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Effect of Shear Stress, Corrosion Behavior, and Microstructural Analysis of Al7075-B_4C-TiO_2 Hybrid Metal Matrix Composite Fabricated by Electro-magnetic Stir Casting

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The present work delves into how the phenomena of shear stress and corrosion affect the structure of a hybrid metal matrix composite (HMMC) fabricated from the Al-7075 alloy strengthened with titanium dioxide (TiO_2) and boron carbide (B_4C) particles. To achieve better homogeneity and distribution of the reinforcements in the matrix, the electromagnetic stir casting method was employed to manufacture the composite. The plasticity and failure mechanisms of the composite are characterized by testing specimens subjected to different shear stress conditions. On the other hand, corrosion activity in 3.5% NaCl solution was analyzed to investigate how catalysts affect the electrochemical stability of the alloy. Due to increased bonding and microstructural modification, shear strength is significantly increased due to the synergistic effect of B_4C and TiO_2. Nevertheless, the synergy of the two reinforcement types led to a complex response of corrosion resistance, with TiO_2 affecting the general corrosion rate while B_4C facilitating the formation of the passive layer. The results demonstrate the importance of controlling mechanical stress and corrosion resistance, which also provides valuable information for applications in the aerospace, marine and aviation industries.

KEYWORDS: **Al-7075; Electromagnetic Stir Casting; Boron Carbide; TiO_2, Microstructure.**

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1. Introduction

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Aluminum 7075 is an alloy that is commonly used in aerospace and structural applications because of its high strength-to-weight ratio, but it has a problem with corrosion resistance. It has been found that the addition of ceramic reinforcements such as B_4C and TiO_2 will improve the mechanical and corrosion properties to a great extent [1-2]. One of the advantages of hybrid reinforcement is that it can utilize the good properties of both materials: B_4C can provide the material with hardness and strength, and TiO_2 can supply better corrosion protection by the formation of passive films [3-4]. In a very short time, the global demand for materials that are both lightweight and strong has doubled. The main factors behind this trend are the requirements of fuel-efficient cars and the environmental concerns of the ozone layer. These materials are essential for applications where traditional alloys fail. The choice of the electromagnetic stir casting (EMSC) method to solve the problem of non-uniform particle distribution in casting has turned out to be a very good solution [5-6]. Additionally, the knowledge of the net effect of using multi-reinforcements is very important when it comes to designing the right features to meet the specifications of the engineering demands. Hybrid composites can simultaneously draw from the toughness and wear resistance of B_4C as well as the corrosion-resisting nature of TiO_2, making them potentially very suitable for service under very harsh environments. On the other hand, the most significant challenge in achieving uniform microstructure and strong interfacial bonding is still disaffiliation under such advanced casting methods. Some relevant works emphasized the emerging trends in Al-based hybrid metal matrix composites (MMCs), by explaining the influence of various reinforcements on mechanical as well as tribological behavior [7]. Stir casting method was used by researchers to fabricate Al7075 based hybrid composites and revealed that the addition of dual reinforcements increases the hardness as well as tensile strength up to a great extent [8]. In another study, the role of B_4C and fly ash reinforcements in MMCs was studied for wear resistance and grain refinement progress [9]. The research based on TiO_2 additions revealed that TiO_2 leads to corrosion resistance in saline environments in a very efficient way [10]. The EMSC method is found to be very efficient for uniform distribution of particles by significantly breaking their clustering as compared to traditional stirring techniques [11]. The above-mentioned research studies collectively established a theoretical foundation for investigating the synergistic effects of uniformly distributed B_4C and TiO_2 reinforcements on the microstructure, shear strength, and corrosion behavior of Al7075 composites.

The present research contributes to the body of literature on hybrid metal matrix composites by providing experimental evidence on how the properties of Al7075 can be tailored through controlled reinforcement percentages.

2. Materials and Methods

Al7075 aluminum alloy was selected as the primary matrix material because it is widely used in structural and aerospace applications. It is known for its impressive strength and outstanding fatigue resistance. The chemical composition of Al7075 aluminum alloy is shown in Table 1. The basic mechanical properties of Al7075 aluminum alloy are listed in Table 2.

Boron Carbide (B_4C) and Titanium Dioxide (TiO_2) particles of 30 microns and 20 microns are used as reinforcement material (**Fig. 1(a) and Fig. 1(b)**). High-tech sectors including light weaponry, fast breeding, and high-temperature thermoelectric conversion use boron carbide. Excellent mechanical properties include a wide cross-section for neutron absorption, a low specific weight, a high melting point, and high hardness [12]. The applications of titanium dioxide (TiO_2) as a catalyst, photocatalyst, antibacterial agent, and nanocolor (self-cleaning) have all been well studied. TiO_2 doped with noble metals is therefore a great option for performance in these applications. The crystalline phase, particle size, and shape all affect TiO_2's physical and chemical characteristics.

First, the pieces of Al 7075 alloy were put into crucible (**Fig. 1(c)**) [Size No. 3] and heated in the furnace. Using a billet, the parts were cut to fit the crucible's dimensions. To make one casting, 300g of aluminium alloy 7075 must be melted. In parallel, particles of titanium dioxide and boron carbide were weighed based on the composition of the sample, deposited in crucible [Size No. 1], and then heated. They were both heated to about 400°C. The main line is then turned on, and the wheel of the autotransformer rotates to progressively supply power to the motor. The wheel must be turned gently; if it is turned too quickly, the great rotational force may cause the molten metal to escape the crucible. When the right vortex forms in the melt, the speed is measured. With the aid of a reinforcement feeder, the reinforcements are now progressively injected into the walls of the vortex. Particle aggregation in the finished composite may result from adding it all at once. Inside the motor cavity are the crucible and the rotating melt. After the crucible is removed from the motor cavity, the melted composite material fills the die, which is composed of mild steel and the dimension of die is 23 mm in thickness, 75 mm in width, and 160 mm in height. After filling the mold with the composite material, it cools at room temperature for two to three hours. The workpiece and open die are prepared for machining.

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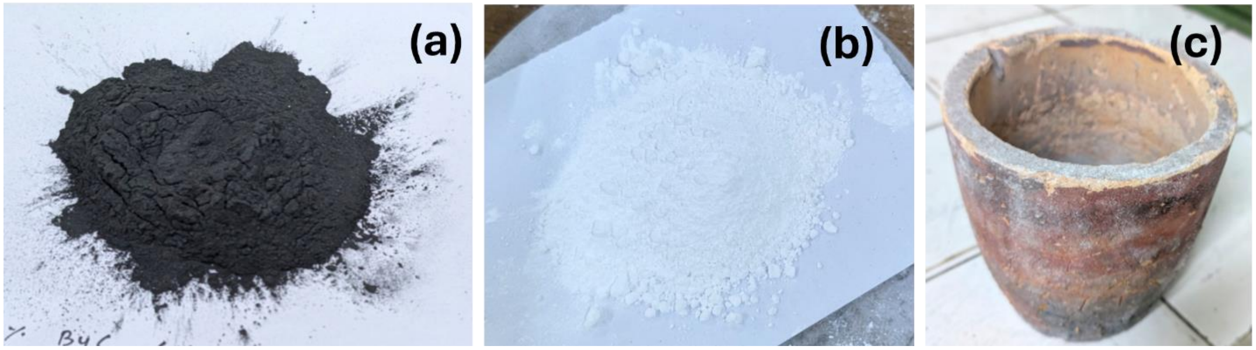

Fig. 1(a) Boron Carbide Powder, (b) Titanium Dioxide Powder, (c) Ceramic crucible.

Table 1. Processing parameters to fabricate Al7075-B_4C-TiO_2 Hybrid Metal Matrix Composite.

Sample name	Material composition	Temperature (°C)	Stir speed (rpm)	Stir time (s)
0	Al7075+ 0%B_4C + 0% TiO_2	900	-	-
1	Al7075+ 2% B_4C + 2% TiO_2	900	600	10
2	Al7075+ 4% B_4C + 4% TiO_2	1000	600	15
3	Al7075+ 6% B_4C + 6% TiO_2	1100	600	20
4	Al7075+ 2% B_4C + 2% TiO_2	900	700	15
5	Al7075+ 4% B_4C + 4% TiO_2	1000	700	20
6	Al7075+ 6% B_4C + 6% TiO_2	1100	700	10
7	Al7075+ 2% B_4C + 2% TiO_2	900	800	20
8	Al7075+ 4% B_4C + 4% TiO_2	1000	800	10
9	Al7075+ 6% B_4C + 6% TiO_2	1100	800	15

3. Results and discussion

3.1. Shear Stress Test

The specimen for the Al7075/TiO2/B4C HMMC shear stress test has been created (Dia=6mm, L=40 mm). The table displays the parameters for the Shear Stress test.

Table 2. Shear stress test results of Al7075-B_4C-TiO_2 Hybrid Metal Matrix Composite.

Sample name	Shear Strength (MPa)
0	320
1	325
2	321
3	340
4	337
5	320
6	325

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7	333
8	344
9	350

The samples before and after shear tests are shown in **Fig. 2**.

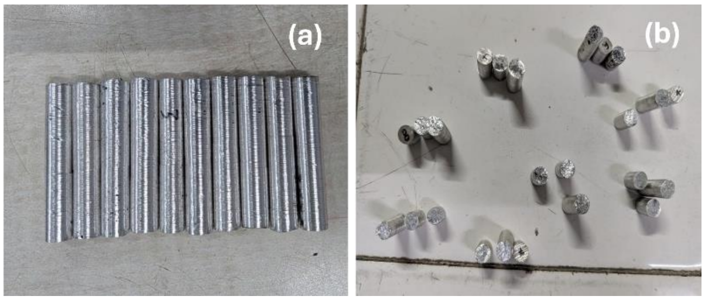

Fig. 2 Shear stress samples before and after test.

3.2. Corrosion Test

Corrosion behavior was evaluated using weight loss and potentiodynamic polarization methods in 3.5% NaCl solution. Samples were immersed for 120 hours, and corrosion rates were calculated. Table 3 shows a 0.001 g Weight loss in Sample 0, 2 and 4 after 120 hrs. While superior corrosion rate is found in the rest of samples. Samples in NaCl solution, samples for corrosion test and samples after corrosion test are shown in **Fig. 3.**

Table 3. A Weight loss of 0.001 g in Sample 0, 2 and 4 after 120 hrs.

Sample No.	W_i (g)	W_f (g)	W= (W_i-W_f) g
0	2.528	2.527	0.001
1	2.278	2.278	0
2	2.477	2.476	0.001
3	2.60	2.60	0
4	2.302	2.301	0.001
5	2.128	2.128	0
6	2.481	2.481	0
7	2.102	2.102	0
8	2.769	2.769	0
9	2.518	2.518	0

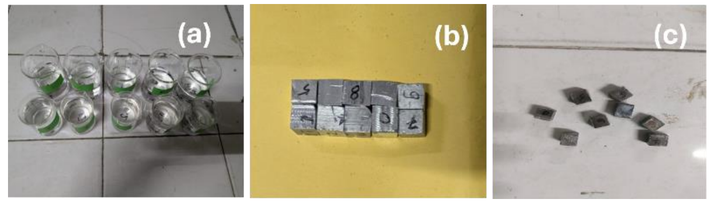

Fig. 3(a) Sample in NaCl solution, (b) Samples for corrosion test, (c) Samples after corrosion test.

3.3. Microstructural Test

SEM (Scanning Electron Microscopy) was performed to study the surface morphology and distribution of reinforcement particles in different AL7075-based composites with varying percentage of B_4C and TiO_2 (**Fig. 4**)

- **Sample 0** (0% B_4C & 0% TiO_2) showed a relatively smooth surface with minimal reinforcement and clear signs of surface irregularities, voids and micro-cracks. This indicates poor load-bearing capacity and a weaker matrix.
- **Sample 6** exhibited visible scratches and grooves along with scattered micro-particles embedded across the surface. These could be due to partial reinforcement distribution and some plastic deformation from mechanical testing.
- **Sample 3** presented improved surface uniformity with fewer defects compared to sample 0. The presence of fine particles suggests better dispersion of reinforcements, contributing to enhanced mechanical strength.
- **Sample 9,** which had the highest reinforcement content, showed a dense and uniform distribution of particles across the matrix. The surface appeared more refined and compact, with minimal cracks or porosity. This indicates strong interfacial bonding between the matrix and reinforcement.

3. Conclusions

1. The Al7075-B_4C-TiO_2 HMMC specimens demonstrated good mechanical and corrosion resistant properties. The shear stress test showed a narrow range of strength values, suggesting uniform distribution of reinforcement and strong interfacial bonding. The maximum shear strength reached 350 MPa, with most samples clustering around the mid-320 to 340 MPa.

2. In terms of corrosion resistance, the weight loss observed in only three out of 10 samples confirms that the composite material offers excellent stability in chloride-rich environments. Therefore, this HMMC composite is a promising candidate for structural applications requiring both mechanical strength and corrosion resistance.

3. The SEM analysis clearly demonstrates the influence of B_4C-TiO_2 reinforcement on the microstructure of al7075 composites. As the reinforcement percentage increased, surface quality improved, and the material showed fewer defects and better particle distribution.

4. Specially, Sample 9, which had the highest amount of reinforcement, showed the most uniform and refined microstructure. This correlates with its highest shear strength observed in mechanical testing. In contrast, the unreinforced Sample 0 had visible microstructural flaws, reflecting its lower mechanical performance.

5. These observations confirm that the addition of B_4C and TiO_2 significantly enhances the microstructural integrity and mechanical behavior of AL7075 hybrid composites.

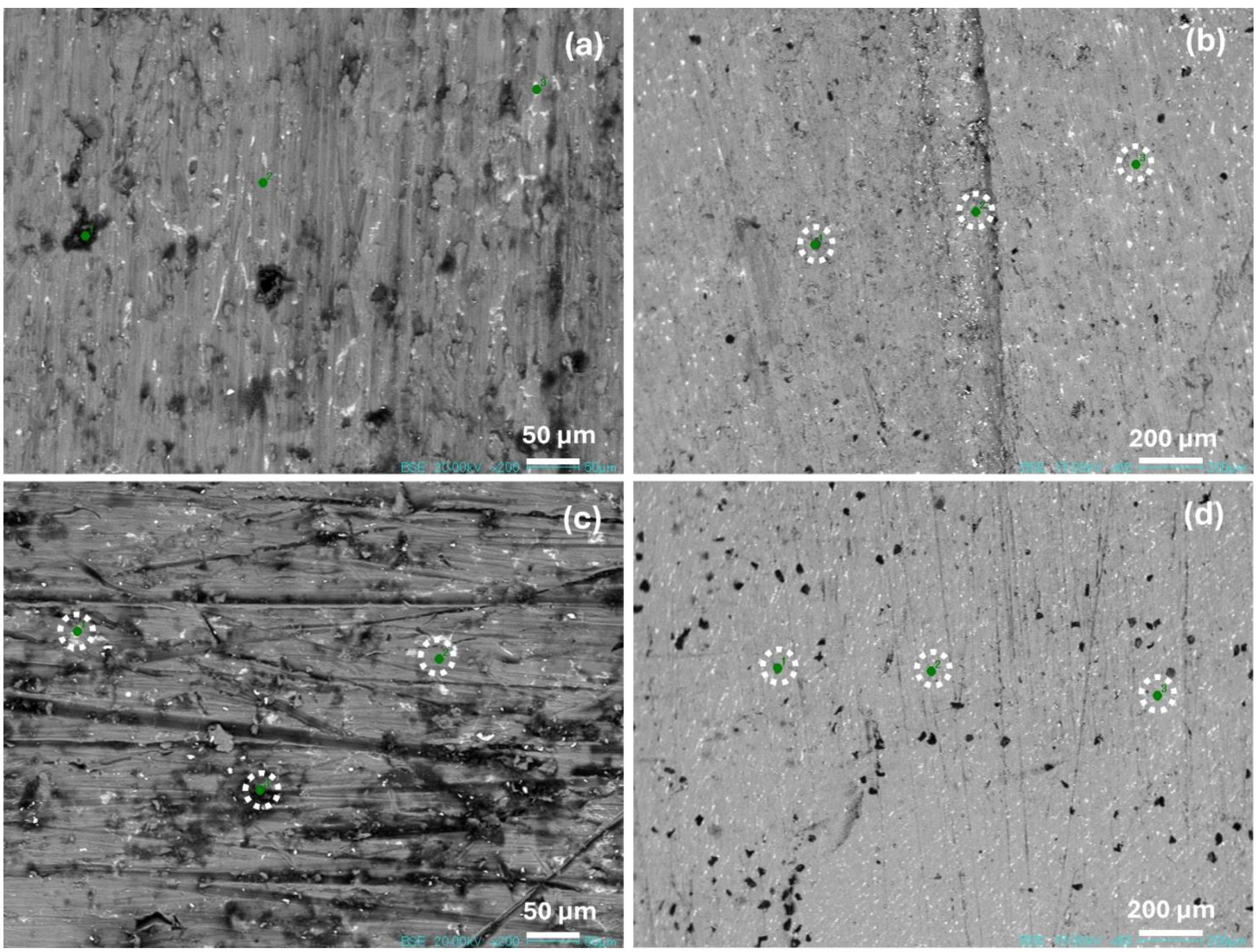

Fig. 4. SEM images of (a) Sample 0, (b) Sample 3, (c) Sample 6, (d) Sample 9. The dotted white circles indicate the presence of TiO_2 particles.

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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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