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Evaluation of Corrosion Behavior, Shear Stress Response, and Microstructural Characteristics of Hybrid Aluminium Metal Matrix Composites Reinforced with TiO_2 and MoS_2

Saurabh Shahi*, Rajeev Kumar

In recent years, hybrid aluminum metal matrix composites (HAMMCs) demand increased for engineering application and in harsh environments such as marine and aerial buildings. In this study, Al7075 alloy was used as the base matrix and titanium dioxide (TiO_2) and molybdenum disulfide (MoS_2) used as reinforcement material. The aim was to investigate the corrosion resistance, shear strength and microstructural characteristics of the synthesized Al7075 materials. In this research work composites were made using the melt-cast process and placed in a series of tests. Corrosion testing, Shear strength measurement, and microstructural analysis with a Scanning Electron Microscope (SEM) performed in this research work. The results showed that the combination of TiO_2 and MoS_2 s improved corrosion resistance and shear strength. Observed that the distribution of particles of reinforcement is uniform. It will help to improve the efficiency of the design and mechanical work. Overall, these findings show that hybrid reinforcement improves the strength and durability of Al7075 composites. In corrosive environments it makes them suitable for load-bearing applications. These materials (Al70750) are commonly used in the aerospace, marine, and also used where superior strength is required.

Affiliation:

Department of Mechanical Engineering, Noida Institute of Engineering and Technology, Greater Noida, Uttar Pradesh, 201306

Correspondence:

shahisaurabh5232@gmail.com

1. Introduction

Aluminium alloys, especially Al7075, have extensive applications in aerospace, shipbuilding, and structural uses because they exhibit a high strength-to-weight ratio, light weight, and inherent corrosion resistance in sea environments. Despite the foregoing benefits being at one's command, the majority of aluminium alloys have poor wear resistance along with low shear strength, thereby limiting their applications in high-stress components like heavy machinery and heavy industrial environments with abrasion. To balance such constraints, metal matrix composites (MMCs) have been developed with ceramic reinforcements in aluminium matrices to increase hardness, strength, and wear resistance. In more recent times hybrid metal matrix composites (HMMCs) utilizing two or more different reinforcements for strengthening and improving the properties of the metal. Ceramic reinforcements provide greater stiffness and wear resistance and secondary reinforcement as solid lubricants enhance toughness of the material. The titanium dioxide (TiO_2) helps in enhancing higher surface wear resistance and mechanical hardness. Molybdenum disulfide (MoS_2) as a good solid lubricant which helps in avoiding rusting surface. Mixing these reinforcements into an aluminum matrix should produce composites that hold up well both mechanically and chemically and prevent them from rusting. Many studies have explored Al7075 composites with a single type of reinforcement, yet detailed work on how TiO_2 and MoS_2 interact is still scarce especially when it comes to corrosion resistance and how the material handles shear stress under load. This study tackles the gap by creating Al7075-based hybrid composites, blending different amounts of TiO_2 and MoS_2 through the stir casting method, where molten metal swirls like thick honey in the mold. We carefully test the fabricated samples for corrosion, measure their shear strength, and study their microstructure under the microscope to see how dual reinforcements boost overall performance. Aluminium metal matrix composites, or AMMCs, are gaining attention in automotive, aerospace, and structural work because they're strong yet light, resist corrosion, and hold steady under heat like a car panel that won't warp on a scorching summer day. Even with these benefits, pure aluminium's built-in strength and wear resistance often can't keep up in tough service conditions, where grit and constant friction quickly take their toll. To get around these limits, engineers often strengthen aluminium matrices with tough ceramics and a dash of solid lubricants, like tiny graphite flakes. Titanium dioxide (TiO_2), a tough, chemically stable ceramic that holds up under heat, is widely used to boost hardness, resist wear, and increase the load-bearing strength of aluminium-based composites. In contrast, molybdenum disulfide (MoS_2) a layered solid lubricant often gets mixed in to cut friction and boost performance, especially when surfaces rub dry, like metal-on-metal without a drop of oil. Recent studies show that mixing ceramic particles with a slick, lubricating phase can boost the performance of hybrid composites. Adding TiO_2 and MoS_2 as dual reinforcements strikes a balance between mechanical strength and self-lubrication, letting AMMCs run longer and more reliably in demanding conditions, like the heat and grit of heavy machinery. Still, although these hybrid systems look promising, we know too little about how dual-phase reinforcement affects microstructure, bonding at the interface, or even corrosion like the faint pitting you might see on metal left in salt air, so they need a thorough, systematic study [5], [6]. We still don't fully understand how mechanical loading, especially under shear stress, affects the way these hybrid composites corrode, like the faint pitting that creeps along a stressed edge. This literature review takes a close look at earlier studies on Al-based hybrid composites reinforced with TiO_2 and MoS_2, zeroing in on how they resist corrosion, handle shear stress, and reveal their microstructure right down to the grain boundaries. Maivizhi Selvi et al. investigated Al6061-based composites reinforced with 6% Al_2O_3 and hybrid composites containing 6% Al_2O_3 with an additional 2% MoS_2, fabricated through stir casting. The study reported that the incorporation of Al_2O_3, a hard ceramic, enhanced tensile, compressive, flexural strength, and hardness compared to the unreinforced alloy. However, the simultaneous addition of MoS_2, a solid lubricant, slightly reduced these improvements. Microstructural analysis using optical microscopy confirmed uniform dispersion of reinforcements, while variations in density and porosity were also observed [8]. Ramadoss et al. examined the influence of incorporating silicon carbide (SiC) and MoS_2 into Al6063-T6 nanocomposites produced by stir casting. The addition of MoS_2 was observed as fine, dark particles distributed throughout the alloy matrix. The results demonstrate that the hybrid composites exhibited significantly improved wear resistance compared to the base alloy, particularly under variable loading conditions. Furthermore, corrosion resistance was enhanced, as confirmed through ASTM B117 salt spray testing, where the hybrid composites maintained a stable surface after prolonged exposure. Scanning Electron Microscopy (SEM) revealed the formation of thin protective layers on the composite surface, which served as barriers to corrosion and contributed to improved durability.

Ravikumar conducted a study on the microstructure, mechanical properties, and fracture behavior of Al6061-based hybrid composites reinforced with Al_2O_3 and MoS_2 in concentrations ranging from 0 to 9 wt.% using the stir casting process. Microstructural observations indicated a uniform distribution of reinforcements within the matrix. Increasing Al_2O_3 content enhanced both tensile and compressive strength, whereas the inclusion of MoS_2 generally reduced mechanical performance. SEM analysis of fracture surfaces revealed mixed-mode fracture behavior, characterized by microvoid formation and reinforcement particle pull-out in regions containing MoS_2 [9].

2. Materials and Methods

In this study, a composite was developed using Aluminium 7075 (Al7075) as the matrix, reinforced with Titanium Dioxide (TiO_2) and Molybdenum Disulfide (MoS_2). The materials employed in this work, along with their key properties, are summarized in **Table 1**. Percentage of reinforcements used in this study are shown in **Table 2**.

Table 1 Properties of Materials Used in Composite Fabrication.

Property	Al7075	TiO_2	MoS_2
Density (g/cm³)	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

Initially, accurately measured quantities of Al7075, TiO_2, and MoS_2 powders were weighed using a digital balance with an accuracy of ±0.01 g. 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. They eased the preheated reinforcements into the molten metal, letting each piece sink slowly into the shimmering, glowing surface. They stirred the mixture by hand with a ceramic-coated stirrer, spinning it at 600–800 rpm for 10–20 seconds, until the contents blended evenly. They poured the mixture into hot iron moulds, the metal faintly hissing, and left it cool.

Sample Preparation and Cutting Process: The team started by sawing the cast aluminium-based hybrid metal matrix composite (HMMC) bars into neat, uniform lengths, each sized precisely for mechanical and corrosion tests. We made sure every sample kept the same shape and size one uneven edge could throw off the accuracy and make results harder to repeat. They carefully weighed the Al7075 alloy along with TiO_2 and MoS_2 on a digital precision scale, the display steady to the last decimal, to keep every sample's composition exactly the same.

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

Measured Al7075 ingots along with TiO_2 and MoS_2 powders weighed out one by one, marking each batch with its exact reinforcement ratio in bold black ink. The powders were handled with care during transfer, their fine grains kept still to prevent clumping or stray dust from mixing in. For example, we weighed a sample with 3 wt% TiO_2 and 1 wt% MoS_2, taking care to keep the matrix-to-reinforcement ratio exact down to the last grain. Before melting, we scrubbed the graphite crucibles and steel moulds clean, brushing away every trace of dust until the metal smelled sharp and dry.

Mould and Furnace Preparation: Before melting began, workers scrubbed the graphite crucibles and steel moulds cleaned, then heated them until any lingering moisture hissed away, taking the last traces of dirt with it. We chose graphite crucibles for their ability to handle intense heat and stay chemically stable, so the molten alloy never reacted with the container's surface. They checked the furnace chamber and scraped away every trace of old residue, then set out the tongs, stirrers, and crucible holders on the bench so they'd be easy and safe to grab. Throughout the melting process, workers wore the right PPE and followed strict safety steps, keeping hazards from the searing heat to a minimum.

Preheating of Reinforcements: Preheating the reinforcements was essential both TiO_2 and MoS_2 powders were gently warmed before mixing to help them wet properly and avoid the sharp crack of thermal shock. They heated the powders to about 350–400°C in a separate crucible or shallow metal tray, the surface glinting faintly in the light. This step drives out moisture and volatile bits—like the faint hiss of steam—so the molten aluminium bonds more tightly.

Addition of Reinforcements into the Melt and Manual Stirring Operation: Once the melt held steady at the right temperature and the reinforcements were warmed, TiO_2 and MoS_2 powders were slowly sifted into the shimmering pool of molten aluminium. We added it a little at a time, stirring steadily so everything blended smoothly. They made sure the particles stayed suspended, neither drifting to the surface nor sinking to the bottom like sand in a jar. In stir casting, you've got to stir the mixture by hand to spread the reinforcements evenly, like swirling grit through warm, thick syrup. Fig. 1 shows a metal rod spinning through the molten mixture, churning it for roughly ten minutes at about 500–600 RPM. As you stir, a small whirlpool forms in the molten mix, pulling the reinforcements deep into the bulk matrix. Right after the last stir, the molten composite hissed as it flowed into the warm, waiting steel moulds.

Casting into Moulds and Sample Preparation with Surface Cleaning: Immediately after stirring, the molten composite was poured into preheated mild steel moulds. Pouring was done carefully to avoid oxidation and turbulence. The moulds were kept on a sand to reduce heat loss and thermal shock. The molds were left to naturally cool at room temperature after they were filled. Wire brushes and grinding wheels were used to remove unwanted oxide layers or casting fins. After marking each specimen, we cut it in accordance with the tests that were required, such as shear, corrosion, or a close examination of its microstructure under a microscope. Used a very precise caliper to measure each sample's size and weigh each one to make sure they were all the same size before carefully going over all the prepared samples. After the parts were machined and tested, this made sure they were all equal. For example, it made sure that all of the holes drilled were in the right places.

3. Results and discussion

3.1. Shear Test

Shear strength of TiO_2-MoS_2 hybrid Al7075 was assessed by applying different percentages of TiO_2 and MoS_2 using universal testing machine. Shear Tests were performed according to applying standard ASTM procedures. ASTM B831 standard used for shear testing of aluminium alloys. The sample wise ultimate shear strength of composites is shown in **Table 3** and depicted graphically in **Fig. 1**.

Table 3: Ultimate Shear Strength of Composites.

Sample No.	Ultimate Shear Strength (MPa)
S0	271.447
S1	253.559
S2	373.895
S3	594.590
S4	306.248
S5	379.820
S6	483.240
S7	585.650
S8	435.509

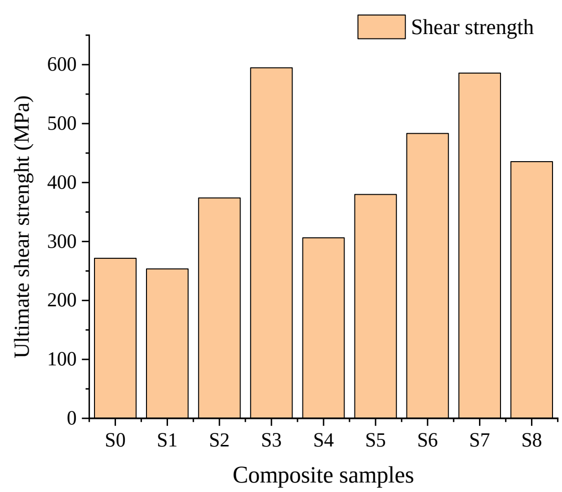

Fig 1. Ultimate Shear Strength of Composite Sample

The shear test showed that using of TiO_2 and MoS_2 reinforcements into the Al7075 matrix increased the shear strength compared to the base material. Sample S3 with 1.5% TiO_2 and 4.5% MoS_2 had the highest shear strength of 594.590. Sample S7 with 4.5% TiO_2 and 1.5% MoS_2 also achieved 585.650 MPa which is higher than the base alloy and highest in all samples. Overall, the results show that keeping the TiO_2–MoS_2 ratio balanced boosts shear strength and also raises hardness and toughness, helping the composite stay durable even when it's pressed and scratched. Shear forces and the stresses that hit from multiple directions.

3.2. Corrosion Test

We tested how hybrid composites made from Al7075, reinforced with different weight percentages of MoS_2 and TiO_2, resisted corrosion, watching how they held up when exposed to harsh, almost salty air. To know if the material will last and work well in salty or chemically harsh environments, you've got to test how it holds up against corrosion like seeing if it pits after weeks in a briny soak. To run the tests, we soaked the specimens in a 3.5% NaCl solution for a set period of about 100 hours until a faint salty film clung to their surface. As we studied the sample surfaces, the patterns of corrosion and the way the reinforcements shielded the metal became clearer; at the same time, we recorded weight loss to track exactly how much material had worn away (**Table 4**). Representative images of composite samples before and after immersion in 3.5% NaCl solution are shown in **Fig. 2** and **Fig. 3**.

Table 4. Initial Weight and Weight Loss of Composites After Corrosion Test.

Sample No.	Initial Weight (g)	Final Weight Loss (g)	Difference
S0	2.983	2.968	0.015
S1	2.998	2.986	0.012
S2	2.820	2.780	0.04
S3	2.983	2.846	0.137
S4	3.039	3.017	0.022
S5	2.965	2.955	0.01
S6	3.010	2.989	0.021
S7	2.830	2.786	0.044
S8	3.289	3.279	0.01

Fig. 2. Representative Images of Composite Samples Before Immersion in 3.5% NaCl Solution.

Fig. 3. Representative Images of Composite Samples After Immersion in 3.5% NaCl Solution.

Corrosion tests on Al7075-based hybrid composites showed that some reinforcement mixes held up best in a 3.5% NaCl solution, with the surface staying smooth instead of pitted. In particular, **Samples S5 (1.5% TiO_2, 1.5% MoS_2)** and **S8 (6.0% TiO_2, 1.5% MoS_2)** exhibited the lowest weight loss, indicating enhanced corrosion resistance. The boost comes from a thin MoS_2 layer that shields the aluminium, keeping corrosive agents from seeping in like water through a cracked roof. On top of that, TiO_2's chemical inertness works like a shield, blocking contact and giving the surface extra toughness.

In contrast, Sample S3 (1.5% TiO_2, 4.5% MoS_2) the one with the strongest mechanical results lost the most weight, hinting at weaker corrosion resistance as its surface dulled. A higher MoS_2 content might've created more active sites for galvanic reactions or caused the protective film to form unevenly like patches of thin paint leaving the surface more vulnerable to corrosion. Samples with mid-range TiO_2 and MoS_2 levels showed different amounts of wear some surfaces dulled at the edges making it clear that boosting mechanical strength doesn't always deliver the best corrosion resistance. These findings highlight how crucial it is to fine-tune the balance of TiO_2 and MoS_2 in hybrid composites, adjusting the mix to achieve just the right blend of strength and corrosion resistance like choosing the perfect ratio of grit and polish in a metal finish. The results point to a clear need for more research to fully uncover how corrosion develops in these dual-reinforced Al7075 composites, right down to the first faint pitting on the metal's surface.

3.3. Microstructural Analysis

We used Scanning Electron Microscopy (SEM) to study how the reinforcement particles were spread and to see the fine microstructural details in the hybrid aluminium matrix composites for Sample 0 (**Fig. 4**), Sample 3 (**Fig. 5**), and Sample 7 (**Fig. 6**), not even tiny grain patterns in the images. We chose these samples to show the unreinforced base alloy, a medium-level reinforcement mix, and one with the highest reinforcement like moving from bare metal to its most fortified form.

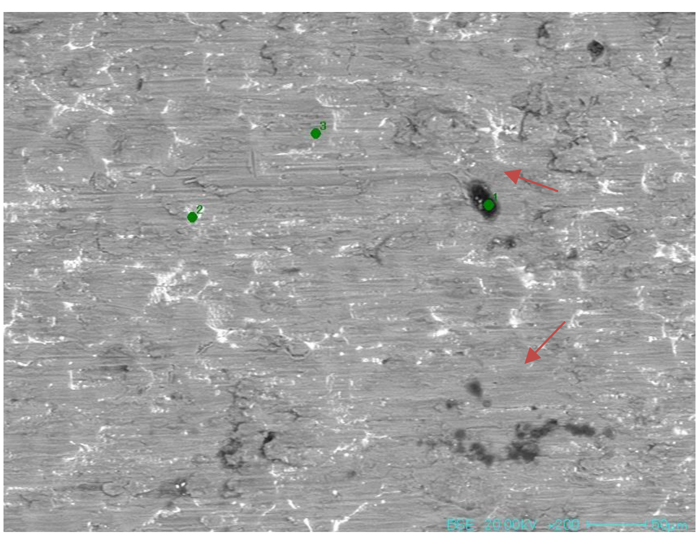

Fig. 4. SEM micrograph of Sample 0 (0% TiO_2 and MoS_2).

In the SEM micrograph of Sample 0 (unreinforced Al7075), the aluminium matrix lies smooth and even, just as you'd expect without any reinforcing particles. The microstructure exhibits fine grains along with occasional micro-voids and casting pores, which are typical features of cast aluminium alloys. Due to the lack of TiO_2 and MoS_2 particles, there are no additional nucleation sites, resulting in a coarser grain structure compared to reinforced samples. Furthermore, no distinct secondary phases or phase contrasts are observed, confirming the homogeneity of the base alloy matrix.

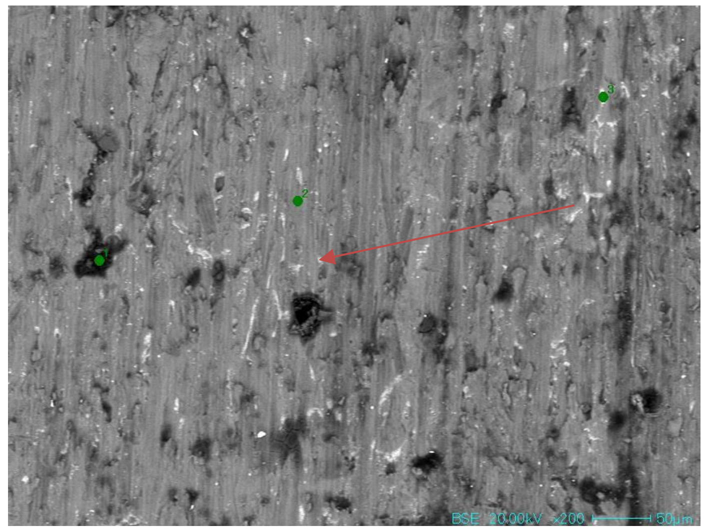

Fig 5. SEM micrograph of Sample 3 (with moderate TiO_2 and MoS_2 content)

In Sample 3, the presence of reinforcement particles becomes noticeable. The microstructure exhibits evenly dispersed TiO_2 and MoS_2 particles embedded within the Al7075 matrix. These reinforcements act as grain refiners, leading to a more refined and compact grain structure compared to Sample 0. Some micro-clusters of particles can be observed, which might be due to slight agglomeration during stir casting. However, the particle distribution remains reasonably uniform. The interface bonding between the matrix and reinforcements appears satisfactory with minimal porosity, indicating effective wettability.

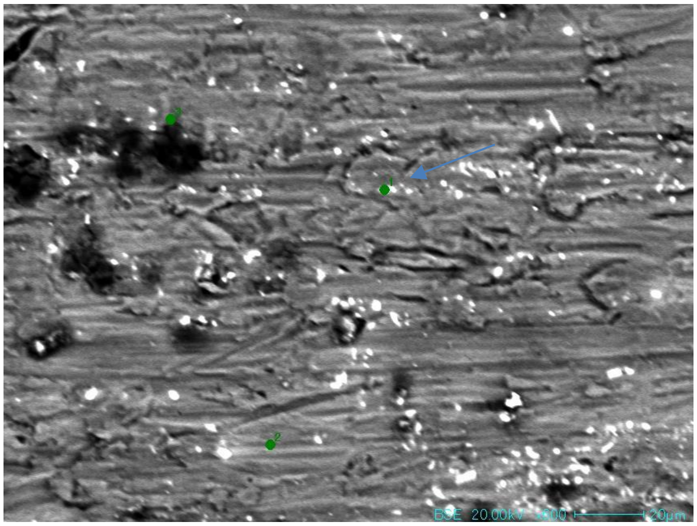

Fig. 6. SEM micrograph of Sample 7 (highest TiO_2 (6%) and MoS_2 content).

The SEM image of Sample 7 shows a dense population of reinforcement particles, indicating the highest loading of TiO_2 and MoS_2. The distribution is generally uniform, though localized agglomeration is more prominent in some areas due to the high reinforcement content. Despite this, the overall grain structure appears highly refined, and the microstructure is closely packed, indicating enhanced densification. Some micro-cracks or interfacial gaps may be present around agglomerate regions, which could act as potential sites for stress concentration under mechanical loading. Nevertheless, the matrix–particle interface in most regions is well bonded.

- The SEM microstructural analysis confirms that the addition of TiO_2 and MoS_2 significantly modifies the morphology and grain structure of Al7075:
- Sample 0 (unreinforced) shows a coarse-grained, porous matrix with no reinforcements.
- Sample 3 shows better homogeneity and grain refinement, with moderate particle incorporation.
- Sample 7, despite showing some agglomeration, has the finest grain structure, most compact morphology, and highest particle concentration.
- The results clearly indicate that reinforcement particles act as nucleation sites during solidification, which leads to grain refinement and improved matrix bonding. However, beyond a certain limit, excess reinforcement can result in agglomeration and interfacial gaps, which may slightly affect mechanical integrity.

3. Conclusions

The study demonstrates that adding a hybrid reinforcement of TiO_2 and MoS_2 significantly improves the shear strength of Al7075 composites, with Sample S3 (1.5 wt% TiO_2, 4.5 wt% MoS_2) showing the highest shear strength due to an optimal balance that enhances load transfer and reduces internal friction. Sample S7 (4.5 wt% TiO_2, 1.5 wt% MoS_2) also exhibited high shear strength, highlighting the important strengthening role of TiO_2. However, samples with either low or excessive reinforcement showed reduced shear strength, likely due to poor particle distribution or agglomeration. In terms of corrosion resistance, Samples S5 and S8 (both with 1.5 wt% MoS_2 but different TiO_2 content) demonstrated superior resistance, likely because MoS_2 forms a protective film that limits corrosion, while chemically inert TiO_2 acts as a physical barrier. Interestingly, Sample S3, which excelled mechanically, exhibited the highest corrosion rate, suggesting that excessive MoS_2 may promote galvanic corrosion or disrupt protective film uniformity. These observations show there's a careful trade-off between mechanical strength and corrosion resistance, underscoring the need to fine-tune reinforcement levels for the exact job whether it's holding up a bridge or sealing a marine joint. SEM analysis showed that adding TiO_2 and MoS_2 refined the grains and made the matrix more uniform, with the particles acting like tiny seeds around which the metal solidified. Of all the samples, S7 showed the finest grain structure and the most reinforcement particles, but clusters of particles like tiny clumps of sand were also visible and could weaken performance if they became too numerous. The results show that, with the right balance of TiO_2 and MoS_2, hybrid reinforcement can boost both the strength and corrosion resistance of Al7075 composites like giving the metal a tougher skin and a longer life. The findings show we need deeper studies to uncover exactly how the corrosion starts like where the first faint rust spots form and to fine-tune composite designs for specific uses.

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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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