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Corrosion Behaviour and Electrical Conductivity of Reinforced $TiAl_3$ and B_4C Hybrid Aluminium Composites

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In this study, corrosion and electric conductivity of aluminum hybrid composites (*in situ* $TiAl_3$ and *ex situ* B_4C) produced by powder metallurgy are investigated. Hybrid (*in situ* and *ex situ*) aluminum composite powders are produced by adding different amounts of titanium and B_4C into AA7075 alloy powders. After the hybrid composite powders are cold pressed (600 MPa), they are sintered in atmosphere controlled furnace at 580 °C for 4 h. As a result of this study, it was observed that increase of B_4C%(Ti constant) decreases density and increase of Ti%(B_4C constant) increases the density of composites. It was determined that corrosion resistances (R_p) of hybrid composites decreased due to interface surfaces formed between the reinforcement phase and the matrix.

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1. Introduction

Aluminium matrix composites (AMCs) have considerable potential to substitute number of conventional materials for their light weight, strong corrosion resistance, and high performance in many practices. These materials have combined a number of properties such as hardness, high strength, dimensional stability, low density, and good wear behaviours [1–3]. There is certain need for materials with properties in extensive spectrum for desired service performance expected in numerous modern engineering systems. However, it is rather difficult to bring those properties in monolithic materials. In order to solve this problem, researchers usually benefit from various reinforcement materials so as to introduce new material systems as a solution [4–7]. Al_2O_3 and SiC are the most common reinforcement elements used in the production of particle reinforced composites. Use of B_4C in production of these composites is being popular in recent years. However, their high cost limits the production of B_4C reinforced composites. Since their wettability with Al is quite low, it is rather difficult to produce them by mixing within the liquid metal [8]. However, their wettability property could be increased with K_2TiF_6 flaxes added into the alloy. B_4C is an attractive reinforcement material in production of aluminium composites due to its low density, high rigidity, and thermal stability [9]. Although Al–B_4C offers superior characteristics, there are some limitations in terms of its extensive use. One of them is economic and the other is the technical problems. Relatively high cost of B_4C powders with respect to other reinforcement materials such as SiC or Al_2O_3 results in limited number of studies on B_4C reinforced materials [10]. This study deals with the corrosion behaviours and electrical conductivity of ACMs *in situ* $TiAl_3$ and *ex situ* B_4C produced by addition of reinforcement materials.

2. Materials and method

In the experimental study, AA7075 alloy powder (< 100 μm) is produced by gas-atomization and used as the matrix material. The chemical composition of matrix material is given in Table I.

TABLE I

Chemical composition [wt%] of the AA7075 alloy used in the production of the AMCs.

Zn	Mg	Cu	Fe	Si	Zr	Cr	Mn	Al
5.48	2.58	1.568	0.549	0.403	0.0305	0.125	0.014	bal.

AMCs are produced by addition of (2–6%) Ti and (3–9%) B_4C into gas-atomized AA7075 alloy. After mixture of powders in the Turbula Shaker Mixer (T2F Glenn Mills) 67 rpm for 45 min, powders were cold pressed under 600 MPa pressure so that cylindrical samples were produced in Φ12 × 7 mm dimensions. Produced green compacts were sintered at 580 °C within atmosphere controlled (argon) environment for 4 h, then cooled down (10 °C/min) in furnace to room temperature. Following the standard metallographic processes, samples were etched with 95 ml distilled water, 2.5 ml HNO_3, 1.5 ml HCl, 1 ml HF (Keller's) solution for 15–20 s. Density measurements were carried out according to the Archimedes principle. Microstructures of produced *in situ* and *ex situ* aluminium composites were examined through scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). The Tafel and impedance diagrams

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of the samples prepared for the corrosion tests were determined by platinum reference and operation electrodes within 0.1 M H_2SO_4 solution. In electrical conductivity measurements, electrical resistance of *in situ* and *ex situ* composite samples is measured by placing a copper material. The results are obtained based on the IACS% conductivity values according to the ASTM (B193-02) standard.

3. Results and discussion

From the microstructure SEM images given in Fig. 1a and b, it can be observed that B_4C used as reinforcement phase in titanium hybrid composites, produced by the P/M method, are concentrated around grain boundaries. As the amount of B_4C reinforcement in AA7075 aluminum matrix increase, agglomeration increases as well. The powder size of less than and equal to 10 µm, which is added into matrix as an *ex situ* reinforcement material, results in agglomeration. Figure 2 gives the X-ray diffraction (XRD) results of hybrid ACMs.

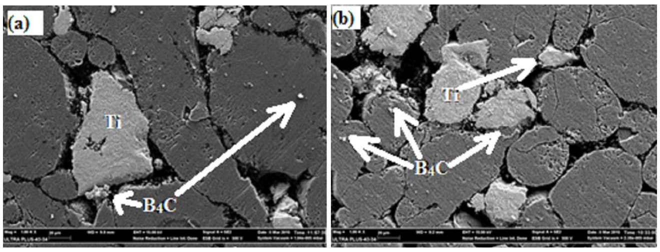

Fig. 1. Microstructure SEM images of the hybrid ACMs: 4%Ti (constant)–9%B_4C (a) and 9%B_4C (constant)–6%Ti (b).

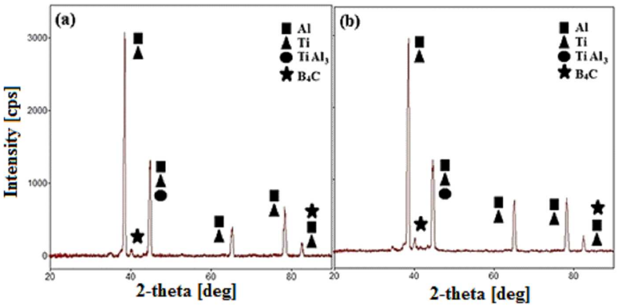

Fig. 2. XRD results of hybrid aluminum composites added 6%Ti (a) and 9%B_4C (b).

XRD pattern given in Fig. 2a,b shows that *in situ* $TiAl_3$ particles are successfully formed in the structure. Together with the $TiAl_3$ phase, there are Al, Ti, and B_4C phases in the structure. Figure 3 gives the Tafel polarization diagram and polarization resistance of produced hybrid composites reinforced by 4%Ti constant (3–9) (a),(b) and 9%B_4C constant (2–6 Ti) (c),(d) and Table II gives corrosion parameters, density and electrical conductivity results.

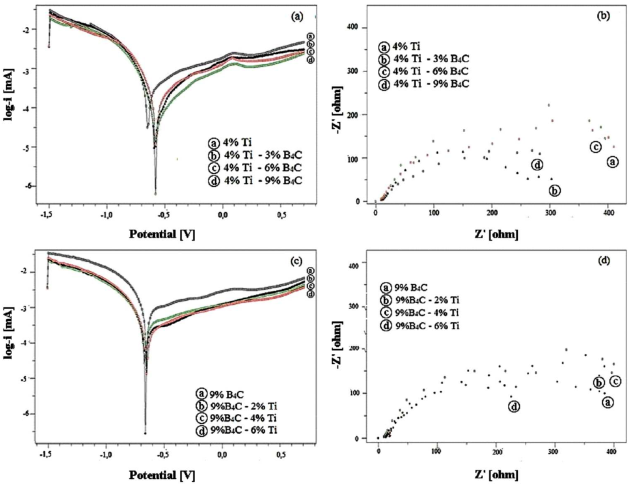

Fig. 3. Tafel polarization diagram and polarization resistance of hybrid composites reinforced by 4%Ti constant (3–9), (a,b) and 9%B_4C constant (2–6 Ti) (c,d).

TABLE II

Operation electrodes (% Ti/% B_4C) of hybrid composites with aluminium matrix and corrosion parameters, density and electrical conductivity results obtained from Tafel diagrams in 0.1 M H_2SO_4 solution.

Comp.	$-E_{\text{kor}}$ [mV]	R_p [Ω]	$-\beta_a$ [mV]	$-\beta_c$ [mV]	Cor. rate $[\frac{\mu m}{y}]$	ρ $[\frac{g}{cm^3}]$	S [IACS%]
4/0	0.6139	363.1	0.515	0.127	1.260	2.666	2.84
4/3	0.5819	536.8	0.321	0.120	0.675	2.758	66.60
4/6	0.5999	579.3	0.292	0.109	0.617	2.744	34.19
4/9	0.6461	234.6	0.524	0.146	2.138	2.735	33.20
0/9	0.6550	209.3	0.826	0.147	2.69	2.629	3.60
2/9	0.6895	361.1	0.776	0.162	1.912	2.719	64.80
4/9	0.6461	306.2	0.606	0.132	1.446	2.721	58.60
6/9	0.6660	92.9	1.063	0.182	7.147	2.745	23.90

In Fig. 3a, corrosion ratios of hybrid composites produced with different amounts of reinforcement (4%Ti (constant) and B_4C (3–9%)) are given as 1.26, 0.6756, 0.617, and 2.38 μm/year. Higher corrosion ratio is measured with the corrosion potential of the hybrid composites produced with 9%B_4C reinforcement (Fig. 1b). Corrosion currents decrease parallel to them. While corrosion ratio of hybrid composites reinforced with 3%and 6%B_4C decreases, corrosion ratio of hybrid composites reinforced with 9%B_4C increases. It was determined that corrosion ratio of hybrid composites produced with 9%B_4C reinforcement in 0.1 M H_2SO_4 solution is threefold greater than other hybrid composites (with less B_4C amount). In Fig. 3c, corrosion ratios of hybrid composites produced by using reinforcement at different amounts of (2–6%) Ti (9%B_4C constant) are measured as 1.912, 1.446, and 7.147 μm/year, respectively. The lowest corrosion ratio is measured with the hybrid composite reinforced with 4%Ti; the highest corrosion ratio is measured with the hybrid composite produced with reinforcement of 6%Ti.

Corrosion ratios obtained from the results of Tafel measurements show that the amount of titanium reinforced into the aluminum hybrid composites has a critical threshold limit. Similar results are reported in the study of Chen and Mansfeld [11]. Due to density differences among the reinforcement phases reinforced into the hybrid composites, there is a significant difference among the densities of the composites. When 3%B_4C reinforced into *in situ* composites obtained with reinforcement of 4%Ti (constant) into AA7075 alloy, density of composite is measured as 2.758 g/cm^3; when 6%B_4C reinforced, density is measured as 2.744 g/cm^3; and when 9%B_4C is reinforced, density is measured as 2.735 g/cm^3. The reason for difference in densities of ACMs depends on two factors: the first one is the possible pores in the structure during production of composites, the second is the different densities of Ti (4.52 g/cm^3) and B_4C (2.52 g/cm^3) reinforced into the AA7075 alloy. According to the electrical conductivity values given in Table II, IACS% value of composites reinforced by different amounts of B_4C (4%Ti constant) decreases as the amount of B_4C increases in the structure. This decreasing tendency is more evident with the composites reinforced by 3%B_4C and 6%B_4C. IACS% values of composites reinforced with 6%B_4C and 9%B_4C are closer to each other. IACS% values of hybrid composites reinforced by different amounts of Ti (9%B_4C constant) shows that as Ti amount in the material increases, conductivity values decrease.

4. Conclusion

As a result of the experimental study, since size of B_4C powder reinforced into produced hybrid composite matrix as *ex situ* reinforcement material is equal and less than 10 μm, agglomeration is observed. Because of the density difference of reinforcement material of hybrid composites (according to type of the reinforcement material), there are increases and decreases in densities of composites. It is observed that corrosion potential of the hybrid composites produced with reinforcement of 9%B_4C has increased greatly. Accordingly, corrosion currents have reduced in a parallel direction. Although the corrosion ratios of hybrid composites reinforced by 3%and 6%B_4C decrease, that of hybrid composites reinforced by 9%B_4C increases. IACS% values of hybrid composites reinforced by different amounts of Ti (9%B_4C constant) decrease parallel to the amount of Ti within the material.

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