Deepwater Horizon Leftovers' Aromatic Polycyclic Hydrocarbons Spilled Oil Shows Various Aging Patterns When Exposed to Sunlight

G Sivaraman1, P Vamsi Sagar2, M.D.Raj Kamal3, T. Nagalakshmi4, M Ramya5,a), Vijayanandh Raja6

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

2 Department of Mathematics, Aditya University, Surampalem, Kakinada, Andhra Pradesh-533437, India .

3 Department of Mechanical Engineering, Velammal Institute of Technology, Chennai-601204. Tamil Nadu, India.

4 Department of Mathematics, Veltech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, 600062 , Tamilnadu, India.

5 Division of Research and Development, Lovely Professional University, Jalandhar - Delhi G.T.Road, Phagwara, Punjab– 144411, India.

6 Department of Aeronautical Engineering, Kumaraguru College of Technology, Coimbatore-641049, Tamil Nadu, India.

Corresponding Author: a)[ramyalpu@yahoo.com](mailto:ramyalpu@yahoo.com)

**Abstract:** A significant volume of light petroleum was spilled into the waters of the Gulf of Mexico (GOM) as a result of the Deepwater Horizon (DWH) spillage incident. Immersed oil matting (SOMs) was created when an unidentified quantity of the fluid that had reached the state's coastline mixed with the close-to-shore layers and sank. Such submerged SOMs included a significant quantity of petroleum products, particularly polycyclic aromatic hydrocarbons (PAHs). A number of PAHs, particularly those with greater molecular weights (three or greater fragrant rings), are carefully aging in comparison with what was encountered by the oil while it was first hanging throughout the GOM, according to new research employing the spilled oil leftovers gathered from the state of Alabama beachfront. According to our hypothesis, the reason why PAH weather processes in SOMs are going up is because the underground oil was shielded from sunlight, which hampered its photodegradation process. We also predicted that different degradation processes may be reactivated by introducing SOMs to sunlight again. Additionally, SOMs have a sand content of 75–95% (by composition), and the imprisoned sand may either prevent sunshine or create broad oil clusters with little to no accessible land area, which may impede degradation responses.

**Keywords:** Deepwater; Horizon; Aromatic; Estimation of oil content; Oil spill samples; Sunlight.

# Introduction

The study estimated that 5.4 109 kilograms of oil from the Macondo himself well were leaked during the Propublica Boom (DWH) catastrophe, that happened on March 20, 2010, for a duration of 88 nights. Approximately 26 percent of the spilled oil was thought to still be in an aqueous solution. The petroleum is predicted to have dispersed in a variety of ways: some would be believed to have been deposited near the MC252 well, some would have been dispersed into the atmosphere and ultimately shipped into the deeper parts of the Gulf of the United States (GOM), some would have fallen to the bottom of the sea as underwater slush, and the rest of the crude was dumped together along different GOM coastlines. A great deal of the spilled oil debris that washed up on Alabama's shores was water-in-oil, an emulsion sometimes referred to as "mousse" because of its intense viscosity and zero buoyancy [1] Underwater oil matting (SOMs) was created when a mysterious amount of this emulsion reacted with floating objects close to the beach and sank. Later, waves and other ways of transport broke up the SOMs, creating movable subsurface oil-residue balls (SRBs). The majority of the SRBs and SOMs are constructed out of sand [2]. It was discovered that the residual oil confined in SOMs and SRBs included a number of dangerous compounds, particularly hydrocarbons with polycyclic aromatics, which may be detrimental to human and natural systems alike [3]. Some of the most dangerous groups of environmental factors found in crude oils are an assortment of chemical compounds known as PAHs. PAHs belong to the category of chemical molecules that include more than one fused aromatic ring structure. PAHs are categorized as hazardous organic chemicals because of their ability to cause cancer and mutation. Recent research has revealed that the PAHs that are identified in SOMs and SRBs along the northwestern Gulf of Mexico coastline seem to have experienced a relatively low degree of weathering [4]. It is yet unclear why these sluggish weathering rates are occurring. The inherent weathering steps that crude oil goes through when it is discharged into a body of water include propagating, advection, combustion, dissolving, sunlight degradation, emulsion, settling, and microbiological decomposition. One of the most significant chemical reactions associated with numerous oil spill disasters is volatility, which could substantially decrease the amount of oil that was spilled [5].

A different important degradation mechanism that might change the PAHs found in petroleum is degradation by sunlight. The total solubility rates for PAHs and additional compounds can be increased by decomposition processes because photodegradation often produces end-products that have improved reactivity and are soluble in water. Additionally, decomposition might make crude oil more vulnerable to microbiological deterioration. By making the oil more accessible to marine organisms, decomposition might potentially raise the oil's overall hazard to its surroundings. Previous research has demonstrated that PAHs contained in the DWH from oil spill remnants can be photodegraded [6]. The PAHs in those remains would have gone through significant corrosion, which includes volatilization, disintegration, and decomposition whenever the crude oil floated in the GOM lakes while crossing from a wellhead to the beachfront, according to a recent research investigation employing DWH spillage leftovers retrieved from the Alabama coastline. The research also revealed that once the petroleum was immersed, creating SOMs, its overall weathering process appeared to have been significantly cooled down.

In this investigation, we anticipated that one of the main methods of weathering, a process known as submerging, was hampered because the SOMs received protection from the sun, slowing the decay processes of PAHs in SOMs. Remember that we use the terms "weathering quantities or increases have decreased downward" or "low deteriorating the amount or rates" to suggest that the methods of weathering have decreased in comparison with the ones that the DWH oil underwent as it travelled through the drilling site to the GOM coastline, whereas it had been gliding across the expanse of the ocean. In addition, we predicted that re-exposing SOMs to daylight would trigger the degradation processes once more, speeding up the overall rate of weathering. In addition, SOMs include up to 90 percent inert sand by size, and this inert sand may actually obstruct sunlight or let oil clump together on top of sand particles, reducing the surface area, which may prevent decomposition and other weathering reactions. This finding is important since SOM and SRB leftovers from the DWH oil disaster are still detectable throughout the Gulf of Mexico coastline. Understanding the many ecological mechanisms that might destroy these leftovers is crucial. The findings of this investigation can be used to better understand how PAHs contained in SOMs and SRBs could deteriorate as time passes if they are regularly subjected to sunlight when being carried in shallow seas or dumped along the beach.

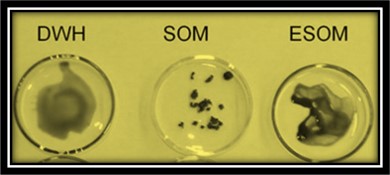
# Material and Methods

## Materials

The hydrocarbons and the substance utilized in this investigation were at least of analytical quality. VWR Worldwide supplied the liquids, the gel of silica (50–100 m), and the sodium sulphate. Centaur sold the science portion version of the Total Environmental C30-hopene certification. The standard that was used internally was a PAH standardization combination made up of 27 PAHs, which was obtained from Accu Standardization. Philips Solutions' J&W DB-EUPAH column was used to separate different PAH chemicals chromatographically. Philips Laboratories' inert fused silica column was utilized in the back flush configuration. 250 mL each of a solution of the chemical hex and the substance were serially used to wash around 180 to 300 g of silicon dioxide gel three times before it had been dried for 12 hours in the fume hood. Following drying out, the silica gel was toasted for seven hours in the oven at between 70 and 80 °C before activating for 40 hours at 200 °C. In order to purify anhydrous sodium sulphate, it was simmered at 600 °C for five hours, chilled, and subsequently kept in tightly capped glass flasks.

## Oil content Estimations

The procedures outlined in earlier investigations were used for estimating the amount of oil in SOM materials. To eliminate humidity, the SOM specimen was first separated into smaller components and air dried. 10 mL of the substance were used to extract around 1 g of the pulverized material. There were four iterations of the extraction procedure. To calculate the amount of oil in the SOM specimen, the hard leftovers were air-dried and measured. Its SOM's mean amount of oil was determined to be 14%. Figure 1 shows the different types of spill samples used in the research [14-18].



**Fig.1** shows the different types of spill samples used in the research

## Experiment under Sunlight exposure

In each of the outside deteriorating studies, we split each of the petri dishes that included various kinds of specimens into two distinct sets: (1) ultraviolet rays samples used as controls, which comprise an overall of 21 petri meals and supplied information at eight points in time for each of the three kinds of specimens with DWH, SOM, and ESOM; and (2) sunlight-exposed (SE) samples, which comprise a total of 42 petri meals and offered identical information at the same moments i for all three kinds of specimens [19-23]. The SE materials were set up in a container coated with an ordinary photograph frame window surface, while the SC specimens were housed in a box coated with a black cloth to avoid the accumulation of sand along with external pollutants. The containers' sidewalls included several mesh-covered holes for ventilation. To ensure that the glass material utilized in this investigation would not obstruct the photodegradation routes of different target PAHs, we carried out first-pass screening studies (see S3). The standard control (SC) specimens are going to be subjected to practically all of the typical outside circumstances, with the exception of direct natural light, during their outdoor deterioration studies. The SC and SE specimens had been placed in proximity to themselves in sunlight, with one wrapped in a black sheet and the other partially obscured with an acrylic plate [7]. Nevertheless, temperatures inside the SE specimens were significantly higher compared to the SC specimens because they had direct sunlight exposures [25-29].

# Results

## Identification of Source

Initially, the SOM specimen's source was confirmed by analysis. It is commonly known that the DWH spilled oil remnants discovered across Alabama's beachfront have unusual physical features. They are composed primarily of sand and were dark in colour, slippery, greasy materials with strong gasoline Odors [8]. These physical properties were all present in the SOM collection that was used in this investigation. Using the methods of analysis mentioned in earlier investigations, the material was further analysed for hopene’s as well as steranes to analyse their chemistry signatures [30-35]. The present investigation employed the subsequent origin-specific Hopene diagnosis ratio to determine the origin. Figure 1 sonar map displays the source-specific hopene diagnosis ratios calculated for the DWH and SOM specimens. The information demonstrates the way the source-specific analytical proportions matched the biochemical fingerprints of the DWH model oil leak, proving that the leftover oil in SOM came straight from the DWH oil disaster [10]. The steranes database might be utilized to offer extra assurance that the original source is known. Figure 1 compares the collected ions by chromatography for steranes with both DWH and SOM. The outcomes and the good agreement between the chromatograms offer more proof that the gasoline in SOM came through the DWH algorithm oil disaster [11, 36-41].

## Results of exposure in Sunlight

It required a total of 27 days to finish the direct sunlight contact research, including a few days when it rained or was overcast and the specimens weren't subjected to the bright sunlight. Towards the conclusion of the trial, the samples had received an aggregate of sixty-one hours of sunshine. Figs. 4 through 9 provide an overview of the percentage of PAHs still present in DWH, SOM, and ESOM samples following exposure to sunlight at different intervals [42-47]. We analyse these findings and contrast the PAH degradation levels of controlled (SC) and outdoor (SE) specimens in the subsections that follow. Because the SC specimens have been subjected to every type of outdoor weather with the exception of direct sunlight, they should take into consideration all non-photodegradation mechanisms. The SE specimens exhibit mixed decomposition and non-photodegradation mechanisms and have been subjected to direct sunlight. The SE specimens, which were directly exposed to solar radiation and therefore received more temperature than the SC specimens, may have also had a little greater amount of volatilization, as was previously described. Since the majority of the larger-molecular-weight target PAHs that were important proved rather resistant to combustion, such temperatures had a negligible influence on our investigation. Figure 2 shows the PAH concertation with sediments [12].



**Fig.2** shows temporal changes in PAH concentrations

## DWH oil experiments

The results of the experiments with the DWH oil control samples show that one of the main ways PAHs break down, especially those with smaller molecules, is that they evaporate. The information on C0-to-C4-naphthalene may be used to deduce this outcome. The degradation processes from C0- to C4-naphthalenes reduced with a rise in alkylation, which according to these results as well [13]. It is generally acknowledged that the rate of volatilizing lowers as atmospheric pressure falls (also, vapor pressures will go down as molecular mass increases; for instance, at the outside temperature, the pressure of the vapor of a substance called benzopyrene is around 10 Pa, while that of benzopyrene is 107 Pa). Alkylation also raises the weight of molecules; hence, it is predicted that as alkylation levels rise, so will the degree of vaporization [14, 48-50]. Whenever withering information regarding volatile organic compounds in DWH-LC and DWH-SC is investigated, it is evident that DWH-SC specimens exhibit faster weather speeds and total eradication of PAHs than do DWH-LC samples. These outcomes make it clear that environmental corrosion levels for PAHs should have risen. This rise was brought about by the infrared heating by radiation that the DWH-SC specimens underwent, which raised temperatures and, as a consequence, increased vaporization [15, 51].

# Conclusion

In summary, the analysis of the crude oil that was released from the well at Deepwater Horizon and its fragrant cyclic compounds has shown an amazing variety of aging processes when exposed to sunlight. This study provides important insights into the complicated behaviours of hydrocarbons in aquatic environments by shedding the spotlight on multiple steps that occur as oil reacts with the surroundings. Understanding the many changes that these compounds go through as time passes can help us estimate the long-term consequences of such natural catastrophes and create more potent preventive and repair plans. Unquestionably, more research into the aging process of oil that gets released will increase our knowledge about ecological chemicals and assist in the creation of viable strategies for protecting our seas and coastlines.

# References

1. Sayed, K., Baloo, L., & Sharma, N. K. (2021). Bioremediation of total petroleum hydrocarbons (TPH) by bioaugmentation and biostimulation in water with floating oil spill containment booms as bioreactor basin. *International Journal of Environmental Research and Public Health*, *18*(5), 2226.
2. Parkerton, T., Boufadel, M., Nordtug, T., Mitchelmore, C., Colvin, K., Wetzel, D., ... & Loughery, J. (2023). Recommendations for advancing media preparation methods used to assess aquatic hazards of oils and spill response agents. *Aquatic Toxicology*, 106518.
3. Vala et al., (2024). Investigation of varying tip clearance gap and operating conditions on the fulfilment of low-speed axial flow fan. International Journal of Turbo & Jet-Engines, (0). https://doi.org/10.1515/tjj-2024-0067
4. Samuel, O., Othman, M. H. D., Kamaludin, R., Kurniawan, T. A., Li, T., Dzinun, H., & Imtiaz, A. (2022). Treatment of oily wastewater using photocatalytic membrane reactors: A critical review. *Journal of Environmental Chemical Engineering*, 108539.
5. Mearns, A. J., Reish, D. J., Oshida, P. S., Ginn, T., Rempel‐Hester, M. A., Arthur, C., & Rutherford, N. (2013). Effects of pollution on marine organisms. *Water Environment Research*, *85*(10), 1828-1933.
6. 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.
7. Weis, J. S. (2015). *Marine pollution: what everyone needs to know*. Oxford University Press.
8. Oldenkamp, A. G. (2014). The 2010 Deepwater Horizon Gulf Region Oil Spill: Educational Modules and Methods for Long-Term Remediation.
9. Mehta et al., (2024). Twisted tape inserts in parabolic trough solar collectors: Assessment of Energy, Exergy, and Environmental impacts. *Applied Thermal Engineering*, *250*, 123566.
10. Granlund, A. C. (2020). *Developmental effects of embryonic exposure to a water-soluble fraction of crude oil on early life stages of capelin (Mallotus villosus)* (Master's thesis, UiT Norges arktiske universitet).
11. Ramirez-Llodra, E., Tyler, P. A., Baker, M. C., Bergstad, O. A., Clark, M. R., Escobar, E., ... & Van Dover, C. L. (2011). Man and the last great wilderness: human impact on the deep sea. *PLoS one*, *6*(8), e22588.
12. Seeniappan, K. (2024). Optimizing Carbon Monoxide Emission Reduction Using Rice Husk Activated Carbon in Automobile Exhaust Systems (No. 2024-01-5054). SAE Technical Paper. https://doi.org/10.4271/2024-01-5054
13. Chukka, N. D. K. R., S., Balaji, V., Ross, N. S., (2025). An integrated Artificial neural network technique to optimize the various parameters of Pineapple/SiO2/epoxy-based nanocomposites under NaOH treatment. Results in Engineering, 26, 104737.
14. Manzoore Elahi M. Soudagar et al. Higher performance solar air dryer functioned with palmitic acid phase change material and hybrid nanofluid: Thermal performance evaluation, Applied Thermal Engineering (2025). Volume 272, 2025,126413, https://doi.org/10.1016/j.applthermaleng.2025.126413
15. P. P. Singh et al. Hybrid Thin Film Coating Performance and Functional Characteristics of Silicon Nitride (SiNx) Layer for Solar Cell Application. J. Electron. Mater. (2025). https://doi.org/10.1007/s11664-025-11888-6
16. Seeniappan, K. (2024). Effectiveness of titanium dioxide nano fillers on sisal fiber for enhanced mechanical properties and occupant protection in hybrid nanocomposites (No. 2023-01-5114). SAE Technical Paper. https://doi.org/10.4271/2023-01-5114
17. N. Nagarajan et al. Hybrid Stir Cast Featured with Wettability Agent and Ultrasonic Action of Magnesium Alloy Composite Composed with Nanofiller: Study Characteristics. Inter Metalcast (2025). https://doi.org/10.1007/s40962-025-01603-w
18. A. Sharma et al. Structural Modification and Enhancement of Optoelectronic Behaviour of ZnO Nanofilms Featuring Cu and Ti Particles. J. Electron. Mater. (2025). https://doi.org/10.1007/s11664-025-11951-2
19. V. Mohanavel et al. Tribological characteristics and optimization of ZrB2 configured magnesium alloy composite via squeeze casting technique. J Mech Sci Technol. 39(5), 2025. https://doi.org/10.1007/s12206-025-0425-9
20. Shah, Ronit, Arockia Selvakumar Arockia Doss. Advancements in AI-Enhanced Collaborative Robotics: Towards Safer, Smarter, and Human-Centric Industrial Automation. Results in Engineering (2025): 105704.
21. Ameen, F., Chinta, N. D., Teja, N. B., Muthu, G., Kaliappan, S., ... & Vadiveloo, A. (2024). Antibacterial and dynamical behaviour of silicon nanoparticles influenced sustainable waste flax fibre-reinforced epoxy composite for biomedical application. Green processing and synthesis, 13(1), 20230214. https://doi.org/10.1515/gps-2023-0214
22. Raja et al., (2025). Sustainable High-Strength Composites: Hybrid Bamboo and Cellulose Reinforced Polyester for Automotive Engineering. Journal of Bio-and Tribo-Corrosion, 11(3), 85.
23. K. Vijetha, Arockia Selvakumar Arockia Doss, KJN Sai Nitesh, Nimel Sworna Ross, Dual-Scale Evaluation of Hybrid Al-SiC/Graphene Composites: Mechanical Properties and Deep Learning-Driven Machinability Insights. Results in Engineering (2025): 105742.
24. 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.
25. 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.
26. P.R. Sekaran, and H. Ramakrishnan, "Mechanical and physical characterization studies of nano ceramic reinforced Al–Mg hybrid nanocomposites", Silicon, vol. 15, No. 10, pp. 1-13, Apr 2023.
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. 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
30. 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
31. P. K. Singh et al. Integration of phase change material for enriching the solar collector featured with dryer configuration enhanced via alumina/titanium dioxide nanoparticle: performance study. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-025-14302-9>
32. Vinodh et al., (2025). Integration of ceramic reinforcements in AA5083 composites for enhanced mechanical and thermal properties in friction stir welding. Engineering Research Express, 7(3), 035519.
33. Karthick et al., (2025). Experimental investigation of photocatalytic degradation and antioxidant activities of biosynthesized gold nanoparticles from royal poinciana tree leaves. Discover Applied Sciences, 7(8), 838.
34. Chinta, N. D., Gogulamudi, B., Swamy Nadh, V., Muthu, G., Kaliappan, S., & Srinivas, C. (2024). Investigation on mechanical properties of the green synthesis bamboo fiber/eggshell/coconut shell powder-based hybrid biocomposites under NaOH conditions. Green Processing and Synthesis, 13(1), 20230185. https://doi.org/10.1515/gps-2023-0185
35. Mohan, G., G. Komala, K. Manikannan, Pallavi Baghel. Heart Disease Detection in Cloud Platforms: A Privacy-Driven Approach using Exponential Distribution Optimized Hopfield Networks and Blockchain Security. In 2025 International Conference on Inventive Computation Technologies (ICICT), pp. 1084-1089. IEEE, 2025.
36. Seeniappan, K., & Sree, G. V. (2024). Enhancing the mechanical and thermal properties of Kevlar composites for advanced vehicle components using montmorillonite nano clay integration (No. 2023-01-5113). SAE Technical Paper. https://doi.org/10.4271/2023-01-5113
37. Manzoore Elahi M. Soudagar, Ravindra Pratap Singh, Nagabhooshanam Nagarajan. et al. Featuring of in-situ carbon capturing and functional performance study of hydrogen from aquaculture wastewater algae biomass via supercritical steam gasification route, Chemical Engineering Science 313 (2025) 121704. https://doi.org/10.1016/j.ces.2025.121704
38. M. Aruna et al. Integration of Magnesium Fluoride and Nano Alumina–Silicon Carbide Actions on Properties of AZ91 Alloy Hybrid Nanocomposites. Inter Metalcast (2025). https://doi.org/10.1007/s40962-025-01617-4
39. P. Sharma et al. Effect of paraffin with salt hydrates PCM and hybrid Al2O3/Tio2 nanofluid on thermal and energy storage characteristics of solar thermal heat exchanger. J Therm Anal Calorim (2025). https://doi.org/10.1007/s10973-025-14224-6
40. Jothi Arunachalam et al. Integration of nanographene and action of fiber sequences on functional behaviour of composite laminates" International Polymer Processing, 2025. https://doi.org/10.1515/ipp-2024-0149
41. Janardhan, G., Nadh, V. S., Srinivas, C., & Velmurugan, G. (2024). Eco-friendly zinc oxide nanoparticles from Moringa oleifera leaf extract for photocatalytic and antibacterial applications. Clean Technologies and Environmental Policy, 1-13. https://doi.org/10.1007/s10098-024-02814-1
42. Naga Dheeraj Kumar Reddy Chukka, M. Karthick, Nimel Sworna Ross. Optimization of thermal efficiency in double pass solar air heating systems with emphasis on collector design parameters and operating conditions. Results in Engineering 26 (2025): 104948.
43. Chinta, N. D., Teja, N. B., Muthu, G.., Kirubanandan, S., & Paramasivam, P. (2024). Evaluating mechanical, thermal, and water absorption properties of biocomposites with Opuntia cladode fiber and palm flower biochar for industrial applications. Discover Applied Sciences, 6(2), 30.
44. Neelashetty, K., et al. Energy Management for PV-Powered EV Charging With Grid Integration and Battery Energy Storage System using Dung Beetle Optimizer. 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM). IEEE, 2025.
45. Kaliappan, S., Balaji, V., & Mahesh, V. (2024). Effects of Injection Molding on Linum usitatissimum Fiber Polyvinyl Chloride Composites for Automotive Underbody Shields and Floor Trays (No. 2024-01-5053). SAE Technical Paper. https://doi.org/10.4271/2024-01-5053
46. 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
47. 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>
48. 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
49. 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
50. 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
51. 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