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Fabrication and Mechanical Characterization of Aluminium Hybrid Composites Using TiO_2 and MoS_2 Particulates by Stir Casting Process

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In this research, we developed hybrid metal matrix composites (HMMCs) based on an alloy of Al7075, watching its silvery surface glisten and radiate as it cooled. For the purpose of increasing the alloy's strength and wear resistance, we incorporated the glimmering fine powders of titanium dioxide (TiO_2) and molybdenum disulfide (MoS_2). We employed the economical stir casting technique, which provides sufficient stirring and even distribution of particles, akin to sugar dissolving in tea. We used composites of 1.5 to 6 weight percent of reinforcements and examined the microstructural and mechanical behaviours of the composites to surface stiffness changes. Close attention was paid to the stirring speed, melt temperature, and mixing times as the parameters, which were adjusted as a chef would attend to a boiling sauce. The fabricated composites were then examined using tensile, impact, and hardness testing until scores were made along the edge of the steel clamp. The addition of TiO_2 and MoS_2 was found to substantially increase the strength and hardness of Al7075 in comparison to the alloy in its unreinforced state, which exemplified scratch resistance in comparison to a blade. Gains came as a result of effective load transfer between matrix and reinforcement.

KEYWORDS: **Aluminium Hybrid Composites, Al7075 Alloy, Titanium Dioxide (TiO_2), Molybdenum Disulfide (MoS_2), Stir Casting.**

1. Introduction

In hybrid metal matrix composites (HMMCs), the aluminum alloys have recently attracted significant attention as substitutes for traditional materials in aerospace, automotive, and arms industry, which are sensitive to weight. Among aluminum alloys, Al7075 is highly appreciated for its specific strength, fatigue resistance, and corrosion performance. Further, the mechanical properties are even improved enamete xed with ceramic and solid lubricant reinforcements. The stiffness and tensile strength are improved with the addition of titanium dioxide (TiO_2), while the modified molybdenum disulfide (MoS_2) increases the toughness with its layered crystal structure by suppressing the crack initiation and propagation. Stir casting is now one of the more practical and lower cost methods for the fabrication of these composites. This is as a result of the relatively uniform distribution of reinforcements, which in turn increases the performance of the final material. The quality of the material is also influenced greatly by the processing parameters, such as melt temperature, stirring speed, and mixing time which dictate the matrix-reinforcement bonding and dispersion of the particles. The attention of the present work is directed to the synthesis and mechanical assessment of Al7075–TiO_2–MoS_2 hybrid composites made by conventional stir casting. Other processing parameters included melt temperatures of 900 °C. The composites produced were then subjected to tensile strength, impact, and hardness tests. The central objectives included real world evaluation of the mechanical performance of processing parameters to determine the optimum setups for hot processing of the Al 7075 based hybrid materials composites with Al 7075 reinforced with TiO_2 and MoS_2 and the evaluation for structural applications. Notably, aluminium-based HMMCs, especially those with multiphase reinforcement, continue to demonstrate considerable promise for advanced engineering applications by offering customizable mechanical profiles alongside weight reduction—a key advantage in sectors such as transportation. The unique benefit of hybrid composites is the potential for synergistic improvements, often exceeding what single-phase systems can provide. Al7075 remains the go-to matrix alloy here, precisely because of its high strength-to-weight ratio and dependable fatigue and corrosion properties. TiO_2, as a ceramic reinforcement, is well-established for its capacity to enhance hardness, tensile strength, and oxidation resistance. Conversely, MoS_2—thanks to its intrinsic lubricating effect and lamellar structure—improves impact resistance and energy dissipation under load. Stir casting, among various composite fabrication methods, dominates due to its combination of scalability and cost-effectiveness. Recent progress in electromagnetic stir casting has enabled even finer control over particle dispersion and matrix–particle interface, as evidenced by reports emphasizing the positive effect of Lorentz forces in reducing agglomeration and promoting wettability. Work by Dwivedi et al. (2014) strongly supports the notion that electromagnetic enhancement can minimize both clustering of reinforcements and weak particle–matrix bonding. While literature covering TiO_2-reinforced Al7075 composites is extensive, research into MoS_2 addition—and its impact on dynamic mechanical attributes—is less prevalent. The existing body of work consistently shows that TiO_2 generally elevates tensile strength and hardness via robust interface formation. Studies on MoS_2 remain limited, but available data highlight notable improvements in impact strength and damping, consistent with expectations for materials with such layered microstructures. Recent investigations, such as that by Jayanth H. et al. (2024), indicate that dual-ceramic reinforcement can yield significant enhancements in both impact resistance and hardness, provided dispersion is uniform—an insight supported by SEM and EDS characterization. Several researchers have investigated alternative hybrid reinforcement systems, such as Al_2O_3–graphite and SiC–CNT combinations within Al7075 matrices, demonstrating the versatility of hybrid approaches for tuning composite properties. Sahu et al. (2019) demonstrated that the incorporation of fly ash and B_4C into aluminium matrices improved hardness and promoted more uniform microstructures, thereby underscoring the effectiveness of dual-phase reinforcement strategies, even in systems without MoS_2.Al 7075 alloys with composites of titanium dioxide and molybdenum disulfide have been studied less extensively than the TiO_2 and MoS_2 blended Al 7075 alloy. This study attempts to fill this gap in the literature research by measuring the impact strength, hardness, and tensile of the Al 7075 TiO_2 MoS_2 composites, developed under controlled stir casting process parameters. What makes this research unique is the first attempt to study the use of the composite system with both TiO_2 and MoS_2 as the ceramic and solid lubricant mechanics, of the Al 7075 which appears to have not been studied before. While the processing conditions were controlled and the weights of the reinforcements were varied, these results indicated that the composition of Sample 3 presented the most optimum blend to enhance strength and to toughness as well as hardness. Rather than the previous findings which were based upon the single-phase confined reinforcements, the results of this study have shown that the reinforcements can work in synergy, whereby TiO_2 increased the stiffness and tensile strength while MoS_2 adversely affected the impact and toughness retention. Unlike earlier studies that focused on single-phase reinforcements, the present findings demonstrate a synergistic effect: TiO_2 enhanced stiffness and tensile strength, while MoS_2 contributed significantly to improved impact energy absorption and toughness. Collectively, this dual-reinforcement strategy exhibited great mechanical properties with improved strength and dynamic load bearing capacity, which extend their usage for structural elements in critical engineering conditions.

2. Materials and Methods

2.1. Materials

The present work emphasizes the development of a high-level composite with Aluminium 7075 (Al7075) as the matrix and reinforced by Titanium Dioxide (TiO_2) and Molybdenum Disulfide (MoS_2). Al7075 has been extensively known for its superior specific strength, good fatigue and corrosion resistance, and good machinability and weldability. All these factors have contributed to its extensive use in aerospace, automobile, and structural applications where reliability and high performance are needed. Its synergy of properties also renders it a strong contender for composite development. In this, TiO_2 was used as a main ceramic reinforcement. TiO_2 is characterized by high chemical stability, thermal stability, and the ability to transfer strong interfacial adhesion with aluminium. To further enhance the composite's properties, a secondary reinforcement—Molybdenum Disulfide—is introduced. MoS_2 is well recognized as a layered solid lubricant. Its inclusion reduces internal friction during mechanical deformation and significantly elevates the composite's toughness, impact resistance, and damping response under dynamic loading conditions. In summary, by combining Al7075, TiO_2, and MoS_2, this composite system emerges as a promising candidate for structural applications where high strength, superior energy absorption, and reduced friction coexist as critical requirements. The properties of materials used in present work are shown in **Table 1**.

Table 1 Properties of Materials Used in Composite Fabrication.

Property	Al7075	TiO_2	MoS_2
Density (g/cm^3)	2.81	4.23	5.06
Hardness	~150 BHN	~800–1000 VHN	~100 VHN
Ultimate Tensile Strength (MPa)	~570	—	—
Melting Point (°C)	477–635	~1843	~1185
Thermal Stability	Moderate	High	Moderate–High
Special Features	High strength, fatigue resistant	Enhances hardness, oxidation resistant	Reduces friction, improves toughness

2.2. Composite Fabrication Process

The fabrication of Al7075-based hybrid composites was carried out via the stir casting method. A total of nine composite samples were prepared, each using 300 grams of Al7075 as the base matrix. The reinforcement distribution was designed to study the effect of varying MoS_2 content while keeping TiO_2 constant in some samples, and vice versa in others. This systematic variation allows evaluation of the individual and combined effects of TiO_2 and MoS_2 on the mechanical properties of Al7075-based composites. The compositions of each fabricated sample are given in **Table 2**. Initially, precise amounts of Al7075, TiO_2, and MoS_2 powders were weighed using a digital balance (±0.01 g accuracy). The reinforcements were preheated to 300°C for 30 minutes to remove moisture and enhance wettability. Al7075 melted at 900°C in a graphite crucible. The preheated reinforcements were then introduced gradually into the molten metal. Manual stirring was performed at 600–800 rpm for 10–20 seconds using a ceramic-coated stirrer to ensure uniform dispersion. The mixture was cast into preheated iron moulds and allowed to cool. The solidified ingots were later machined into standard specimens for mechanical testing (including tensile, hardness, and impact tests, following relevant ASTM standards). The flow diagram of fabrication process is shown in **Fig. 1**.

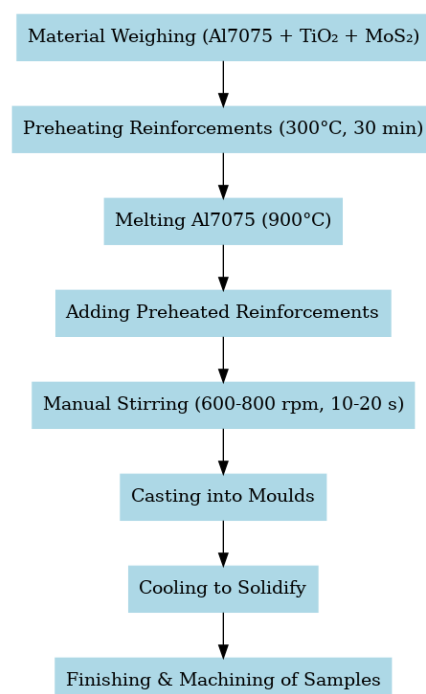

Fig. 1 Fabrication process flow diagram.

Table 2: Percentage of reinforcements used.

Sample No.	TiO_2 (wt%)	MoS_2 (wt%)
S0	0.0	0.0
S1	1.5	1.5
S2	1.5	3.0
S3	1.5	4.5
S4	1.5	6.0
S5	1.5	1.5
S6	3.0	1.5
S7	4.5	1.5
S8	6.0	1.5

2.3. Mechanical Testing

To evaluate the mechanical properties of the Al7075-based hybrid composites reinforced with TiO_2 and MoS_2, three principal tests were conducted: tensile testing, hardness assessment, and impact evaluation. Each test addressed a distinct aspect of mechanical performance, assessing, respectively, tensile strength and ductility, surface hardness, and the material's ability to absorb energy under dynamic loading.

Tensile Test: The tensile properties were determined using a Universal Testing Machine (UTM) in accordance with the ASTM E8M standard. Sub-sized specimens with a gauge length of 45 mm and cross-sectional dimensions of 6 mm × 12 mm were utilized. Specimens were subjected to uniaxial tension at a constant strain rate of 3 mm/min, enabling the measurement of ultimate tensile strength and percentage elongation at fracture.

Hardness Test: Surface hardness was measured using the Brinell Hardness Test, complying with ASTM E10. A 5 mm diameter steel ball was employed to indent the specimen under a load of 250 kgf for a dwell time of 10–15 seconds Hardness measurements were taken at three different points on each specimen, and the average of these values was used to ensure accuracy and reproducibility of the results.

Impact Test: Impact resistance was evaluated using the Izod impact test in accordance with ASTM E23. Standard notched specimens were prepared, and the energy absorbed during fracture was measured to assess the toughness of the composites, with emphasis on the effect of MoS_2 reinforcement on resistance to sudden impact loading.

Together, the applied testing methods provided a comprehensive assessment of the mechanical performance of the Al7075-based hybrid composites, enabling reliable and consistent quantification of their key properties.

3. Results and discussion

3.1. Brinell Hardness Testing

Brinell hardness testing was performed in accordance with ASTM E10 to evaluate the hardness characteristics of Al7075-based hybrid metal matrix composites reinforced with TiO_2 and MoS_2. A steel ball indenter with a diameter of 5 mm was employed under a load of 250 kgf for a dwell time of 30 seconds**.** For each sample, three indentations were made, and the average diameter (shown in **Table 3**) was used for BHN calculation using equation (1). The results of Brinell harness test for each composite specimen are shown in **Fig. 2**.

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \tag{1}$$

Where:
BHN= Brinell harness number in kg/mm^2
P = applied load (250 kgf)
D = diameter of ball (5 mm)
d = average diameter of indentation (mm)

The test results are presented in **Table 3**.

Mixing TiO_2 and MoS_2 into the Al7075 alloy made it distinctly harder than the unreinforced baseline, which is worth noting. The sample with both reinforcements in balance topped out at 167.09 BHN—that's the kind of result that suggests the particles got distributed pretty efficiently and weren't just clumping or lurking in certain spots. TiO_2 contributed most to this hardness gain, thanks to its inherently robust properties and solid bonding with the metal, while MoS_2 seems to have stepped in during cooling, working almost like a lubricating agent that encouraged the reinforcements to settle in more consistently. This outperforms what you'd expect from using just one ceramic alone, pointing to hybrid reinforcement as a genuinely promising route for making stronger, tougher structural materials. It's a pretty compelling case for moving beyond traditional single-additive alloys.

Table 3: Brinell Hardness testing data.

Sample No.	Avg. indentation dia. (mm)
S0	1.433
S1	1.533

S2	1.367
S3	1.467
S4	1.433
S5	1.467
S6	1.433
S7	1.367
S8	1.367

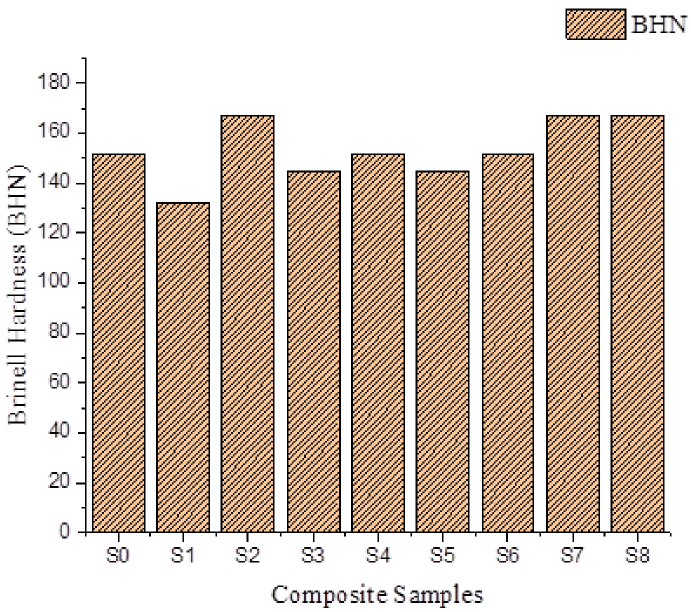

Fig. 2 Brinell hardness test result for each specimen.

3.2. Impact Testing

The impact test, conducted using the Izod method (ASTM D256), evaluated the toughness of Al7075 composites reinforced with varying amounts of TiO_2 and MoS_2. Nine samples were tested, with energy absorption recorded in divisions (1 division = 2 Joules). MoS_2, acting as a solid lubricant, helped improve ductility and energy dissipation under sudden loads. Overall, the results showed a combined effect of TiO_2 and MoS_2, enhancing the composites' impact resistance and structural integrity. The impact energy absorbed sample wise is shown in **Table 4.** Impact Test (Izod Test) result for each composite sample in terms of impact energy and composite samples is shown in **Fig. 3**.

Table 4: Impact Energy absorbed sample wise.

Sample No.	Avg. indentation dia. (mm)
S0	1.0
S1	1.5
S2	1.5
S3	2.5
S4	1.2
S5	1.0
S6	1.1
S7	2.4
S8	1.3

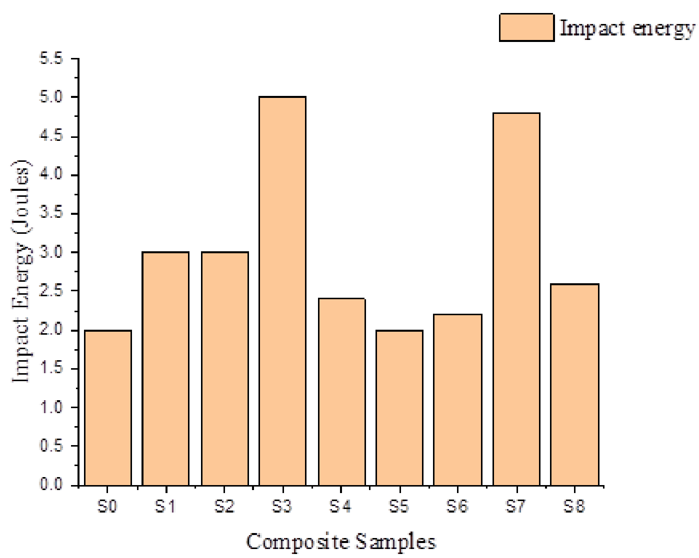

Fig. 3 Impact Test (Izod Test) result for each composite sample.

The highest impact strength, measured at 5.0 J, was obtained for Sample 3, which contained 1.5% TiO_2 and 4.5% MoS_2. This was closely followed by Sample 7, which registered 4.8 J. These results indicate that a higher proportion of MoS_2 plays a critical role in enhancing impact resistance. The solid lubricant nature of MoS_2 assists in energy absorption and dissipation during fracture, thereby contributing to improved toughness. In contrast, the unreinforced base alloy (Sample 0) absorbed only 2.0 J, highlighting the beneficial influence of the hybrid reinforcements. Similar trends have been reported in earlier works—for instance, Mula et al. (2009) observed increased impact energy in Al-based composites reinforced with lubricating ceramic particles such as graphite and MoS_2 [24]. Likewise, Sahu et al. (2019) noted that hybrid composites containing soft-phase reinforcements, including fly ash and B_4C, displayed greater resistance to dynamic loading [25]. Overall, the findings suggest that the combined addition of TiO_2 and MoS_2 produces a synergistic effect: TiO_2 contributes to strength and hardness, while MoS_2 enhances ductility and impact resistance. An optimal balance appears to occur at moderate MoS_2 concentrations, as demonstrated in Samples 3 and 7. However, when MoS_2 is added in excess or in disproportionate ratios, the structural cohesion of the composite is reduced, which explains the decline in toughness observed in Samples 5 and 6.

3.3. Tensile Testing

The tensile strength and ductility of the fabricated Al7075-based hybrid composites were evaluated using a Universal Testing Machine (UTM) in accordance with ASTM E8M standards. Sub-sized dog-bone specimens were machined for testing to determine the ultimate tensile strength and percentage elongation. The tensile tests provide crucial insights into the composite's load-bearing capabilities and its ability to withstand static loads. The results of the tensile tests, including tensile strength (**Table 5**), peak load-displacement data and load displacement curve are presented in **Fig. 4** and **Fig. 5**.

Table 5 Tensile strength (UTS) of composites.

Sample No.	Engineering UTS (N/mm²)	True UTS (N/mm²)	Elongation at break (%)
S0	210.6	220.3	4.63
S1	163.0	169.3	3.87
S2	234.3	250.0	5.15
S3	273.4	290.0	6.10
S4	114.5	118.3	3.30
S5	260.2	274.8	5.63
S6	206.8	216.1	4.50
S7	265.4	279.5	5.33
S8	266.8	281.1	5.37

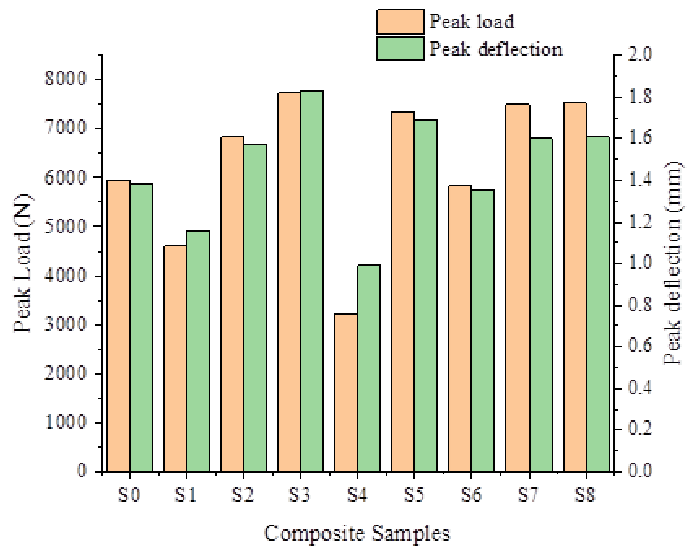

Fig. 4 Peak load and peak displacement data of all composite samples

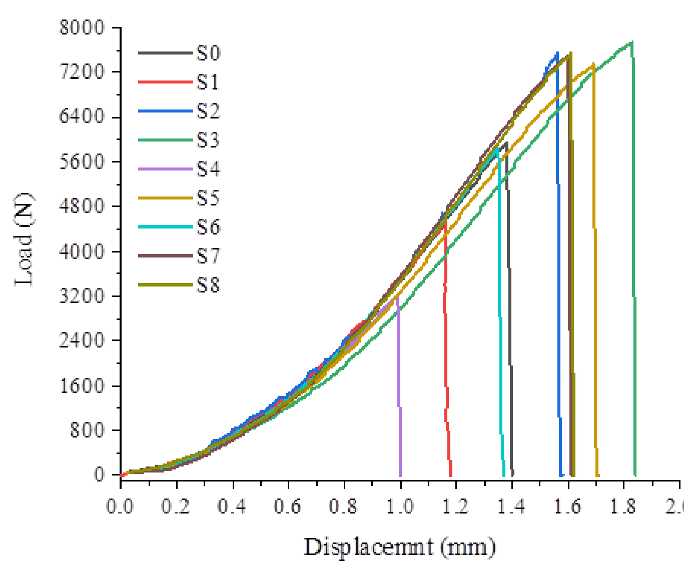

Fig. 5 Load displacement curve of fabricated composite samples obtained from tensile test

The tensile test results demonstrate the influence of TiO_2 and MoS_2 hybrid reinforcement on the mechanical performance of

Al7075 composites. Comparing the reinforced samples (Sample 1-8) to the pure Al7075 control sample (Sample 0), the addition of reinforcements generally leads to an increase in both engineering and true stress values, indicating an improvement in strength. This aligns with the overall findings of the study, which reveal notable improvements in strength and hardness compared to the unreinforced matrix. Specifically, Sample 3 exhibits the highest engineering stress (273.4 MPa) and true stress (290.0 MPa), as well as a higher strain (0.06). This sample contains 1.5 wt% TiO_2 and 4.5 wt% MoS_2. This suggests that a specific combination and proportion of TiO_2 and MoS_2 are beneficial for optimizing tensile strength, likely due to effective load transfer from the matrix to the hard ceramic (TiO_2) and the synergistic effect of the solid lubricant (MoS_2) in potentially improving ductility or interface bonding. The variations in strength and strain across the different reinforced samples (Sample 1-8), which involve varying MoS_2 content while keeping TiO_2 constant, or vice versa, highlight the sensitivity of mechanical properties to reinforcement composition and distribution. The lower stress values observed in Sample 4 (114.5 MPa Eng. Stress, 118.3 MPa True Stress) with 6.0 wt% MoS_2 and 1.5 wt% TiO_2 might indicate that an excessive amount of MoS_2 could lead to agglomeration or reduced interfacial bonding, thereby degrading the strength. Similarly, Sample 1 and 2, which have constant TiO_2 (1.5 wt%) but increasing MoS_2 (1.5% and 3.0% respectively), show initial improvement in stress (Sample 2 at 205.4 MPa Eng. Stress vs. Sample 1 at 163.0 MPa Eng. Stress), but Sample 4 shows a decrease. This suggests an optimal MoS_2 content for tensile strength.

4. Conclusions

The Al7075 hybrid composites reinforced with TiO_2 and MoS_2 demonstrated significant improvements in mechanical performance: notably, Sample 3 (1.5% TiO_2, 4.5% MoS_2) achieved the highest metrics—273.4 MPa tensile strength, 5.0 J impact energy, and 144.65 BHN hardness—indicating that optimized hybrid reinforcement can enhance strength, toughness, and wear resistance through improved load transfer and particle synergy. Looking ahead, further investigation using microstructural and SEM-EDS analysis would help clarify reinforcement dispersion, while tribological and corrosion testing would assess suitability for real-world applications; future work could also explore nano-reinforcements or functionally graded materials. Such advancements will expand the use of these composites in aerospace brackets and skin panels, automotive suspension arms and brake components, and high-impact machine casings and lightweight structural parts.

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Disclosure statement

The authors declare no relevant financial or non-financial interests.

Data availability

Raw data of the research article is available with the authors and will be provided as per request from the journal.

Ethical approval

Not applicable.

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