improved by the ceramic reinforcing prevents heat transfer and postpones disintegration at high temperatures. Based on these findings the composite is appropriate for high temperature thermal reliability applications.

COF decreased as reinforcement content rose. Hard AlO₃ particles combined with the solid lubricant MoS₂ produced less sliding adhesion and finer surface contacts. With the lowest COF (0.30 at 10 N) Sample 5 demonstrated superior tribology. Under dynamic thermal and mechanical demands lubricating and wear resistant reinforcements work in concert to give automotive and aerospace components adequate thermal durability and low friction operation [47-50].

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Load (N)** | **10 N** | **20 N** | **30 N** |
| S1 | 0.43 | 0.46 | 0.48 |
| S2 | 0.39 | 0.42 | 0.44 |
| S3 | 0.35 | 0.37 | 0.39 |
| S4 | 0.32 | 0.35 | 0.36 |
| S5 | 0.3 | 0.33 | 0.34 |



**Figure 3.** Coefficient of Friction (COF)

# Applications in Structural Components

The created AZ91 based hybrid nanocomposites improved mechanical strength, thermal resistance and surface hardness make them ideal for structural applications requiring high performance lightweight materials. The dual reinforcement technique can significantly improve components including heat sensitive casings, lightweight frames, automobile structures and aerospace housings. A material system that can sustain dynamic mechanical loads and high temperature variations is produced by the combined effects of MoS₂ increases ductility and decreases friction and AlO₃ increases hardness and thermal stability. In the automobile and defence industries where strength and dependability under tribological and thermal stress are crucial are decided by the design factors balance which is extremely beneficial.

# Conclusion

According to this study the overall performance of AZ91 magnesium alloy is incrteased by adding nano sized molybdenum disulphide and alumina particles via squeeze stir casting. The optimum combination of mechanical properties was found in Sample 4 of AZ91 + 1 weight % MoS₂ + 10 weight % Al₂O₃ having high ultimate tensile strength of 215 MPa and elongation of 7.2% along with better thermal resistance (up to 430 °C) and a lower friction coefficient. MoS₂ improves plastic deformation and lubrication and Al₂O₃ boosts load bearing and thermal shielding. This composite system makes a convincing case for use in lightweight structural components that require a combination of mechanical strength, wear resistance and thermal durability.

# References

1. Victor, M. Thomas, G. Selvakumar, S. Surendarnath, and P. Ravindran. "Mechanical Properties of magnesium hybrid composite reinforced with Al2O3 and MoS2 particles through PM route." Materials Today: Proceedings 37 (2021): 2396-2400.
2. Senthilkumar, V., A. Nagadeepan, S. Senthilkumar, and K. Raja. "An investigation on microstructure and mechanical characterization of high performance magnesium hybrid nanocomposites with Al₂0₃ and MoS₂ nanoparticles." In International Conference on Bio-Based Environment for Sustainable Territory (ICBEST 2024), pp. 123-131. Atlantis Press, 2025.
3. More, Aarti P., and Pradnya D. Desai. "Tribological hybrid materials." In Surface Engineering, pp. 11-68. CRC Press, 2022.
4. Tharanikumar, L., B. Mohan, and G. Anbuchezhiyan. "Synthesization and characterization of silicon carbide and boron nitride-reinforced Al–Zn–Mg alloy hybrid nanocomposites using squeeze casting method." International Journal of Metalcasting 18, no. 2 (2024): 997-1011.
5. T. S. Thangavel, (2019). Experimental Investigation of Silicon Carbide Nanoparticles Reinforced Magnesium Alloy (AZ91E) Metal Matrix Composite by Vacuum Stir Casting Method. In SAE Technical Papers. SAE International. https://doi.org/10.4271/2019-28-0169
6. Vuddagiri, Hari Kiran, Sivasankara Raju Rallabandi, Srinivas Vadapalli, and Thimothy Pandi. "Assessment of mechanical and tribological performance of hybrid Al/MoS2/Al2O3 composite by GFRA." Metallurgical and Materials Engineering 28, no. 1 (2022): 79-102.
7. 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>
8. 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>
9. 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>.
10. 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>
11. 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>
12. 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>
13. 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>
14. 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>
15. 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>
16. 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>
17. 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>
18. 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
19. 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.
20. 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.
21. 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>
22. 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>
23. 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
24. 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>
25. 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>
26. 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
27. 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>
28. 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>
29. 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>
30. 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>
31. 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>
32. 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>
33. 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>
34. 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
35. 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>
36. 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>
37. 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.
38. 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.
39. 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>
40. 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>
41. 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>
42. 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>
43. 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>
44. 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>
45. 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>
46. 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>
47. 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.
48. Raja, S., Ali, R. M., Babar, Y. V., Surakasi, R., Karthikeyan, S., Panneerselvam, B., & Jagadheeswari, A. S. (2024). Integration of nanomaterials in FDM for enhanced surface properties: Optimized manufacturing approaches. *Applied Chemical Engineering, 7*(3).
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.