

Special Issue of the 6th International Congress & Exhibition (APMAS2016), Maslak, Istanbul, Turkey, June 1–3, 2016

Electrical Conductivity and Corrosion Performances of *In Situ* and *Ex Situ* AA7075 Aluminum Composites

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The present study investigates corrosion behaviors and electric conductivity of AA7075 *in situ* (TiAl₃) and *ex situ* (B₄C) composites produced by powder metallurgy method. In production of *in situ* composites, various amounts of Ti (2, 4 and 6%) are added to AA7075 and for production of *ex situ* composites, B₄C (3, 6, and 9%) are added. Prepared *in situ* and *ex situ* composite powders were pre-shaped at 600 MPa pressure with cold pressing. Pre-shaped samples were sintered in the atmosphere-controlled furnace at 580 °C for 4 h. Corrosion test of produced composites was conducted in 0.1 M H₂SO₄ solution. As a result of these analyses, corrosion examinations on *in situ* manufactured composites revealed that anode and cathode currents are close to each other and those composites do not exhibit different corrosion behaviors. Corrosion rate of B₄C added *ex situ* composites increases by B₄C rate (due to increase of density of current).

DOI: [10.12693/APhysPolA.131.153](https://doi.org/10.12693/APhysPolA.131.153)

PACS/topics: 82.45.Bb

1. Introduction

Aluminum and its alloys are second most widely used materials after iron-based alloys. Low strength of pure aluminum limits industrial use of this material. Therefore, alloying is used to improve properties of pure aluminum to use them for desired purposes [1, 2]. Titanium is an element having a high strength/density ratio and resistance to high temperatures [3]. Al–Ti alloys are one of the most promising materials for the future applications. The distinctive properties of Al–Ti alloys are resistive to oxidation and wear, having a good strength in high temperatures and low density. Therefore, these alloys are preferred in aerospace and automotive technology for engineering applications. The main problem for this alloys is low elongation capacity at room temperature. Low elongation capacity at room temperature is the biggest obstacle to the common use in applications [4]. Al alloys are used in automotive and aerospace industries due to its superior properties such as low density, easy forming, high electric conductivity, and corrosion resistance. Due to these superior properties, aluminum alloys are used in the production of metal–matrix composites. The most widely used ceramic reinforcement materials in the production of aluminum composite materials (ACMs) are SiC [5], Al₂O₃ [6], SiO₂ [7], Si₃N₄ [8], AlN [9], ZrB₂ [10], TiB₂ [11], B₄C [12], and TiC [13]. B₄C is an attractive reinforcement material used in production of aluminum composites having low density, high rigidity and thermal stability [14]. Nevertheless, there are some problems preventing widely use of Al–B₄C composites, one of which is economic and the other one is

technical. In this study, corrosion behaviors and electric conductivity of *in situ* and *ex situ* produced, ACMs are investigated using AA7075 alloy added Ti (2–4 and 6%) and B₄C (3–9%) at various amounts (wt%). Corrosion behaviors and electric conductivity characteristics of the ACMs produced by *in situ* and *ex situ* methods were compared in order to determine ideal compositions.

2. Materials and method

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

TABLE I

Chemical composition of the AA7075 alloy used in the production of ACMs.

Element	Zn	Mg	Cu	Fe	Si	Zr	Cr	Mn	Al
[wt%]	5.48	2.58	1.568	0.549	0.403	0.0305	0.125	0.014	bal.

The ACMs are produced by adding 2–6% Ti and 3–9% B₄C into gas-atomized AA7075 alloy. After mixing the powder in Turbula Shaker Mixer (T2F Glenn Mills) 67 rev/min for 45 min, it is cold-pressed under 600 MPa pressure to produce cylindrical samples in dimensions of Ø12 × 7 mm. Produced green compacts are sintered at 580 °C in an atmosphere-controlled (argon) environment for 4 h (10 °C/min) and then cooled down in furnace to the room temperature. Following standard metallographic processes, produced AMC samples are etched with 95 ml distilled water, 2.5 ml HNO₃, 1.5 ml HCl and 1 ml HF (Keller's) solution for 15–20 s. Density measurements are conducted based on the Archimedes principles. Microstructures of produced *in situ* and *ex situ* aluminum composites are investigated with scanning

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electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). Tafel and impedance diagrams of samples prepared for corrosion tests are determined by platinum reference and operation electrodes in 0.1 M H_2SO_4 solution. Regarding electrical conductivity measurements, electric resistance of *in situ* and *ex situ* composite samples are measured by placing a copper material. Results (IACS %) are calculated according to the ASTM (B193-02) standard.

3. Results and discussion

3.1. Microstructural characterization

Figure 1 shows the microstructure SEM images of *in situ* and *ex situ* produced aluminum composites with powder metallurgy.

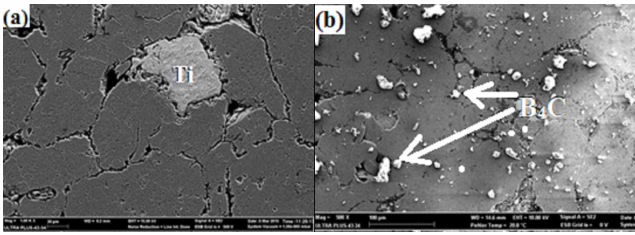


Fig. 1. SEM micro-structure images of ACMs *in situ* (a) and *ex situ* (b).

In the SEM image given in Fig. 1a it could be seen that titanium added into the structure in order to form *in situ* precipitates is seen as coarse grains in the matrix. Formation of *in situ* $TiAl_3$ phase in the structure could be explained by α -Al and $TiAl_3$ structural transformations in the Al-Ti diagram. From the Al-Ti phase diagram, peritectic reaction occurs between $TiAl_3$ intermetallic phase and aluminum. Titanium diffuses through Al/ $TiAl_3$ borders to form strong mechanical bonds in these areas [15], whereas homogeneous distribution of B_4C reinforcement material added into AA7075 alloy is observed from Fig. 1b. Figure 2 shows the XRD result of the *in situ* produced aluminum composite added Ti by 6%.

XRD pattern in Fig. 2 shows that *in situ* $TiAl_3$ phases are successfully formed in the structure. Besides $TiAl_3$ phase, Al and Ti phases can be observed in the structure. Figure 3 gives the Tafel polarization diagram and polarization resistance values of added Ti (*in situ*), (a),(b) and B_4C (*ex situ*) (c),(d) composites.

As it could be seen from the Tafel diagram of the composites produced by addition of different amounts of Ti into the AA7075 alloy, corrosion rates of *in situ* composites are determined as 0.556 mm/year (2% Ti), 1.26 mm/year (4% Ti) and 0.600 mm/year (6% Ti), Fig. 3a. Aluminum's corrosion resistance against variety of environment is a result of amorphous or crystalline aluminum-oxide layer formed on the surface subject to current conditions. As purity of aluminum decreases, corrosion resistance decreases as well. Increase of

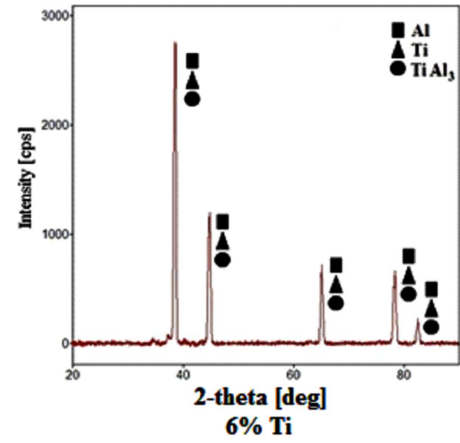


Fig. 2. XRD result of the *in situ* aluminium composite added 6% Ti.

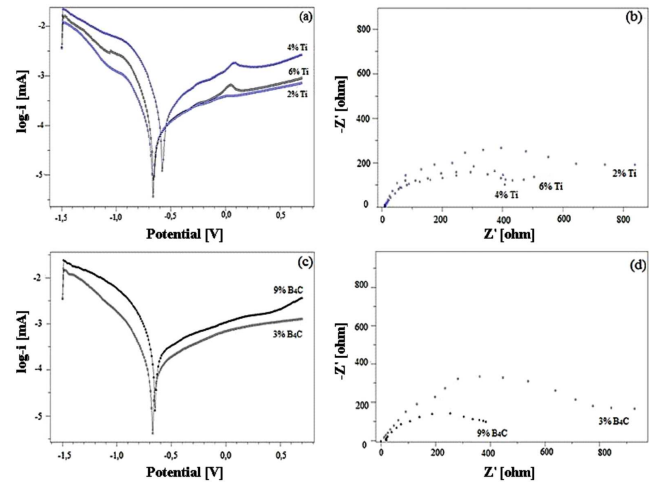


Fig. 3. Tafel polarization diagram and polarization resistances of composites added Ti (*in situ*) (a),(b) and B_4C (*ex situ*) (c),(d).

impurities in the structure of material is the most significant factor in reduction of corrosion resistance. According to Fig. 3b, impedance measurements polarization resistance supports behavior of *in situ* composite containing 4% Ti (as it was seen with the Tafel diagrams). Table II gives corrosion parameters obtained from the Tafel diagrams, density and electric conductivity results. Polarization resistances obtained from the measurement (Fig. 3d) are compatible with load transfer resistance values obtained from impedance measurements.

It is seen from Table II that density of *in situ* composites (2% Ti) (4% Ti) and (6% Ti) were measured as 2.647 g/cm³, 2.666 g/cm³ and 2.732 g/cm³, respectively. This result shows that as the amount of titanium added into the alloy increases, densities of *in situ* composites increase. The reason is that although the density of AA7075 alloy was 2.74 g/cm³, density of added titanium is 4.52 g/cm³. As the amount of Ti added into the alloy increases, density of produced composites increases as well. On the other hand, as the amount of B_4C

TABLE II

Corrosion parameters obtained from Tafel diagrams of composites use electrodes produced by addition of *in situ* (Ti) and *ex situ* (B₄C) in 0.1 M H₂SO₄ solutions, density and electric conductivity results.

Electrode type	$-E_{kor}$ [mV]	R_p [Ω]	$-\beta_a$ [mV]	$-\beta_c$ [mV]	Cor. rate [$\mu\text{m}/\text{year}$]	Density [g/cm^3]	Electrical conduct. [IACS %]
2% Ti	0.6969	869.2	0.601	0.142	0.556	2.647	3.18
4% Ti	0.6139	363.1	0.515	0.127	1.260	2.666	2.84
6% Ti	0.6660	513.0	0.527	0.081	0.600	2.732	2.25
3% B ₄ C	0.7069	540.9	0.873	0.168	1.107	2.732	10.5
9% B ₄ C	0.6550	209.3	0.826	0.147	2.690	2.629	3.60

added into the AA7075 alloy increases, densities of produced *ex situ* composites tend to decrease. As for electric conductivity of *in situ* and *ex situ* produced composites, increasing amount of reinforcement phase decreases the electrical conductance (IACS%) in *ex situ* aluminum composites produced by addition of different amounts of (3–9%) B₄C. IACS% value of the *in situ* aluminum composites decreases as the amount of Ti added into the *ex situ* composite increases. These results are expected from the electrical conductivity tests. It is related with a number of microstructural factors such as electrical conductivity or electrical resistance of metallic materials. These are effective on dimension and volume ratio, pores, lattice defects and precipitates within the structure of metallic materials. IACS% values obtained from the experimental studies suggest that homogeneity of microstructure, amount and size of reinforcement materials added are effective on electrical conductivity.

4. Conclusion

It can be concluded from the microstructure investigations of the composites produced by adding Ti and B₄C into gas-atomized AA7075 alloy powders that reinforcement materials exhibit a homogeneous distribution in the structure. XRD investigations show that TiAl₃ phase occurred in the structure of the *in situ* composites produced by adding different amounts of Ti. Because of density difference, as the amount of reinforcement

material added into the alloy increases, density of *in situ* composites increases as well. Such a situation decreases density of *ex situ* composites. Similar currents measured at anode and cathode during corrosion investigations of *in situ* composites suggest that composites do not have different corrosion behaviors. On the other hand, as B₄C amount increases in *ex situ* composites containing B₄C, corrosion rate (occurrence of current density) increases as well.

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