

Research Article

Influence of SiC/TiB₂ Particles Addition on Corrosion Behavior of As-Cast Zn-Al-Cu Alloy Hybrid Composites

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In this work, the silicon carbide (SiC) and titanium diboride (TiB₂) reinforced as-cast Zn-Al-Cu alloy-based hybrid composites were produced with ultrasonic-assisted stir casting. The corrosion behavior of as-cast Zn-Al-Cu/TiB₂/SiC hybrid composites with varying 0, 5, 10, and 15 weight percent of SiC + TiB₂ particulates in Zn-Al-Cu matrix alloy was investigated in this study. The effect of additional reinforcements content on the corrosion behavior of hybrid composites with respect to Zn-Al-Cu alloy was investigated. The corrosion rate of hybrid composites was taken by using potentiodynamic polarization equipment (with 3.5 wt.% NaCl solution). The potentiodynamic polarization test findings showed that the hybrid composites' uniform and localized corrosion resistances were enhanced by the addition of dual reinforcements. As the weight fraction of the SiC/TiB₂ reinforcement increases, weak microgalvanic cells that form between the constituent phases of the fabricated as-cast Zn-Al-Cu hybrid composites weaken, improving their resistance to uniform and localized corrosion. The results revealed that the corrosion rate values were reduced to 28.88% at 15% of reinforcement when compared to the base alloy.

1. Introduction

The hybrid composites outperform typical metal matrix composites in terms of mechanical and functional performance which suits to be widely adopted in structural engineering and functional device applications[1]. With a larger reinforcement content, typical MMCs reinforced with fibers or micron particles can attain ultrahigh strength and improved elastic modulus [2, 3]. But due to the inverse relationship between strength and ductility, toughness and ductility dropped dramatically with increased reinforcement volume [4]. The addition of nano-reinforcements to metal matrix alloys can enhance strength and elastic modulus without sacrificing ductility and toughness [5, 6]. Furthermore, the nano-reinforcements have a far higher strength-to-weight ratio than their

micron-sized counterparts. However, due to the influence of strong Vander Waals forces and the intrinsic incompatibility of nano-reinforcements with more metal matrix alloys, uniform dispersion in MMCs with more volume% nano-reinforcements is extremely challenging [4]. Therefore, a limited number of nano-reinforcements in nanocomposites (MMNCs) of most metal matrixes showed less increment in strength, which restricted their usage in the engineering and biomedical fields [4]. A great deal of research has been done to help MMCs overcome these difficulties.

Hybrid reinforcing is a distinct and significant technology in the design and fabrication of progressive MMCs. This technique's main principle is to introduce a variety of hybrid reinforcements into a metal matrix and rely on the hybrid reinforcements to demonstrate their potential benefits to achieve synergistic effects that result in excellent overall performance. When compared to the bioinspired structures, the hybrid reinforcement method is more advantageous and appealing for the production of a substantial amount of MMCs because it is based on the selection of the most suitable type, content, and ratio of hybrid reinforcements to achieve excellence. Thus, the existing practices for fabrication of MMCs are also broadly applicable to the producing hybrid MMCs. As a result, the evolution of hybrid composites has the great potential to make a significant contribution to expansion of the range of applications for MMCs.

Zinc-aluminum alloys have grown tremendously in recent years, for applications like bearings, as it provides advantages over other standard materials [7, 8]. The Zn27Al alloy, in particular, is a member of the zinc-aluminum alloy family. It has a wide range of applications. In response, it competes with materials made of bronze, copper, aluminum, and iron [6]. Many structural applications continue to rely on Zn-Al-based composites [9]. As a matrix, Zn-Al alloys are noted for their excellent combo of physical, mechanical, and technical characteristics [10-12]. Generally, metal matrix alloys (MMCs) are preferred for bearing applications that require lightweight, good durability, advanced strength at high temperatures, and corrosion resistance. At this point, hybrid composites are very useful in the industry, especially automotive and aerospace, due to their numerous good properties because it has the content of at least two reinforcement materials inside them.

Furthermore, according to the findings of recent investigations, the isotropic features of MMCs are improved by the addition of reinforcing particles. Even though there are different processes for making composite materials reinforced with particles, stir casting is the most common method for producing hybrid MMCs. Stir casting in the making of hybrid MMCs has a number of advantages including low cost, simplicity, and the ability to disperse the particulates that serve as reinforcement in hybrid MMCs throughout the matrix material [13]. However, because particles can easily agglomerate in the composite material, dispersion alone is insufficient to acquire the essential attributes of hybrid MMCs.

Corrosion can variously impact metal matrix composites, depending on their composition and the surrounding environment. The corrosion resistance of Albased materials must be studied, particularly for their extensive usage in automotive and aerospace applications [14]. In general, uniform corrosion is observed in zincaluminum alloys [8]. A passive layer is formed on the metal surface of ZA alloys in the as-cast condition, which prevents further corrosion attacks from occurring [15]. This passive layer provides adequate corrosion resistance for the majority of atmospheric environments. And also, this alloy exhibits high resistance to corrosion in the natural environment, waters, and soils as a result of the ability of zinc to form a protective layer on the surface primarily of corrosive products containing zinc oxide, simonkolleite, zinc hydroxide, or their mixtures.

Additional corrosion protection needs to be considered in more aggressive environments, such as marine environments.

The corrosion behavior of MMCs in different environments where the material is likely to be exposed is an important factor in selecting the appropriate material for a particular application [16]. It follows from the literature that limited work has been done to study the corrosive behavior of MMCs. Although, some studies on the corrosive behavior of MMCs have shown that they are more susceptible to attack than related nonreinforced alloys [8].

Numerous factors influence the corrosion behavior of MMCs, including the alloy composition and reinforcing particles used, as well as their distribution and size in the matrix, the fabrication technique used to make them, and the nature of the interface between reinforcement and the matrix [16, 17].

Even a relatively minor change in any one of these elements can have a significant impact on the corrosion behavior of the material. The major challenge with the usage of particles in metal alloys for various applications is the effect of reinforcement on corrosion resistance of that particular metal alloy. The incorporation of a reinforcing phase could result in irregularities or defects in the protective layer that forms on the alloy surface to counteract the effect of corrosion, by increasing the number of sites for initiation of corrosion and making the composite vulnerable to severe attack. There have been several investigations on the microstructural, tribological, and mechanical properties of the ZA27 composites using reinforcement materials. However, there have been few investigations into the corrosion behavior of ZA27 composites including nanoparticles. The main objective of this research was carried out to investigate the impact of reinforcing SiC and TiB2 particles on the corrosion behavior of the as-cast Zn-Al-Cu alloy.

2. Constituents and Approaches

2.1. Matrix. "The base material for this experiment is an ascast Zn-Al-Cu alloy. The dimensions of the rectangular ingots are $150 \times 150 \times 25$ mm and are cast by the process of liquid metallurgy in accordance with the ASTM B669-82 standard. Zinc has a purity of 99.90 percent, aluminum has a purity of 99.98 percent, and copper has a purity of 99.00 percent. In a crucible, aluminum and copper were placed and heated to 650 degrees Celsius, and then, zinc is added. The degassing agent C₂Cl₆ was also added after the stirring process was done for 5 minutes. During the duration of this technique, grain refining was not made" [18] (Table 1).

2.2. Reinforcement. Silicon carbide and titanium diboride, which are available commercial ceramic particles with average particle sizes of 20 microns and 30 microns, respectively, and with 99.00% purity, were procured from Sigma-Aldrich in India. Table 2 contains information about ceramic particles, including their sizes and shapes.

2.3. Preparation of the Composites. The alloy was placed into the graphite crucible for 15 minutes and heated to 680° C. Hexafluoro titanate salt (K₂TiF₆) with 2.7 weight percent was

TABLE 1: The chemical constitution of as-cast Zn-Al-Cu alloy.

Material	Zn	Al	Cu	Act
Constitution (wt.%)	Balance	25-28	2.0-2.4	0.01-0.02

TABLE 2: Properties of the reinforcements.

Reinforcement	Density (g/cc)	Melting point (°C)	Young's modulus (GPa)	Tensile strength (MPa)
SiC	3.21	2730	137	625
TiB ₂	4.52	2970	575	754

added to improve the wettability of the molten alloy. X wt% SiC + TiB₂ (X = 0, 5, 10, and 15) particles were incorporated into the molten form of the alloy. Before administering the particulate ceramics to the molten form of alloy, the ceramic particles are heated to 800°C and sustained at that temperature for one hour. "A mechanical stirrer operating at 85 rpm was used to mix the molten alloy, and the rotational velocities were maintained for 15 minutes at the same level to guarantee that the composite was of proper composition. The titanium alloy ultrasonic probe was immersed in the molten slurry's height in the crucible" [19].

Sonication was carried out at a frequency of 20 kHz using ultrasonic processing. A 22-minute ultrasonic energy pulse was used to disperse the grouped reinforcements. Following the sonication procedure, the graphite crucible was removed from the furnace and the molten hybrid metal matrix composite was poured into an MS mold.

By using the Wire Cut EDM (WEDM) machine composite samples were generated for testing as per ASTM standards. Table 3 lists the materials and their composition of the as-cast samples, as well as the designations that will be utilized throughout this study.

2.4. Corrosion Test. The composite specimens were tested under a potentiodynamic polarization test in an aerated 3.5 percent NaCl solution with the pH adjusted to a value of 10 using potassium hydroxide pellets. The pitting corrosion behavior of produced composite specimens with varying vol % of reinforcement was studied using an electrochemical system (Gill-AC). Experiments were carried out on a polished surface with a 1 cm² exposure area and a 0.166 mV/sec potential scan rate from -250 mV initial potential to the final pitting potential. The corrosion potential (Ecorr) was defined from the resulted graphs. Specimens with a higher positive Ecorr (or a lower negative Ecorr) were thought to be less vulnerable to pitting corrosion.

3. Results and Discussion

3.1. Corrosion Behavior of As-Cast Zn-Al-Cu Hybrid Composites. When compared to corrosion of an unreinforced matrix alloy, the presence of reinforcing particles, as well as the processing associated with MMCs manufacturing, can cause severe corrosion of the metal matrix. As a result, it is important to sustain a rate and a type of corrosion that will not be significantly damaging to the characteristics

TABLE 3: Wt.% of the composite samples.

S. no	As-cast Zn-Al-Cu alloy (wt%)	TiB_2 (wt.%)	SiC (wt.%)
1	100	0	0
2	95	2.5	2.5
3	80	5	5
4	85	7.5	7.5

of the MMC during its intended life span. For hybrid composites, the distribution and content of reinforcement powders in the matrix alloy are critical parameters. Pitting and crevice corrosion susceptibility, as well as other types of corrosion, are normally determined by exposure testing or electrochemical test methods on metal matrix composites (MMCs).

Generally, electrochemical test methods show the passive properties of one MMC compared to another and provide understanding of the mechanisms that can cause corrosion. In this work, potentiodynamic curves generated by the potentiodynamic polarization test are used to study the pitting corrosion behavior of the hybrid composite samples. Ecorr, Icorr, and corrosion rate (mpy) values are obtained using the Tafel extrapolation method (Table 4). These values clearly show that the corrosion rate of as-cast Zn-Al-Cu alloy (without any reinforcement) was more than any other composite used in this study. If we examine the corrosion rate trend concerning the vol% of reinforcement, it gradually decreases by increasing the vol% of reinforcement. It is a well-known fact that the addition of SiC as reinforcement can increase corrosion resistance due to SiC plays a significant role as a physical barrier to the initiation and formation of pits [17]. It may be attributed to the inert nature of SiC as a ceramic material. And the formation of Al₃C₄ which is mainly responsible for corrosion attack can be avoided by processing temperatures less than 710 C, which is also the reason for increment in the corrosion resistance in the presence of TiB_2 (Table 4) [3, 17, 20]. Especially, the addition of SiC resulted in a significant difference in the corrosion rate of the composites, as SiC ceramic particles do not react with molten aluminum, which prevents the development of brittle intermetallics at the reinforcements-matrix interfaces [21].

Hybrid composite with 15% reinforcement resulted in better corrosion resistance than as-cast Zn-Al-Cu and with 5% and 10%. As SiC can form a passive layer readily, the presence of SiC may assist actively in the passivity of hybrid composite which resulted in improved corrosion resistance.

TABLE 4: The corrosion data of the as-cast Zn-Al-Cu and its hybrid composites.

Composites	$E_{\rm corr}$ (mV)	$I_{\rm corr} ({\rm mA/cm}^2)$	Corrosion rate (mm/year)
ZA27	-1050	2.388	367
ZA27 + 2.5% TiB ₂ + 2.5% SiC	-984	2.320	334
ZA27 + 5% TiB ₂ + 5% SiC	-906	1.814	297
ZA27 + 7.5% TiB_2 + 7.5% SiC	-867	1.314	261



FIGURE 1: Potentiodynamic polarization curves of the as-cast Zn-Al-Cu and hybrid composites.

15% of $TiB_2 + SiC$ hybrid composite resulted in overall better corrosion resistance than any other sample used in this study. Generally, grain boundaries are more prone to corrosion attack in Zn alloys, as SiC covers most of the region at grain boundaries, inert nature (as a ceramic material) of SiC and acting as nucleating sites for passive layer formation may lead to the enhanced corrosion resistance [17]. The presence of TiB₂ and SiC can decrease the gradient of potential difference between the Zn-Al-Cu matrix and SiC which is responsible for galvanic corrosion in the case of only Al and SiC, which may be the reason for better corrosion resistance which is evident in Figure 1 [22, 23].

4. Conclusions

Zn-Al-Cu with 7.5% TiB_2 + 7.5% SiC resulted in overall better corrosion resistance than other samples in this study and also showed better value than as-cast Zn-Al-Cu alloy

The potentiodynamic polarization curves clearly show that hybrid composite with increasing wt.% of reinforcement has better corrosion resistance

The addition of SiC has a major impact on the improved corrosion resistance of Zn-Al-Cu/15% TiB_2 + SiC hybrid composite due to its inert nature and active participation in the formation of the passive layer

Due to the addition of dual reinforcements to Zn-Al-Cu matrix alloy gives excellent resistance, no corrosionrelated pits could be noticed on the corrosion surfaces. Only a variety of tiny microcracks, depending on the size of the reinforcing particles, were visible on the surfaces.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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