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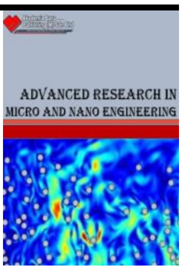

A Review: Characterization Of Aluminium-Metal Matrix Composite Reinforced with Zirconium Diboride

Muhammad Azim Suhaimi[1], Mohd Muzamir Mahat[1], Sabrina M. Yahaya[2], Rosmamuhamadani Ramli[1,*]

[1] Material Sciences and Technology Programme, Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2] Applied Chemistry Programme, Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

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ABSTRACT

Composite materials with aluminium matrices are used in thermal management, defence, aerospace, automotive and aviation. As the prices of useful items decreased, their usefulness increased. Aluminium is reinforced with other metals, non-metals and ceramics to give it the required physical and mechanical properties such as high tensile strength, great hardness and corrosion resistance. Aluminium-metal matrix composites are known for their exceptional physical and mechanical properties and performance. This work also focuses on the fabrication and characterization of zirconium diboride reinforced aluminium-metal matrix composite. Zirconium diboride particles were used as reinforcement material to fabricate aluminium metal matrix composites by the stir casting method. The microstructure, hardness and tensile strength of aluminum-metal matrix composites and its corrosion behaviour were investigated. The results showed that the inclusion of zirconium diboride particles increased the hardness and tensile strength of aluminum-metal matrix composites. Field emission scanning electron microscopy and x-ray diffraction analysis are used to investigate the microstructural properties of aluminum-metal matrix composites reinforced with zirconium diboride particles. Field emission scanning electron microscopy images showed a uniform distribution of zirconium diboride particles in the aluminum-metal matrix composites matrix. X-ray diffraction analysis showed the formation of an intermetallic compound of aluminium and zirconium diboride. From the review that have been made, we can conclude that the inclusion of zirconium diboride particles increased the mechanical properties and corrosion of aluminium-metal matrix composites.

1. Introduction

Researchers and manufacturers have been keeping an eye on metal matrix composites (MMCs) for some time to investigate their physical and mechanical properties and performance. MMCs are composites that differ by their base metal such as aluminium (Al), copper (Cu), or titanium (Ti), depending on the reinforcement, the type of phase (fibres, particles, whiskers), and the

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[*] *Corresponding author.*
E-mail address: rosma614@uitm.edu.my

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manufacturing processes such as powder metallurgy, diffusion bonding, infiltration, and stir casting [1]. These processes allow different combinations of composite properties such as tensile strength, hardness, and corrosion resistance depending on the application. For example, cast iron and aluminium-silicon (Al-Si) have long been produced in foundries. The combination of these two materials results in a composite material that has superior properties that cannot be achieved with monolithic alloys [2]. The properties can also be changed and modified based on the volume, shape and sizes of the phase diagram, which contains all the details of the information about the metal composites.

Aluminium matrix composites (AMC) are used because they have undeniably better properties, namely high mechanical strength and good thermal conductivity. The main objective in the production of AMC is to create a metal that has low mass and density while increasing stiffness. For this reason, Al alloys are one of the materials chosen as the basis for the use of composites, as they are suitable for most large manufacturers, being light and strong. As general, the study shows that the addition of Cu to pure Al increases hardness, reduces grain size and improves the mechanical properties of the metal. Aluminium-copper-zirconium diboride (Al-Cu-ZrB_2) is a MMCs produced by an in-situ reaction that improves mechanical properties. Zirconium diboride (ZrB_2) causes the Al-Cu to increase tensile strength and hardness. Depending on the type of reinforcement, AMC leads to different structures and process-related properties. Surappa and Mirle [3] show that the different processes produce different properties, sizes and shapes. The four process types such as particle reinforced AMCs, whisker or short fibre reinforced AMCs, continuous fibre reinforced AMCs, and monofilament reinforced AMCs are the processes used to produce AMC materials.

ZrB_2, a low-density, ultra-high temperature ceramic material, is a good candidate for aerospace applications. It has relatively high thermal and electrical conductivity. ZrB_2 serves as a grain refiner and greatly improves the mechanical properties of composite materials. ZrB_2 reinforcement has been used with many matrices including Al, Cu, magnesium (Mg) and their alloys [4]. Sivakumar *et al.,* [5] found that the size of agglomerates decreased significantly when ZrB_2 was added to Al in larger amounts. This means that the size of agglomerates in the Al of the particles in the metal composite decreases, the ZrB_2 particles occupy spaces that were not filled in the base metal Al. It is also mentioned that pure Al has rather low hardness, but the mechanical properties of Al-ZrB_2 composites were greatly improved. Al-20wt.% ZrB_2 had a very high yield strength (529 MPa), compressive strength (630 MPa), and compressive elongation of 19.25%. The use of ZrB_2 as reinforcement increases the strength and improves the wear resistance.

2. Casting Technique

Casting is one of the various techniques used to produce MMCs. In the case of Al, conventional casting is used to produce alumina, silicon, and tungsten carbide particles, as well as short-fibre and whisker alumina, silicon carbide, and carbon. In this case, three types of casting processes were analysed: In-situ, ex-situ and stir casting processes. Both processes are used to produce zirconium diboride enriched MMC.

2.1 In-situ Technique

Recently, in-situ methods have been developed for the assembly of Al-based MMC, which can lead to better interfacial adhesion and better mechanical properties. However, the composites treated by these techniques exhibit a number of problems, including thermodynamic imbalance of reinforcement within the matrix, brittle matrix-reinforcement interface with inhomogeneous distribution of reinforcing elements, and loss of good mechanical properties at elevated temperatures. To overcome these problems, researchers have developed in situ fabricated composites.

The literature addresses Al composites fabricated in-situ with various reinforcements in the form of tiny particles to evaluate the morphology and performance of MMCs. In situ Al-based composites were scaled up to improve mechanical characterization through dispersion strengthening and grain refinement achieved by the presence of particles in the melt during the solidification process [6]. In addition, AA2024/ZrB_2 AMCs were prepared by direct melt reaction of potassium fluorozirconate (K_2ZrF_6) and potassium tetrafluoroborate (KBF_4), and ZrB_2 micro-sized particles were found to improve the ductility of the composite.

2.2 *Ex-situ Technique*

Ex-situ techniques are methods for studying the properties and microstructure of materials outside their natural environment. These techniques are widely used in materials science and engineering to study the properties of Al-MMC materials. A common ex-situ technique to study Al-MMCs is transmission electron microscopy (TEM). In a study by Zeng *et al.,* [7], the microstructure and mechanical properties of aluminium-silica carbide (Al-SiC) composites were investigated with TEM. They found that the silica carbide (SiC) particles were well distributed in the Al matrix and that the Al-SiC MMCs exhibited better mechanical properties compared to pure Al.

Another ex-situ technique commonly used to study Al-MMCs is scanning electron microscopy (SEM). According to Zakaria [8], the microstructure of powder metallurgically prepared Al-SiC MMCs was investigated by SEM. They found that the SiC particles were well dispersed in the Al matrix and that the Al-SiC MMCs exhibited better mechanical properties compared to pure Al.

3. Mechanical Properties

3.1 Tensile Properties

The effect of ZrB_2 reinforcement on the tensile properties of Al-MMCs was studied by [9]. They found the specimens were prepared with different weight percentages of ZrB_2 (0, 2, 4 and 8 wt.%) and tensile strength tests were conducted using a universal tester. The results showed that the addition of ZrB_2 significantly improved the tensile properties of the composite, with the highest tensile strength value of 224 MPa found for the composite reinforced with 8% ZrB_2, while pure Al had a tensile strength value of only 95 MPa. The improvement in tensile properties was attributed to the ZrB_2 particles, which served as reinforcing phases, increasing the overall strength of the material. The improved tensile properties were also attributed to the strong bonding between the Al matrix and the ZrB_2 particles. The results are similar to those of previous studies on Al-based composites reinforced with ZrB_2, but are somewhat lower than the results of a recent work by Kumar *et al.,* [9] due to differences in the fabrication and testing procedures. The work provides useful insights into the potential applications for ZrB_2 reinforced AMMC.

The comparable reinforcement used both of TiB_2 and ZrB_2 to Al-Cu also was investigated by Anis *et al.,* [10]. In their research, they found that Al-Cu with 3ZrB_2 displayed higher strength compared to with 3 wt.%TiB_2 which showed that the stronger interfacial bonding between the Al dendrites and ZrB_2 particulates.

3.2 Hardness Properties

Anis *et al.,* [10] also stated that the hardness value of ZrB_2 displayed higher compared to TiB_2 when reinforced to Al-Cu alloy. This statement was supported by the research that have been done by Rigney *et al.,* [11]. They stated that, mechanical hardness testing is essential for the evaluation of the mechanical properties of metallic materials, since the hardness values can be used to determine the wear resistance of the material as well as the approximate values of its ductility, yield stress and other important properties. They also mentioned the definition of mechanical hardness testing, which is used to evaluate some of the most important mechanical properties of materials.

In their studied by [9], the effect of ZrB_2 as reinforcement on the hardness parameters of the fabricated Al-MMCs is investigated. The vickers hardness test was used to determine the hardness of composite samples with different amounts of ZrB_2 reinforcement (0, 2, 4, 6, and 8 wt.%). The results show that the Al-MMCs reinforced with ZrB_2 is much harder than pure Al. The composite with the highest hardness, 142 Hv, was found with 8 wt.% ZrB_2 reinforcement. The presence of ZrB_2 particles in the composite matrix serves as hard reinforcing phases and increases the overall hardness of the material. Moreover, the bonding between the Al matrix and the ZrB_2 particles leads to the improved hardness properties. The increase in hardness is exactly proportional to the volume fraction of reinforcement. The results of this research are similar to those of previous studies that investigated Al-based composites reinforced with ZrB_2; however, differences in preparation and testing methods may cause slight variations in the results. This research supports the use of ZrB_2 reinforcement to improve the mechanical properties of Al-MMCs.

3.3 Corrosive Behaviour

This work describes the corrosion properties of Al-MMCs reinforced with ZrB_2 [12]. The microstructure of Al-MMCs samples prepared by stir casting with different weight percentages of ZrB_2 particles was investigated by scanning electron microscopy (SEM). In a 3.5 wt% sodium chloride (NaCl) solution, the corrosion behaviour of the samples was investigated using the potentiodynamic polarisation method. The study showed that the addition of ZrB_2 particles to the Al matrix significantly increased the corrosion resistance of the Al-MMCs, with the samples reinforced with 6 wt.% ZrB_2 exhibiting the highest corrosion resistance. The improvement in corrosion resistance is due to the formation of a protective oxide layer on the surface of the samples, which acts as a barrier to the diffusion of corrosive ions and reduces the corrosion rate.

Mustafa *et al.,* [12], in their research have investigate the effect of ZrB_2 to Al-Cu alloy. Corrosion potential diminished with rising ZrB_2 content in the alloys. The corrosion current and corrosion rate reveals an exemplary value at 6 wt. % ZrB_2. Inclusion of ZrB_2 has an effective alteration on corrosion barrier in Al-Cu. This action might be associated to beneficial influence of ZrB_2 inclusion on grain size refinement. The fine-grained materials have more conveniences behaviour with account to corrosion together with oxidation have been established [8]. From Figure 1 below, Al-Cu alloy with 6wt.%ZrB_2 displayed the optimum corrosion barrier compare to other compositions. Value of corrosion rate at 3 wt.% ZrB_2 was 2.85×10^{-3} mm y^{-1}, then decreased to 0.36×10^{-3} mm y^{-1} for Al-Cu with 6wt.%ZrB_2. The susceptibility of the Al-Cu alloys towards corrosion decreases in the order of:

Al-Cu-6wt.%ZrB_2> Al-Cu-3ZrB_2 > Al-Cu.

The least value of corrosion rate demonstrated the alloy has a favourable trait to endure corrosion.

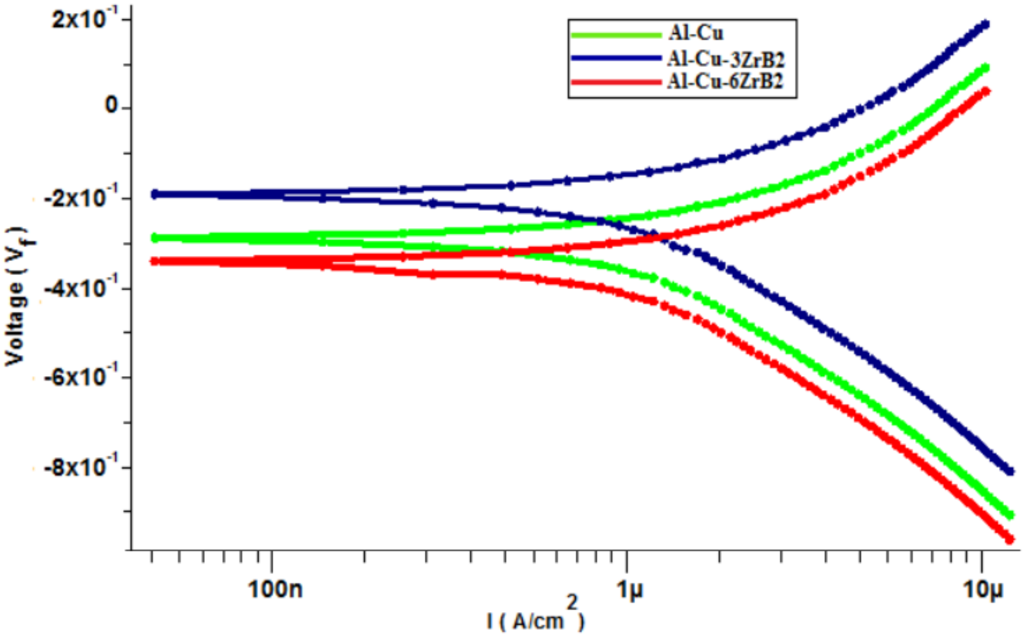

Fig. 1. Potential-Dynamic Polarization Curves on Al-Cu Alloy Reinforced by ZrB_2 [12]

With reference to a studied by Rosmamuhamadani *et al.,* [6], corrosion tests were performed on each alloy in its as-cast condition. Potentiostatic polarisation experiments were performed using a Radiometer Analytical model PG 100 Potentiostat/Galvanostat and VoltaLab software. This method also allows to vary the main results related to the corrosion mechanisms, the rust rate and even the corrosion susceptibility of a particular reinforced alloy in specific settings. The Al-MMC samples were prepared by stir casting method with different weight percentages (0, 5, 10 and 15 wt.%) of ZrB_2 particles. The corrosion behaviour of the samples was evaluated by the potentiodynamic polarisation method in a 3.5 wt% NaCl solution.

3.4. Characterization

3.4.1 Field emission scanning electron microscopy

Recent research has characterized the microstructure and mechanical properties of Al-MMCs with the addition of ZrB_2 using FESEM. Xing *et al.,* [13] and Zeng *et al.,* [7] discovered that the addition of well-dispersed ZrB_2 particles into the Al matrix can significantly improve the mechanical properties of Al-MMCs, such as hardness and tensile strength, compared to pure Al. However, Kennedy, *et al.,* [14] found that the Al-MMCs adversely affect the mechanical properties when the ZrB_2 particles are insufficiently dispersed in the matrix. To maximize the potential improvement in mechanical properties, good dispersion of the reinforcement particles throughout the composite must be achieved. These results indicate that the manufacturing process must be carefully controlled to maximise the dispersion of ZrB_2 particles and achieve the necessary improvements in mechanical properties.

The effect of 5 wt.% addition of Al–10 wt.%Si–0.2wt.%Mg (composition in wt.%) pre-alloyed powder on densification, microstructure and mechanical behaviour of spark plasma-sintered ZrB_2-20 wt.% SiC composite has been investigated by Sengupta *et al.,* [15]. They conclude that the sintered composite records a relative density of 99.83% despite being processed at a relatively low temperature (1700 °C) in argon atmosphere. Interestingly, ZrB_2-20 wt.%SiC–5 wt.%Al-Si-Mg composite does not undergo any shape distortion though the liquidus temperature of this metallic alloy additive is quite low (~ 592 °C). Extensive phase and microstructure analyses by appropriate techniques indicate that no free or unreacted Al-Si-Mg is detected in the sintered composite.

In research conducted by Yadav and Dixit [16], they use FESEM to perform a comparative study on the erosion-corrosion of aluminium-silicon (Al-Si) alloys (AA336) and their composites AA336-7 wt.% silicon carbide (SiC) and AA336-7 wt.% TiB_2 in basic, acidic and marine atmospheres. The microstructure in inter dendritic region of Al shows the formation of Si in the eutectic state. Figure 2 (a) shows a classifiable microstructure of the Al-Si alloy (AA336) in the as-cast state. Figure 2 (b) shows the microstructure of the composite reinforced with SiC particles. SEM shows the homogeneous distribution of SiC.

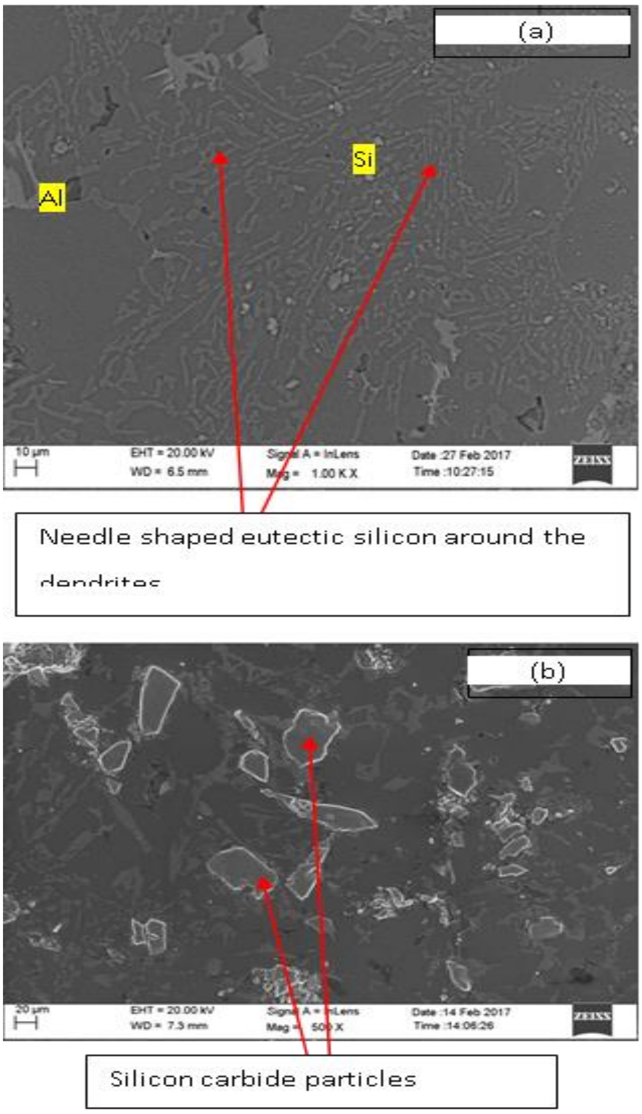

Fig. 2. Micrograph on the Polishes Surfaces of (A) Alloy, B) SiC Composites [16]

3.4.2 X-ray diffraction

Aluminum matrix composites (AMCs) that were reinforced by in-situ ZrB_2 nanoparticles were fabricated from an aluminum-potassium tetrafluoroborate-potassium hexafluorozirconate (Al-KBF_4-K_2ZrF_6) system via a direct melt reaction [17]. The morphologies of the in-situ particles of the composite were investigated by SEM, energy-dispersive X-ray spectroscopy and XRD. XRD and energy-dispersive X-ray spectroscopy showed the existence of ZrB_2 in the composite. The EDS analysis shows that elemental Al, Zr and B are present in the composite. The XRD pattern of this specimen depicts diffraction peaks of the Al_3Zr and ZrB_2 phases, with the latter being the reinforcement. A ZrB_2p/6061Al composite was prepared via an in-situ reaction.

Prasad *et. al* [18] in their work, used aluminium alloy, Japanese industrial standard alloy ADC12 reinforced with various amounts of ZrB_2 (0, 3, 6 and 9 wt.%) were synthesized by an in-situ reaction of molten aluminium with inorganic salts K_2ZrF_6 & KBF_4. XRD analysis revealed the successful in situ formation of ZrB_2 in the composite. The XRD spectral pattern of ADC12/ZrB_2 composites is shown in Figure 3. The peaks which belong to ZrB_2 particulates are visible. The chemical reactions between the molten aluminium and the inorganic salts K_2ZrF_6 and KBF_4 produces ZrB_2 particulates. From the above XRD results, it is clear that the diffraction peaks of Al_3Zr and AlB_2 are absent, which confirms the completion of the in-situ reaction between added inorganic salts.

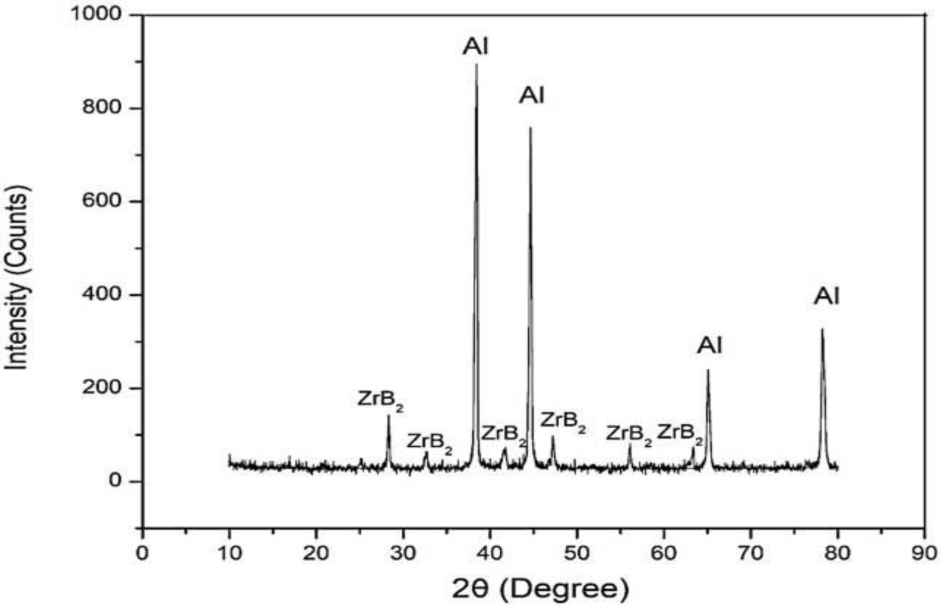

Fig. 3. XRD of ADC12 with ZrB_2 reinforcement [18]

4. Conclusion

The use of Al-MMCs reinforced with ZrB_2 has attracted considerable attention in recent years due to their potential applications in various fields such as aerospace, automotive, and biomedical. The incorporation of ZrB_2 into the Al matrix results in improved mechanical properties such as higher hardness, tensile strength, strength, and toughness compared to pure Al. Characterization of Al-MMCs by XRD analysis is widely used to study the crystal structure and phase formation of the composite. It is important to note that the fabrication process and the amount of added reinforcement can greatly affect the final microstructure and properties of the Al-MMCs. Therefore, it is crucial to carefully control the fabrication process to achieve good dispersion of the reinforcement particles and optimize the mechanical properties of the composite.

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