Study through potentiodynamic techniques of the corrosion resistance of different aluminium base MMC´s with boron additions

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Keywords: corrosion, boron, aluminium matrix composites.

Abstract. This paper compares a wrought aluminium with a PM aluminium and PM aluminium alloys with boron-base additions, containing boron carbide and Fe/B (obtained by mechanical alloying during 36 hours from a Fe-B 50% mixture by weight). The effect of sintering temperature for the Fe/B containing material and the effect of mechanical alloying for the boron carbide containing aluminium alloy on the corrosion resistance of those materials have been studied. Their behaviour is followed through cyclic anodic polarization curves in chloride media. In the Al+20%Fe/B composite, low sintering temperatures (650-950ºC) exert a negative effect. However, when the material was sintered at high temperature (1000-1100ºC) its behaviour was very similar to the PM pure aluminium. The effect of mechanical alloying studied in aluminium with boron carbide was also important in corrosion resistance, finding a lower corrosion rate in the mechanically alloyed material.

Introduction

Lightweight aluminium-matrix composites (AMCs) have been the focus of many studies on account of their outstanding properties. The powder metallurgical (PM) manufacturing of AMCs generally gives good mechanical properties, being an inexpensive process. One strategy to stiffen these materials is the incorporation of particles. Candidate reinforcing particles are those showing high stiffness and low density. Boron carbide (B_4C) is one of them, with a density of 2.52 g/cm^3 and an elastic modulus of 427 GPa. Aluminium base material is readily available, light-weight, and under reasonable processing conditions, reactive to B_4C. Theoretically, the elastic modulus of an AMC can be increased significantly, even at a boron carbide concentration of 10% by volume. Hence B_4C–Al composites have the potential to combine the high stiffness and hardness of B_4C with the ductility of Al without defeating the goal of obtaining a stiff low-density material. Suggested applications for B_4C–Al composites include their use as structural neutron absorber. Compared to other AMCs, the experimental work on B_4C–Al composites for structural application is scattered. There are papers on methods of preparation and mechanical properties [1-4], but scarce works are related to their corrosion properties.

The main objective of this work is to study corrosion AMC's with different reinforcements, using as reference pure PM aluminium and a wrought aluminium. The boron addition is made using boron carbide and iron boride. In the case of B_4C-Al, the effect of mechanical alloying on corrosion properties is studied, whereas in Fe/B containing materials, the influence of sintering temperature of the composite is evaluated.

Experimental procedure

Materials. Aluminium used to manufacture composite materials was a water atomised powder of Alcan-Toyo America Inc. (USA) with +99% purity and a particle size lower than 75 μm (d_{50} = 25 μm). Its morphology is shown in Fig. 1.

B_4C is a commercial powder from Strem Chemicals (France) with +99 % purity and particle size lower than 26 μm (d_{50} = 7.5 μm). Its morphology can be observed in Fig. 2.

Moreover, Fe/B material was synthesized from iron (ASC300 grade, Höganäs, Sweden) and boron (Strem Chemicals, France) powders by mechanical alloying. The mixture of boron and iron powders (weight ratio 1:1) was mechanically alloyed for 36 h at a speed of 700 rpm in an argon filled stainless steel vessel, with a ball to powder weight ratio of 25:1 [5]. It is an amorphous powder with many agglomerates. Fig. 3 and Fig. 4 show micrographs of this powder by SEM and TEM respectively.

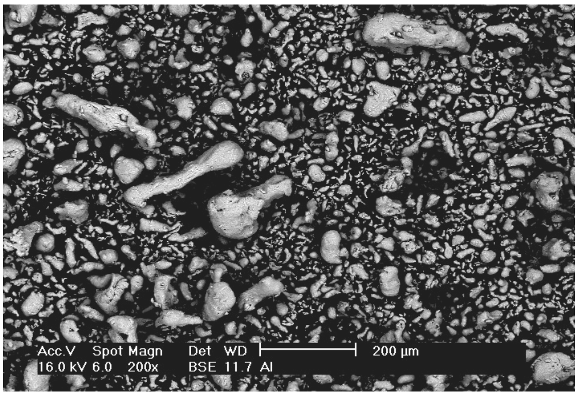

Fig. 1. Aluminium powder used as base material.

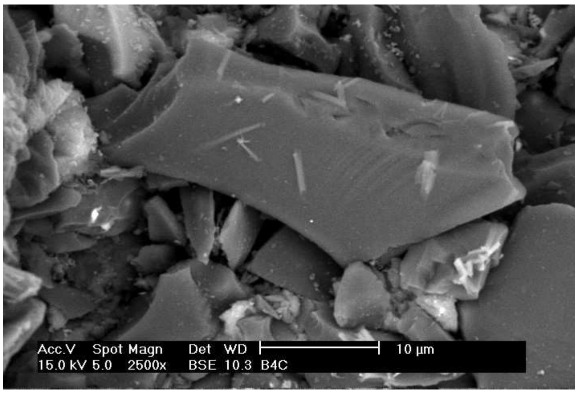

Fig. 2. B_4C powder used as reinforcement in AMCs.

B_4C-Al AMC was prepared adding 10% B_4C (by wt.) to Al powder. Two B_4C-Al mixtures were prepared: one, mixing powders in a low-energy mill to homogenize, and another was mixed at high-energy for 12 h in planetary mill. Mixtures were uniaxially compacted at 700 MPa and sintered in argon at 635 ºC [1].

Fe/B-Al alloy was obtained mixing 20% Fe/B (by wt.) and Al. This alloy was compacted at 700 MPa and sintered in $N_2/10H_2/0.1CH_4$ at different temperatures, ranging from 650 to 1100 ºC [6].

Moreover, a plain PM aluminium sintered at 620 ºC and a wrought aluminium were used to compare results.

Corrosion evaluation. Cyclic anodic polarization measurements were done to evaluate corrosion performance of different materials. This test is based on ASTM G-61 standard [7]. A traditional three-electrode electrochemical cell was selected. As working electrode, transverse sections of materials were used, embedded in resin and ground wiyh 1000 grade

SiC paper. Areas of materials ranged between 0.51 and 0.61 cm^2. A saturated calomel electrode (SCE) was used as reference electrode and a graphite bar was used as counter-electrode. Polarization tests were carried out in a 0.1M NaCl solution, deareated by N_2 bubbling. Tests were carried out after 1 h of exposure in the solutions to assure the corrosion potential (E_{corr}) stabilization. The curves started with a cathodic sweep from 150 mV below the E_{corr}. The potential was increased up to the current became 1 mA/cm^2, and then the potential sweeping rate was inverted until it returned to E_{corr}. The potential sweeping rate was always 0.17 mV/s.

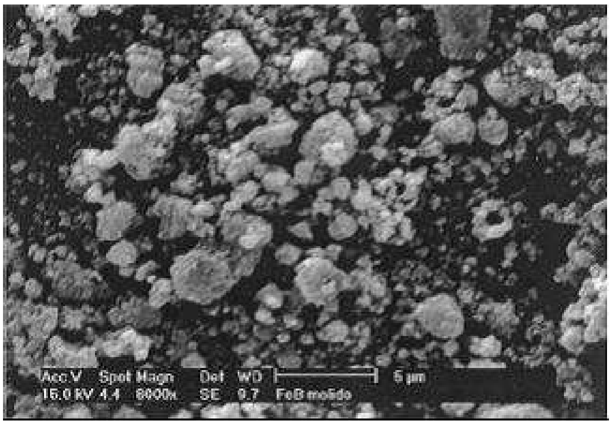

Fig. 3. Micrograph of Fe/B powder by SEM, after 36 h mechanical alloying.

Fig. 4. Micrograph of Fe/B powder by TEM, after 36 h mechanical alloying.

Results and Discussion

The corrosion performance of the materials depends on Fe/B or B_4C additions, and on the typical porosity of PM materials. This porosity dramatically increases the active surface of samples under corrosion test [8,9], and hence the probability of attack. Moreover, pore morphology favours the formation of differential aeration cells [10]. Fig. 5 compares polarization curves of a wrought aluminium and a PM aluminium. As can be seen, PM aluminium has a passivation intensity current of almost one order of magnitude higher than wrought aluminium, possibly due to the real surface of sintered material. Moreover, passivation quality of PM aluminium is not as good as the wrought aluminium, one sintering processes in plain aluminium are very difficult due to the alumina layer formed on the surface of particles, this reducing corrosion performance. Pitting potentials of both materials are very similar, and they easily get repassive. However, length of passive zone is higher in wrought aluminium as its E_{corr} is more cathodic.

Sintering temperatures of AMCs containing Fe/B have a dramatic influence on corrosion behaviour (Fig. 6). Materials sintered at low temperature (below 950 ºC) are actively corroded in the solution, i.e., they do not get passive. Material sintered at 650 ºC is shown as an example of the active behaviour of these materials (Fig. 6), although materials sintered at 700 and 800 ºC present a similar behaviour. The material sintered at 950 ºC, despite showing a typical active polarization curve, has a lower intensity of the cathodic process (Fig. 6). However, materials sintered at higher temperatures (1000 and 1100 ºC) present a stable passivity (Fig. 6), and their passivation ability is slightly lower than plain PM aluminium (Fig. 5). Reason lies on microstructure [6]. Fe/B particles are present after low-temperature sintering (forming galvanic couples with aluminium), while Fe/B disappears from the microstructure after high-temperature sintering, hence aluminium can keep its passivity.

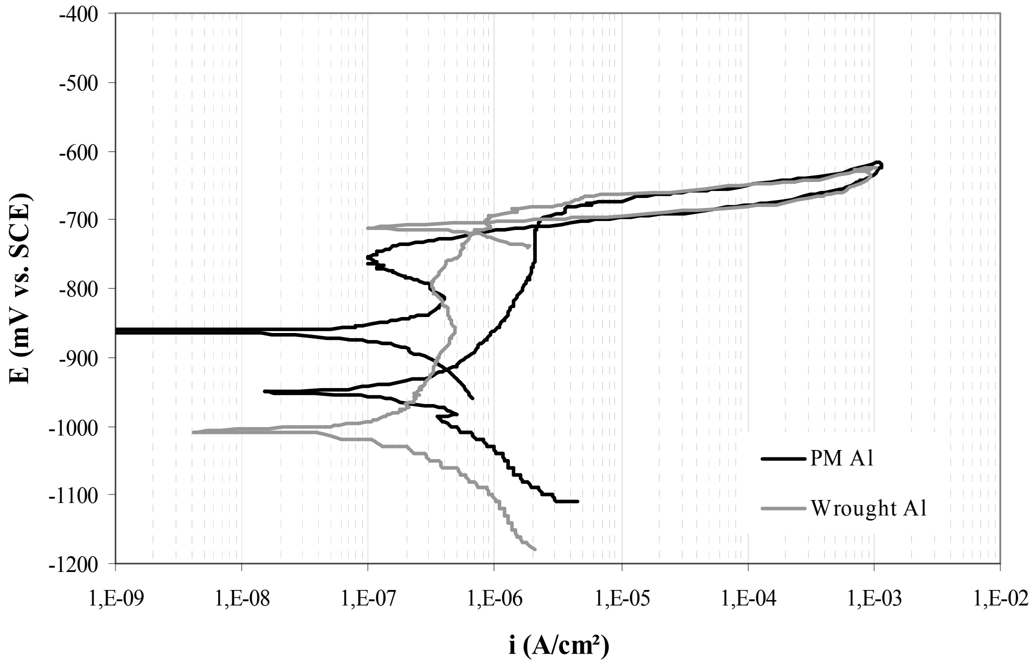

Fig. 5. Cyclic anodic polarization curves of a wrought aluminium and a plain aluminium.

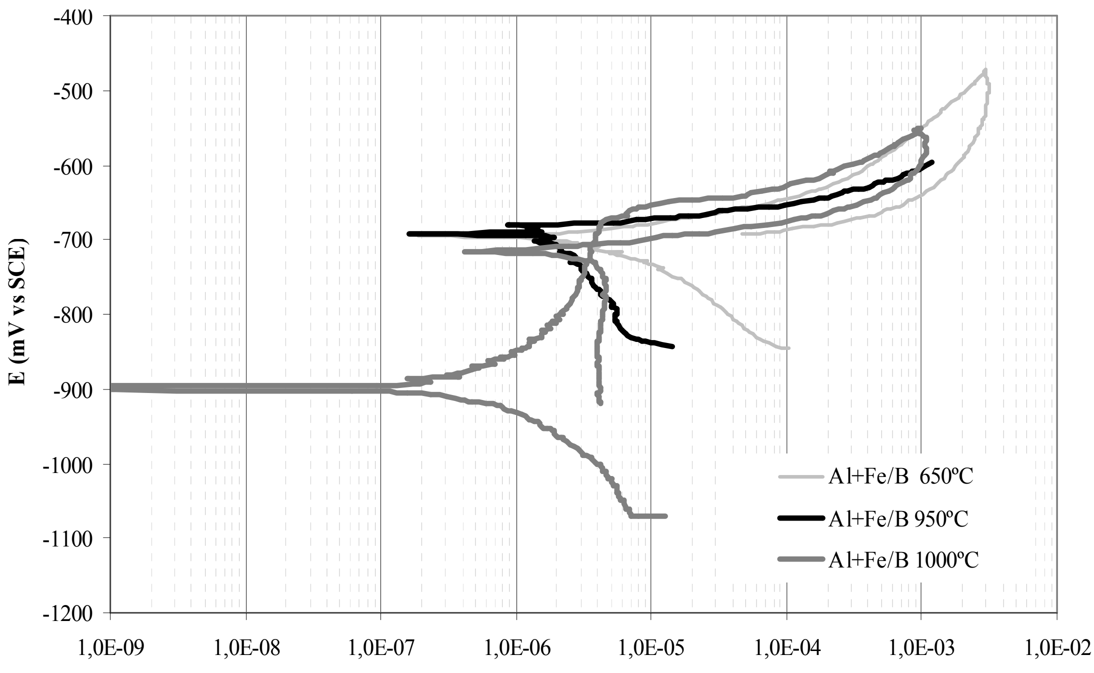

Fig. 6. Cyclic anodic polarization curves of aluminium with 20% Fe/B sintered at 1000, 950 and 650 ºC.

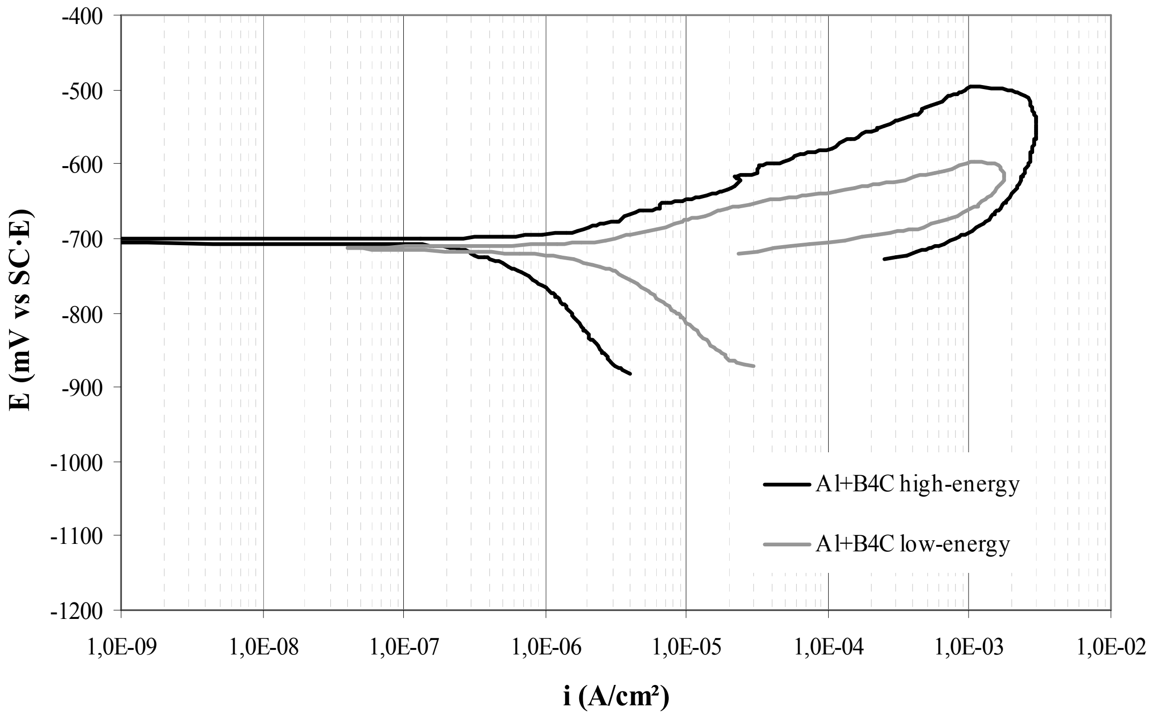

Fig. 7. Cyclic anodic polarization curves of aluminium with 10% B_4C for both mixing powders' conditions.

When 10% B_4C is added to aluminium (Fig. 7), no material can keep the passivity of aluminium (Fig. 5) in deaerated solutions with 0.1 M NaCl. Both polarization curves are typical of active state corrosion. This negative effect of B_4C can lie on two reasons: (a) the slight inhibition of sintering process and the increase of porosity (density changes from 94.41% in plain aluminium to 91.73% in B_4C AMC), and (b) the cathodic behaviour of carbide particles in front of aluminium.

Fig. 8 clearly summarises all these facts. PM aluminium and all AMCs have E_{corr} and corrosion intensity (i_{corr}) values slightly higher than wrought aluminium. These values increase with Fe/B addition. Fe/B containing materials, sintered below 950 ºC, show E_{corr} values (-694 mV vs SCE) higher than those sintered at 1000 and 1100 ºC. i_{corr} values (Fig. 8) follow the same pattern than E_{corr}, being one order of magnitude higher for high-temperature sintered materials. i_{corr} of material sintered at 950 ºC lays between both behaviours (active and passive), as a consequence of the change in cathodic curve (Fig. 6).

Fig. 8 also shows the effect of B_4C. Materials milled at high energy corrode three-times slower than low-energy mixed ones, and only twice faster than PM aluminium. Moreover, all those corrosion intensity values are measured on apparent surface. As B_4C containing materials are more porous than plain aluminium, difference would be less if real area were used. Regarding E_{corr} (Fig. 8), those values do not seem to be influenced by milling, being typical for an active aluminium alloy in chloride media.

Conclusions

The presence of Fe/B dramatically influences the corrosion performance of these materials, depending on sintering temperature. At higher temperatures (1000 and 1100 ºC) present a stable passivity and passivation ability slightly lower then plain PM aluminium

Milling (mixing) process affect the cathodic activity of B_4C containing materials, and hence corrosion performance. This material does not keep a passive layer, but it corrodes at low rate.

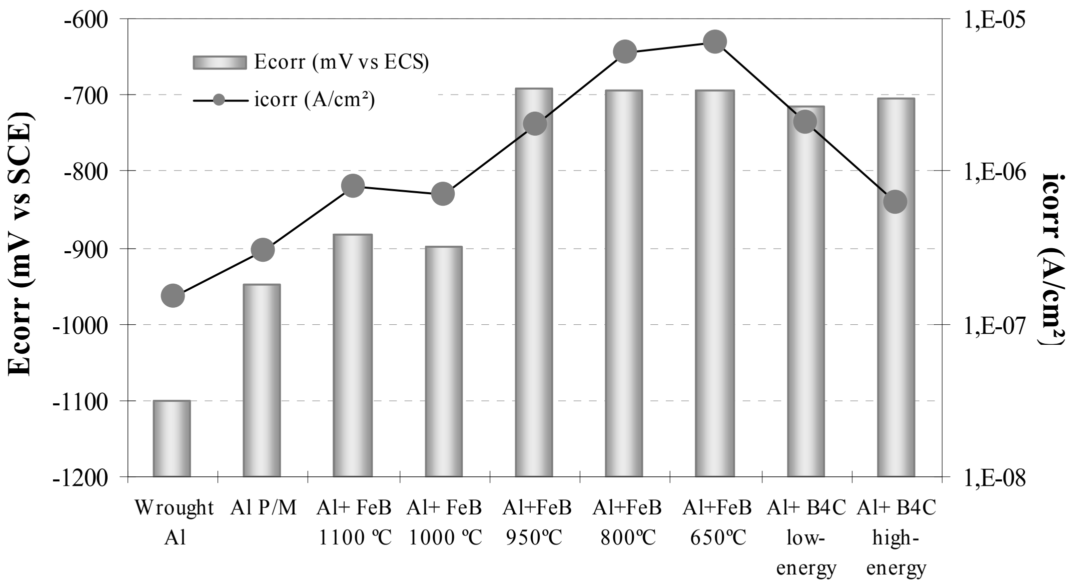

Fig. 8. E_{corr} and i_{corr} values in deareated NaCl 0.1 M of all studied materials.

References

[1] J. Abenojar, F. Velasco and M.A. Martinez: J. Mater. Process. Tech. Vol. 184 (2007) p. 441

[2] R.M. Mohanty, K. Balasubramanian and S.K. Seshadri: Mater. Sci. Eng. A Vol. 498 (2008) p. 42

[3] M. Rahimian, N. Ehsani, N. Parvin and H.R. Baharvandi: J. Mater. Process. Tech. Vol. 209 (2009) p. 5387

[4] M. Khakbiz and F. Akhlaghi: J. Alloy Compd. Vol. 479 (2009) p. 334

[5] J. Abenojar, F. Velasco, J.M. Mota and M.A. Martínez: J. Solid State Chem. Vol. 177 (2004) p. 382

[6] J. Abenojar, F. Velasco and M.A. Martínez: Rev. Metal. Madrid Vol. 42 (2006) p. 114

[7] ASTM G- 61: "Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion susceptibility of Iron-, Nickel-, or Cobalt-Based Alloys" (1993)

[8] F. Velasco, J.M. Ruiz-Román, J.M. Torralba and J.M. Ruiz-Prieto: Brit. Corros. J. Vol. 31 (1996) p. 295

[9] A. Bautista, A. González-Centeno, G. Blanco and S. Guzmán: Mater. Charact. Vol. 59 (2008) p. 32

[10] T. Raghu, S.N. Malhotra and P. Ramakrishnan: Corrosion Vol. 45 (1989) p. 698