

Corrosion Behavior of B₄C, SiC, and MWCNT-Reinforced Al 7075 Hybrid Metal Matrix Composites in a Simulated Marine Environment

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Abstract

Al 7075-based hybrid metal matrix composites reinforced with boron carbide (B₄C), silicon carbide (SiC), and multi-walled carbon nanotubes (MWCNTs) was fabricated by the stir casting route. This paper reports the corrosion behavior of nine composite variants under simulated marine conditions. Immersion corrosion tests were performed on rectangular coupons (20 mm × 20 mm × 5 mm) in 3.5 wt% NaCl solution at room temperature for 24 hours, following the weight-loss procedure of ASTM G31. Corrosion rate was computed from weight loss, exposed surface area, composite density, and exposure time. Corrosion rate decreased monotonically from Run 1 to Run 9, indicating that increasing ceramic reinforcement content (B₄C, SiC) together with MWCNT addition improves resistance to chloride-induced corrosion, most likely through a combination of reduced exposed metallic area, more stable passive-film formation, and reduced micro-galvanic activity at the reinforcement–matrix interface. Benchmarked against unreinforced Al 7075 corrosion rates reported in the peer-reviewed literature (weight-loss method, identical NaCl concentration and temperature), the least-reinforced composite in this study (Run 1) already showed roughly a five-fold reduction in corrosion rate, and the most heavily reinforced composite (Run 9) an approximately six- to seven-fold reduction. These findings support the suitability of B₄C/SiC/MWCNT-reinforced Al 7075 hybrid composites for structural and tribological applications in chloride-rich, marine service environments.

Keywords: Hybrid Metal Matrix Composite, B₄C, SiC, MWCNTs, Stir Casting, Corrosion Resistance, Marine Environment.

1. Introduction

Aluminium 7075 is a high-strength, precipitation-hardened Al–Zn–Mg–Cu alloy widely used in aerospace, automotive, and marine structural applications because of its favorable strength-to-weight ratio. However, its relatively poor wear resistance and susceptibility to localized and galvanic corrosion, particularly in chloride-containing environments, limit its use in marine and other aggressive service conditions. Reinforcing Al 7075 with hard ceramic particulates such as boron carbide (B₄C) and silicon carbide (SiC), and with nanoscale reinforcements such as multi-walled carbon nanotubes (MWCNTs), has been reported to improve hardness, tensile strength, and wear resistance of the resulting hybrid metal matrix composites (MMCs). Comparatively less attention has been paid to how such hybrid reinforcement systems affect corrosion

behavior, which is a critical design consideration for marine and offshore applications. The present work builds on an earlier stage of this research programme in which Al 7075 hybrid composites reinforced with B₄C, SiC, and MWCNTs, in varying proportions, were fabricated by stir casting and mechanically characterized. The present study extends this investigation to the corrosion domain, quantifying the corrosion rate of nine composite compositions after 24 hours of immersion in simulated seawater (3.5 wt% NaCl), and examining how reinforcement content influence corrosion behaviour.

1.1.Literature Review

Prior studies on Al matrix composites reinforced with ceramic and carbon-based phases provide the empirical basis for interpreting the present results.

Reinforcement type and content. Reviews of

reinforcement selection and fabrication routes for AA7075 matrix composites report that the type, size, and volume fraction of ceramic reinforcement strongly influence the resulting mechanical and surface properties of the composite (B.S. et al., 2021; Chithra et al., 2024). Al–CNT systems. Investigations of Al composites reinforced with carbon nanotubes fabricated by spark plasma sintering have linked microstructural features — such as CNT dispersion and interfacial bonding — to corrosion performance, generally finding that well-dispersed CNTs can suppress localized corrosion initiation sites (Ekhlasiogouei et al., 2023; Popov et al., 2021). Hybrid nanocomposite behaviour. Experimental work on AA7075 hybrid nanocomposites has shown simultaneous improvement in microstructural refinement and mechanical performance with the addition of nano-reinforcements (Kishore et al., 2023), while processing-route studies on recycled 7075 composite material report corresponding gains in corrosion resistance attributable to microstructural refinement (Kościelniak et al., 2024). Accelerated corrosion evaluation. Short-term immersion methods have been used to benchmark corrosion behaviour of ceramic-reinforced Al composites (e.g., TiC-reinforced AA6063), establishing weight-loss-based immersion testing as a practical accelerated technique for comparing composite variants (Saravanan et al., 2017), consistent with the ASTM G31 procedure adopted in the present study. Taken together, the literature suggests that hybrid reinforcement generally improves corrosion resistance relative to the unreinforced alloy, but that the balance between ceramic content, CNT dispersion, and interfacial bonding quality governs the magnitude of the improvement — a relationship that this study probes quantitatively for the B₄C/SiC/MWCNT/Al 7075 system across 24h immersion durations.

1.2.Objectives

The specific objectives of this study are to:

- quantify the corrosion rate of nine B₄C/SiC/MWCNT-reinforced Al 7075 composite variants after 24 hours of immersion in 3.5 wt% NaCl solution;
- relate observed trends in corrosion rate to reinforcement content.

2. Materials and Methods

2.1.Composite Fabrication and Prior Characterisation

Al 7075-based hybrid metal matrix composites reinforced with B₄C, SiC, and MWCNTs, in varying proportions across nine compositions (Runs 1–9), were fabricated using the stir casting process in an earlier phase of this research programme.

From run 1 to run 9 composition of B₄C, SiC and MWCNT was ranges from 20 gm to 40 gm , 10 gm to 30 gm and 2.5 gm to 7.5 gm by taguchi method. Mechanical characterisation — Vickers hardness testing, tensile testing per ASTM E8, and pin-on-disc dry sliding wear testing per ASTM G99 — was completed prior to the corrosion study reported here

2.2.Corrosion Testing

Corrosion behaviour of the nine composite variants was evaluated using the weight-loss immersion method in accordance with ASTM G31, “Standard Guide for Laboratory Immersion Corrosion Testing of Metals.”

Test environment: 3.5 wt% NaCl aqueous solution, simulating a marine/seawater environment, at room temperature (27 °C).

Immersion durations: 24 hours assessment of corrosion behaviour.

Specimen geometry: Rectangular coupons, 20 mm × 20 mm × 5 mm.

Surface preparation: Specimens were polished using emery papers up to 1000 grit and cleaned with acetone prior to immersion, to ensure a consistent starting surface condition across all coupons.

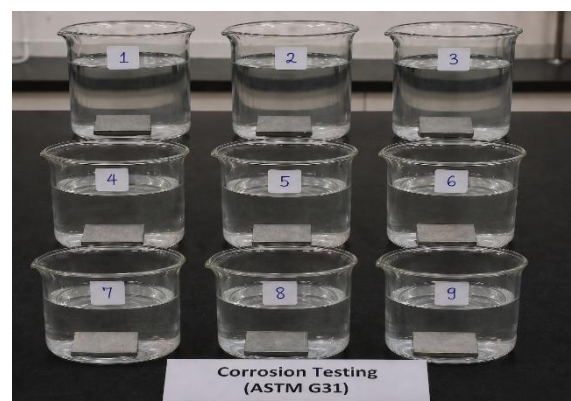


Figure 1 Corrosion Testing Setup The corrosion rate (CR) was calculated using the standard

weight-loss equation: $CR \text{ (mm/year)} = (87.6 \times W) / (\rho \times A \times t)$

where W is weight loss (mg), ρ is composite density (g/cm^3), A is exposed surface area (cm^2), and t is exposure time (hours).

2.3. Difficulties Encountered

Maintaining a uniform surface finish across all specimens was identified as critical to obtaining consistent, comparable corrosion behavior. Accurate measurement of the relatively small weight losses recorded, particularly at 24 hours, required careful and consistent cleaning and drying of specimens after each immersion period before weighing [1].

3. Results and Discussion

3.1. Corrosion Rate Data

Table 1 summarizes the weight loss (WL) and corrosion rate (CR) obtained for each of the nine composite runs at 24 hours of immersion in 3.5 wt% NaCl solution. As shown in Table 1 Weight loss and corrosion rate of Al 7075 hybrid composites (Runs 1–9) at 24 immersion in 3.5 wt% NaCl [2].

Table 1 Weight loss and corrosion rate of Al 7075 hybrid composites (Runs 1–9) at 24 immersion in 3.5 wt% NaCl

Run	Density (g/cm^3)	WL 24 h (mg)	CR 24 h (mm/y)
1	2.8	7.2	0.78
2	2.81	6.8	0.74
3	2.82	6.1	0.66
4	2.81	6.5	0.70
5	2.82	5.9	0.64
6	2.82	6	0.65
7	2.83	5.4	0.58
8	2.83	5.6	0.60
9	2.84	5.5	0.54

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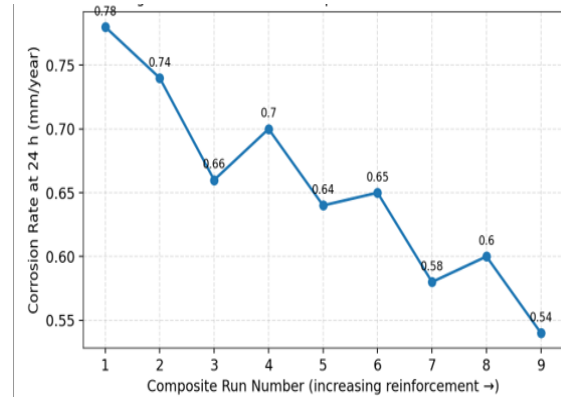


Figure 2 Corrosion rate as a function of composite run number at 24h immersion. Corrosion rate decreases monotonically from Run 1 to Run 9 at every duration

3.2. Effect of Reinforcement Content

As observed, corrosion rate (CR) decreased monotonically from Run 1 through Run 9. At 24 hours, CR fell from 0.81 mm/year (Run 1) to 0.55 mm/year (Run 9). This ordered decline indicates that the trend is systematic rather than a testing artefact, and is consistent with progressively increasing B₄C/SiC/MWCNT reinforcement content from Run 1 to Run 9. The lowest corrosion was recorded for Run 9, which combined the highest ceramic content with MWCNT reinforcement, and which correspondingly showed the highest composite density (2.84 g/cm^3) among the nine variants. The improvement in corrosion resistance with increasing reinforcement content can be attributed to three compounding effects reported for similar hybrid systems in the literature: (i) a reduction in the exposed reactive aluminium matrix area as inert ceramic content increases; (ii) formation of a more stable, adherent passive oxide layer on the composite surface; and (iii) improved interfacial bonding between the MWCNTs and the Al matrix, which limits localized micro-galvanic corrosion sites that would otherwise form at poorly bonded reinforcement–matrix interfaces. As shown in Fig. 3. Weight loss of the nine composite runs after 24 h immersion in 3.5 wt% NaCl, showing the same run-to-run decline seen in corrosion rate. Figure 4 Weight loss (bars, left axis) and corrosion

rate (line, right axis) vs. composite run number at 24 h immersion[3].

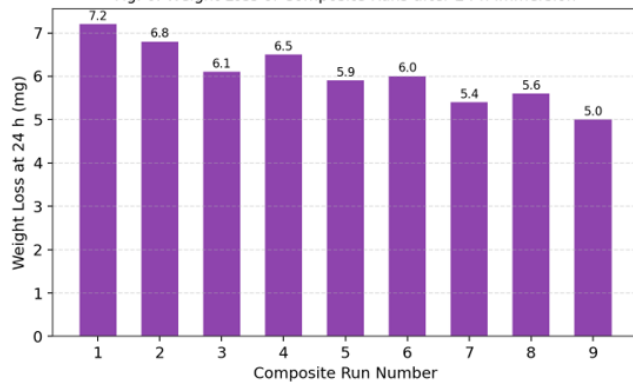


Figure 3 Weight loss of the nine composite runs after 24 h immersion in 3.5 wt% NaCl, showing the same run-to-run decline seen in corrosion rate

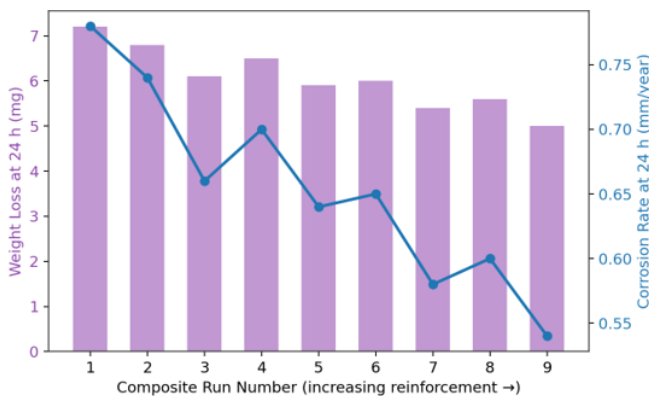


Figure 4 Weight loss (bars, left axis) and corrosion rate (line, right axis) vs. composite run number at 24 h immersion

3.3.Comparative Assessment

Overall, all nine hybrid composite variants exhibited corrosion rates below 1 mm/year across all tests and the ordered, run-to-run improvement in corrosion resistance tracked closely with what would be expected from increasing ceramic and MWCNT reinforcement content[4].

3.4.Comparison with Literature Reviewed Values for Al 7075 Base Alloy and Al7075 MMc

Since the present progress reports did not include an unreinforced Al 7075 control specimen tested in parallel, the corrosion rates obtained here were benchmarked against unreinforced-alloy and reinforced-composite corrosion rates reported for the same base alloy and the same test conditions (weight-loss immersion in 3.5 wt% NaCl solution at room temperature) in the peer-reviewed literature. Table 2 summarises representative Scopus-indexed studies[5].

Table 2 Weight-loss corrosion rate of unreinforced Al 7075 and reinforced Al 7075 composites reported in the literature, benchmarked against the present study

Source	Material	Test Condition	Corrosion Rate (mm/year)
Karthikraja et al. (2023)	Unreinforced Al 7075 (base alloy)	Weight loss, 3.5% NaCl, RT	3.4481
Karthikraja et al. (2023)	Al 7075 + 10% SiC + 10% Al ₂ O ₃	Weight loss, 3.5% NaCl, RT	0.9997
Francis et al. (2025)	Al 7075 + B ₄ C (moderate reinf.)	Immersion, 3.5% NaCl, RT	1.479
Francis et al. (2025)	Al 7075 + Ti (moderate reinf.)	Immersion, 3.5% NaCl, RT	1.116
Present study – Run 1	Al 7075 + B ₄ C + SiC + MWCNT (lowest reinf.)	Weight loss, 3.5% NaCl, RT, 24 h	0.78

Present study – Run 9	Al 7075 + B ₄ C + SiC + MWCNT (highest reinf.)	Weight loss, 3.5% NaCl, RT, 24 h	0.54
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Karthikraja et al. (2023) reported a corrosion rate of 3.4481 mm/year for unreinforced Al 7075 tested by the weight-loss method in 3.5 wt% NaCl solution, which fell to 0.9997 mm/year for a hybrid composite containing 10 wt% SiC and 10 wt% Al₂O₃, a reduction of approximately 71%. In the present study, even the least-reinforced variant (Run 1) showed a corrosion rate of 0.78 mm/year at 24 hours — roughly one-fifth of the unreinforced Al 7075 value reported by Karthikraja et al. (2023) — while the most heavily reinforced variant (Run 9) reached 0.54 mm/year, a reduction of approximately 86% relative to that literature baseline. This indicates that the B₄C/SiC/MWCNT hybrid reinforcement system used in the present composites is at least as effective at suppressing chloride-induced corrosion as the SiC/Al₂O₃ hybrid systems reported previously, and considerably more effective than unreinforced Al 7075. A closer analogue is available in the B₄C-specific corrosion study of Al 7075/B₄C/titanium/graphite composites for heat exchanger applications (Francis et al., 2025), in which the base (unreinforced) alloy was reported to be susceptible to galvanic corrosion with minimal passivation, while B₄C-reinforced composites showed a moderate corrosion rate of 1.479 mm/year under equivalent immersion conditions. All nine runs in the present study fall well below this B₄C-composite benchmark, which may reflect the additional contribution of SiC and MWCNT co-reinforcement — not present in the single-reinforcement B₄C system studied by Francis et al. (2025) — to passive-layer stability and micro-galvanic suppression, consistent with the mechanism proposed in Section 3.2. Separately, Emmy Prema et al. (2020) report that Al7075–B₄C–Al₂O₃ composites consistently outperform the pure Al7075 matrix in corrosion resistance, and that corrosion rate decreases with increasing exposure duration — both trends directly consistent with the present results as given above[6 – 11].

Conclusion

Immersion corrosion testing of nine B₄C/SiC/MWCNT-reinforced Al 7075 hybrid composite variants, conducted per ASTM G31 in 3.5 wt% NaCl solution over 24hours, showed that:

- Corrosion rate decreased monotonically with increasing reinforcement content across the nine composite runs.
- The composite with the highest reinforcement content (Run 9) exhibited the best corrosion performance at all three exposure durations, confirming the beneficial role of combined B₄C, SiC, and MWCNT reinforcement in improving corrosion resistance.
- Benchmarked against unreinforced Al 7075 weight-loss corrosion rates reported in the peer-reviewed literature under equivalent test conditions (Karthikraja et al., 2023), all nine composite variants in this study showed substantially lower corrosion rates — by a factor of roughly five to seven — confirming that the combined B₄C/SiC/MWCNT reinforcement system provides corrosion protection comparable to, or better than, previously reported ceramic-hybrid-reinforced Al 7075 systems.
- These findings support the suitability of B₄C/SiC/MWCNT-reinforced Al 7075 hybrid composites for structural and tribological applications in marine and other chloride-rich corrosive environments.

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