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Corrosion Behavior of *in-Situ* AlB_2/Al-Cu Metal Matrix Composite

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The aim of this study was to fabricate 30 wt.% AlB_2/Al-Cu composites using in-situ casting processes and to investigate the corrosion behavior of the composites and of the matrix material in various media. The electrochemical parameters were obtained from potentiodynamic polarization curves. The composites were prepared by liquid reaction of aluminum matrix with boron oxide at 1400 °C. The results show that the corrosion resistance of the composite was higher than that of the matrix in selected corrosion media. The anodic corrosion current density values were decreased by reinforcing AlB_2 particles.

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1. Introduction

Aluminum metal matrix composite (AMMC) materials have been developed during the last few years. Aluminum matrix composites are the most preferred materials in many areas of the industry due to their superior mechanical and tribological properties [1–2].

Al-B master alloys can be used in the in-situ production of aluminium matrix composites such as the in-situ fabrication of AlB_2 fibre-reinforced aluminium metal matrix composites using an Al-B master alloy [3]. AlB_2 phase shows a high strength, high modulus and a higher density (3.19 g/cm^3) [4] compared to liquid aluminium (2.4 g/cm^3) at 700 °C. Reinforcement phase AlB_2 in Al/AlB_2 type composites is formed in-situ in the molten aluminium. The distribution of reinforcement phase can be made homogeneous, and it was found that the bond between the reinforcement and the matrix is perfect. AlB_2 boride particles generally appear as the thin hexagonal flakes within the matrix. The width of flakes was determined to be in the range of 10 and 2000 μm, and thickness between 0.3 and 6 μm, depending on the type and the parameters of the synthesis process and on alloying elements [5–6].

The major disadvantages of reinforced MMCs is the influence of reinforcement on the corrosion rate. Protective oxide film decreases with the corrosion rate in aluminum alloy-based composite [7]. The addition of reinforcement phase could cause discontinuities or flaws in the protective film. The study of corrosion behavior of AMMCs in various environments gains importance because these materials have the potential for a wide range of industrial applications [8]. These composites can be exposed to a range of corrosive environments during the process like cleaning, pickling, etc. It is known that aluminum materials and its alloys show high corrosion rate in corrosive media [9]. Especially, boron aluminum MMCs shows severe corrosion when exposed to marine environments and MMCs are significantly less corrosion resistant compared to unreinforced aluminum alloys [10–11].

The aim of this study was to fabricate 30 wt.% AlB_2/Al-Cu composites using in-situ casting processes, and to investigate the corrosion behavior of composite and of matrix material in various solutions using potentiodynamic polarization curves method.

2. Experimental work

2.1. Fabrication and characterization

Al-4 wt.% Cu alloy was used as the matrix material to produce composites. Its chemical composition is shown in Table I. The composite material is produced by in-situ synthesis of the reinforcement phase of AlB_2 flakes by adding boron oxide (B_2O_3) into the molten matrix to facilitate chemical reaction at 1400 °C. The composite and matrix samples were shaped using squeeze casting method so as to provide a dense microstructure and to better control the amount of reinforcement phase. The samples were solution treated at 542 °C for 4 h followed by water quenching. Aging was performed at 190 °C for 10 h [12].

TABLE I

Chemical composition of the matrix of alloys.

Alloys	Composition [wt.%]							
	Si	Fe	Cu	Mn	Mg	Cr	B	Al
Al-Cu	0.450	0.321	3.442	0.120	0.551	0.051	0.000	95.119

Density and hardness of the produced materials were determined cccording to ASTM D 792 [13] and ASTM D 2240 [14] standards, respectively. Hardness tests of the composite and matrix samples were performed on AFFRI

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universal hardness testing machine. AlB_2 flake dimension measurements were carried out using the micrograph image analysis technique. Chemical composition of the matrix was obtained using optical emission spectrometer for metal analysis. The measurements were repeated at three different points on each sample, and the maximum standard deviation of the results was approximately 5%. The arithmetic average was taken into account in the present study.

2.2. Corrosion test

The corrosion test was performed in 3.5 wt.% NaCl and in acidic medium of 0.1 M HCl with pH = 1. A solution of 3.5% sodium chloride (NaCl, Merck, 99%), was prepared by dissolving 35 g of NaCl in 200 ml of water in a glass flask. Electrochemical measurements were carried out in a typical three-electrode cell. Platinum plate, Ag/AgCl and the studied alloy were used as the counter, the reference and the working electrodes, respectively. During the experiment, electrochemical measurements were obtained using Interface 1000 potentiostat/galvanostat controlled by a suitable computer. The temperature was kept at 25 °C. Before the measurement, the working electrode is immersed in the respective solution for 60 minutes until a steady free corrosion potential was recorded. The Tafel curves were taken at a scanning rate of 1 mV/s, the potential has ranged between −250 mV cathodically and +250 mV, versus platinum electrode. The corrosion behavior of the aluminum metal matrix composite has been analyzed using corrosion potential E_{corr}, anodic corrosion current density i_a, and anodic Tafel slope β_a.

3. Results and discussion

3.1. Microstructure

Microstructures of the matrix (Fig. 1a) and the composite (Fig. 1b) are given in Fig. 1. AlB_2 reinforcement flake structures are firmly embedded in the aluminum matrix. The cuboidal boride structure phase was not observed in the microstructures as shown in Fig. 1. These results are compatible with the findings presented in the literature [12, 15–17].

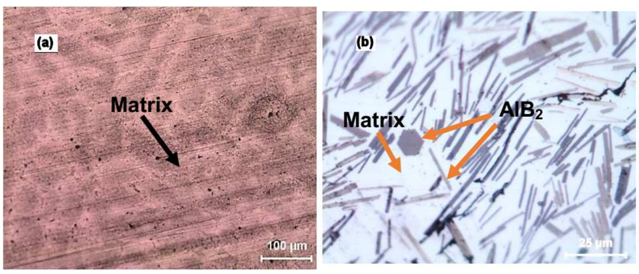

Fig. 1. Optical images of microstructures of the matrix (Al-Cu) (a) and the composite 30 wt.% AlB_2/Al-Cu (b).

The SEM photographs of the composite containing 30 wt.% of AlB_2 reinforcement is shown in Fig. 2. The AlB_2 flakes have a high aspect ratio in the aluminum matrices, and the orientation of flakes in the matrix is non-uniform. These flakes are a random distribution of the boride particle phases which are mostly hexagonal in shape. The width and thickness of hexagonal shapes were 29 μm and 0.62 μm, respectively, as can be seen in Fig 2. This result is found to be compatible with literature, where boride particles shape has also being referred to as hexagonal shape [16, 17].

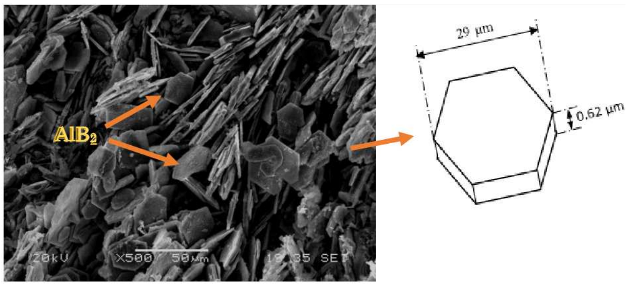

Fig. 2. SEM images of 30% AlB_2/Al-Cu composite showing flake sizes of AlB_2 boride.

The mechanical properties of the Al-Cu (matrix) and 30% AlB_2/Al-Cu composites is shown in Table II. The density of the composite materials decreases with the increasing content of the reinforcement of AlB_2. On the other hand, introduction of AlB_2 has resulted in an increase on the tensile strength from 193 to 226 MPa, and an increase of hardness from 55 to 120 HB. The reason is that the movement of dislocations is hindered, which increases the hardness of the composites. It can be seen from Table II that the % elongation decreases with the increasing content of reinforcement of flakes and also that the % elongation of the composites is lower than that of the matrix alloy. These results are also in good agreement with previous reports [15].

TABLE II

Mechanical properties of the matrix and the composite.

Sample	Al-4 wt.%Cu	30% AlB_2/ Al-4 wt.%Cu
Density [g/cm^3]	2.77	2.73
Porosity [%]	0.01	1.46
Hardness [HB]	55	120
Tensile strength [MPa]	193	226
Young module [MPa]	100	128
Elongation [%]	20	2.15

3.2. Tafel polarization measurements

The effect of seawater and acidic media on the corrosion behavior of the matrix and of the composite was examined at room temperature. The potentiodynamic polarization curves for the corrosion of the matrix and composite material in seawater and in acidic media are shown in Fig. 3a and b, respectively. As can be seen from these figures, the composites and matrix generally show similar polarization curves and passivity characteristics. The corrosion potential values of the samples are very close to the equilibrium potential in seawater, which are −780 mV and −768 mV, respectively. Furthermore, in the acidic media their corrosion potentials are −688 mV and −614 mV, respectively. The electrochemical parameters such as corrosion potential E_{corr}, anodic current density i_{a} and anodic Tafel slope, calculated by Tafel extrapolation method for the anodic branches of the polarization curves at the various medium, are given in Table III. It can be seen from the table that in the seawater, the anodic corrosion current density values i_{a} were smaller in the composite reinforced with AlB_2. Analysis of the corrosion current density values from the figures and from the data in the tables shows that the matrix has smaller corrosion resistance than the composite in the seawater. Melgarejo, et al. [4] show that Al-based composites have a higher corrosion resistance as a result of reinforcement with the boride, in accordance with our results. On the other hand, in the acidic media, matrix has higher corrosion resistance due to formation of oxide layer. The boride particles, which are used as the reinforcing elements, hamper the formation of oxide layer and, as a result, this diminishes the corrosion resistance of the composite, significantly. The oxide layer causes formation of the protective barrier and lowers oxidation rate on the surface layer.

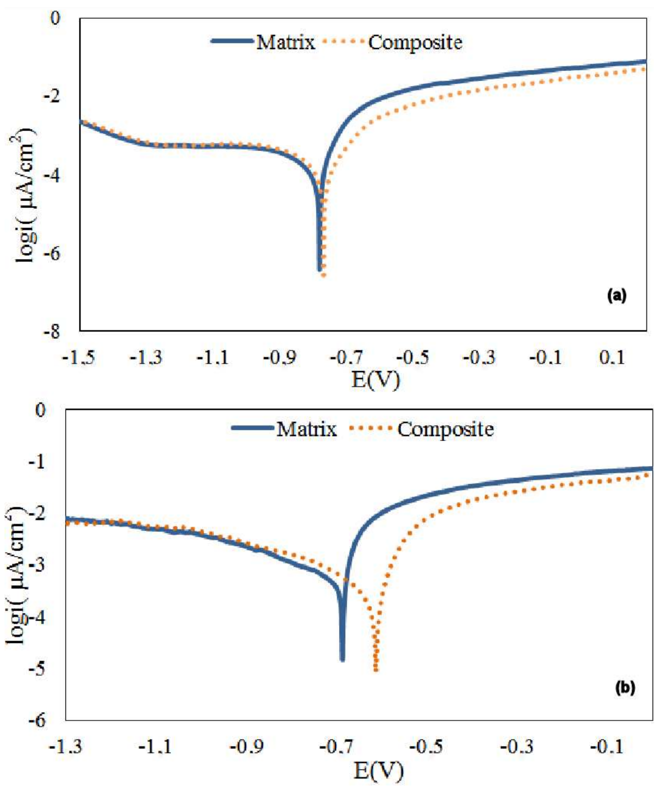

Fig. 3. The Tafel plots for Al-Cu and 30% AlB_2/Al-Cu in seawater (a), and in acidic medium (b).

TABLE III

The electrochemical parameters of the matrix and of the composite in various solutions.

Solutions	Material	E_{corr} [mV]	i_{a} [A cm^{-2}]	β_{a}
Seawater	Al-Cu	−780	1.48×10^{-3}	0.405
	30% AlB_2/Al-Cu	−768	1.41×10^{-3}	0.279
Acidic media	Al-Cu	−688	4.92×10^{-3}	0.669
	30% AlB_2/Al-Cu	−614	5.31×10^{-3}	0.701

4. Conclusions

The production and corrosion behavior of in-situ synthesized Al/AlB_2 type composites based on Al-Cu matrix and reinforced with borides, have been investigated. The composites were prepared by liquid reaction of aluminum matrix with boron oxide at 1400 °C. The conclusions from this study can be listed as follows:

- The tensile strength and the young modulus of the composite was found to be higher than those of the Al-Cu matrix alone. The tensile strength has increased by almost 17% from 193 MPa to 226 MPa, while young module has increased by almost 28% from 100 MPa to 128 MPa by the addition of 33 wt.% of boride to the matrix. The bulk Brinell hardness of Al-Cu matrix has increased almost two times from 55 HB to 120 HB with the addition of 33 wt.% of boride.
- The corrosion resistance of the composite in the seawater was higher than that of the Al-Cu matrix alone. The corrosion potential values have increased by 12% and the anodic current density has decreased by 19% in the acidic media with the addition of 30 wt.% of aluminum boride particles. Based on the experimental results, the passivation layer was not observed on both the composite and the matrix material in both acidic and alkaline media.

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