

COMPARISON BETWEEN Ti_3Al AND Ni_3Al INTERMETALLICS USED AS REINFORCEMENTS IN ALUMINIUM ALLOY MMCs.

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SUMMARY: Aluminium matrix composites reinforced with intermetallics have appeared as very promising materials if a sound interface is achieved. This interface is dependant upon the possible reaction products and interphases that could appear due to the thermal processes implied during fabrication and/or posterior heat treatments, in case the matrix is a high strength heat-treatable alloy. The particulate reinforced aluminium matrix MMCs have been obtained by a combination of powder metallurgy technique and extrusion. This fabrication method guarantees both a good densification of the composite and a homogeneous distribution of the reinforcement in the matrix. Both 2000 and 6000 series aluminium alloys were used as matrix and Ni_3Al and Ti_3Al intermetallic particles as reinforcements.

KEYWORDS: aluminium matrix composite, intermetallics, heat treatment, interface, interphases, powder metallurgy, extrusion.

INTRODUCTION

The development in the past years of particulate reinforced aluminium matrix composites has been mainly correlated to the use of ceramic particles. These comprised oxides, carbides and nitrides, being alumina (Al_2O_3) and silicon carbide (SiC) the most utilised and investigated. Also, their overall benefits, limitations and possible applications are well known [1-5].

The use of intermetallics as reinforcing materials in these composites has received some attention in recent years, because of their interesting properties in relation to the requirements desired for this purpose: high strength, modulus, and thermal stability [3]. These studies have been focused mainly in the use of Ni_3Al intermetallic particles [6-8].

On the other hand, for obtaining a sound composite whichever the reinforcement is, it is agreed that the interfacial bond strength between particle and matrix has to be maximised in order to ensure the correct transmission of stresses [9,10]. Therefore, the study of the interface and the interphases developed under heat treatments in aluminium matrix composites reinforced with intermetallics is a matter of importance for their future development and industrial use.

EXPERIMENTAL

Materials.

Three different aluminium alloys were used in this study, regarding composition and fabrication process. Two of these, of composition similar to AA2014 (Cu: 4.4%, Si: 0.7%, Mg: 0.5%, Al: bal.), were produced by two means: mechanical alloying of elemental powders (A2-MA) and atomisation (A2-A). The third one was again produced by atomisation and its composition was Cu: 1.0 %, Si: 0.74%, Mg:0.19%, Al: bal. (A6-A). The former was chosen for being a heat treatable alloy, which can achieve high mechanical strength. The latter, with low content of alloying elements, was selected in order to minimise the effects produced by these in the reaction layers developed, as previously reported [11].

Ni₃Al and Ti₃Al intermetallics were used as reinforcements. The first one, supplied by CENIM (Spain) was argon atomised. This process produced particles of spherical morphology, being selected those of size ranging from 25 to 50 µm. The second one was obtained through a hydride-dehydride process by Se-Jong Materials (South Korea), which conferred them a polygonal morphology. In this case, the particle size distribution ranged from few microns to a largest particle of 50 µm.

Fabrication process.

The fabrication procedure comprised: mixing of alloy and intermetallic powders, compaction (250 Mpa), graphite lubrication, heating at 500°C for an hour to homogenise the temperature and extrusion with a ratio of 25:1 and a ram speed of 1 mm/s [6]. At the end, a bar of 5 mm of diameter of MMC was produced. Regarding the reinforcement used, Ni₃Al or Ti₃Al with a 10% in weight, different composites were obtained.

Denomination	Composite
A2-MA-Ni ₃ Al	A2-MA+10 weight pct. Ni ₃ Al
A6-A-Ni ₃ Al	A6-A+10 weight pct. Ni ₃ Al
A2-A-Ti ₃ Al	A2-A+10 weight pct. Ti ₃ Al
A6-A-Ti ₃ Al	A6-A+10 weight pct. Ti ₃ Al

Experimental Procedure.

Isothermal heat treatments regarding time were carried out at a fixed temperature of 773K, in order to emphasise the diffusion processes between matrix and reinforcement. In this study, optical (Nikon Microphot FX) and scanning electron microscopy (JEOL 6300) with X-ray microanalysis (Link Isis EDX) were used.

RESULTS AND DISCUSSION

The fabrication process produced a sound composite, with a good distribution of reinforcements and a nearly absence of porosity in every case.

After heat treatment at 773K, it appeared a very different behaviour between the composites studied, but especially in those reinforced with Ni₃Al. The optical micrographs of fig.1,

corresponding to a heat treatment of 6 hours at 773K, show the differences in the reaction layers developed in relation to alloy elements present in the matrix. On the left, for the composite A2-MA-Ni₃Al, there are three reaction layers clearly visible, whereas for the A6-A-Ni₃Al there is only one. Two different illumination techniques have been used to emphasise

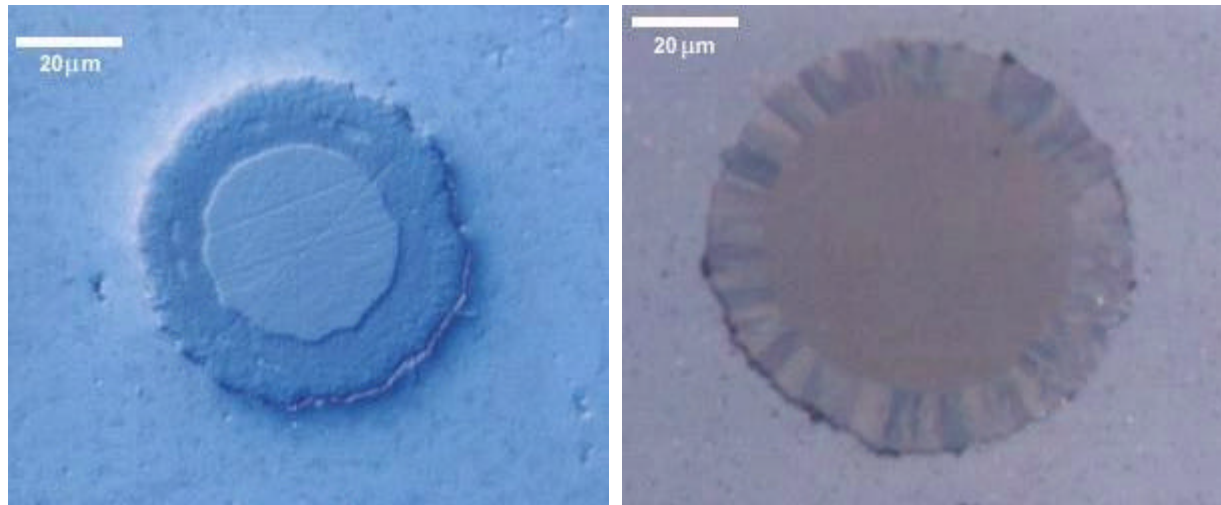


Fig. 1. Micrographs showing reaction layers that appear in two of the aluminium composites reinforced with Ni₃Al particles, after a heat treatment of 6 hours at 773K. Left with A2-MA alloy (Nomarski) and right with A6-A one (Polarised light).

their own main characteristics. For the first composite, the Nomarski technique gives a 3D-coloured virtual image. It can be seen the three layers formed (being discontinuous the central one). Also, and resulting a very interesting feature, it could be perceived the fine and equiaxed grain structure of the outer layer. On the other hand, for the second composite, it is clearly observed the columnar growth of the reaction layer grains with the polarised light technique [8]. This morphology of grains is not observed when looking at the A2-MA-Ni₃Al composite.

Figures 2 and 3 show a SEM image and an EDX line analysis of the same composites, corroborating the previous observations. For the A2-MA-Ni₃Al composite three layers are developed. The line analysis between points 1 and 2 displays the variation of aluminium and nickel content after 6 hours at 773K. After 6 hours it could be noticed 3 different layers of intermetallic compounds as discussed in previous works by the authors [11,12]. Summarising, the outer layer develops with an enrichment in copper content from the matrix, yielding an intermetallic interphase of composition close to Al₃(Ni,Cu)₂. The inner and central layers resulted in compositions near Al₃Ni₂ and Al₃Ni respectively. On the other hand, for the A6-A-Ni₃Al composite and for the same heat treatment, only one reaction layer is developed. In this case, there is not an enrichment of copper at all, whereas only a slightly increment in magnesium (as the counts for this element are very low in comparison to those of Ni and Al). The composition is close to the intermetallic Al₃Ni.

One interesting feature is when comparing these two composites is the fact that the total thickness of the reaction layers developed is similar, and of about 12 µm. By assuming that a transversal cut of the sample will show some equatorial sections of the particles, and considering that the bigger size of these is 50 µm, it could be roughly estimated the thickness of these layers. Thus, although very different reaction layers are developed depending on the aluminium alloy used as matrix, the diffusion of Al and Ni remain nearly the same. For this reason, the differences encountered should be explained either by the influence of the different alloying elements or the influence of the fabrication process of the alloy.

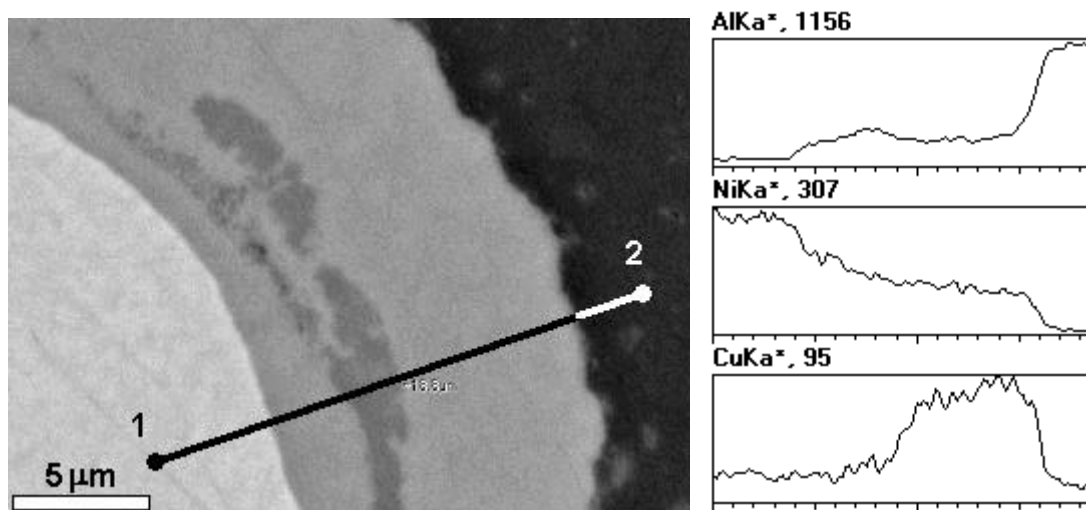


Fig. 2. SEM micrograph of A2-MA-Ni₃Al composite, heat-treated 6 hours at 773K. X-ray line analysis of elements showing the enrichment of Cu content in the outer layer.

Regarding this last point, Minamino et Al. [13] showed that the interfacial diffusion coefficient of copper in mechanically alloyed aluminium alloys is much larger than the volume diffusion one, and this could lead to the enhancement of reactions in these materials. When considering that the A2-MA alloy was mechanically alloyed in comparison to the A6-A alloy that was not, the observed different behaviour in the growth of the reaction layers could be explained. Both the higher quantity of copper present in the matrix and the increased diffusion coefficient, promote the migration of Cu atoms in the formation outer reaction layer of the Ni₃Al particles in the A2-MA-Ni₃Al composite. Also, the sub-micron grained structure of this alloy could favour the nucleation of tiny equiaxed grains in this layer, in comparison to those of columnar shape developed in the A6-A-Ni₃Al composite.

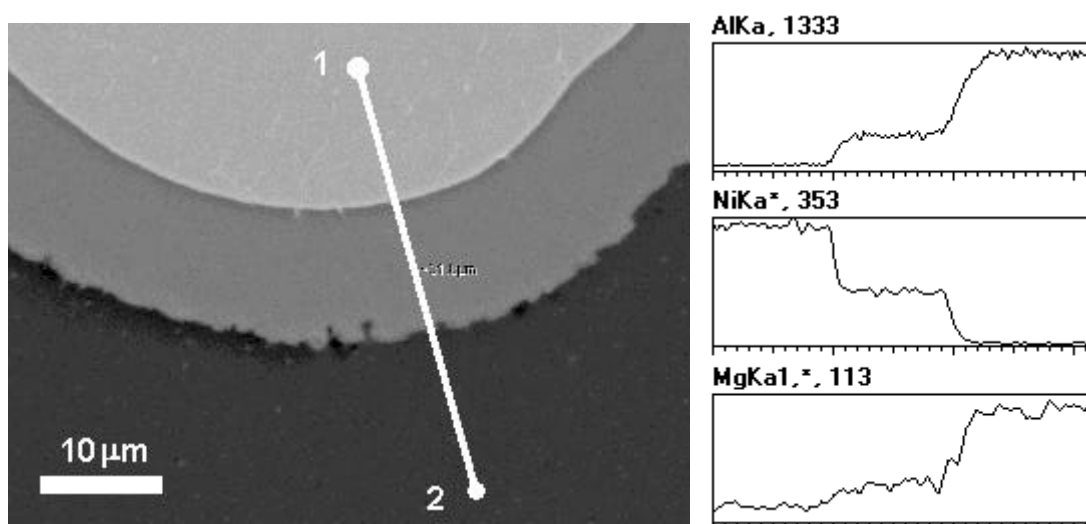


Fig. 3. SEM micrograph of A6-A-Ni₃Al, heat-treated 6 hours at 773K. X-ray line analysis of elements showing the uniformity of the Al₃Ni reaction layer and the slight increment in Mg content.

Figures 4 and 5 show the SEM images and EDX line analysis of the composites reinforced with Ti₃Al with subjected at the same heat treatment as the previous ones. First of all, it can be noticed the more irregular shape of these particles, as a result of its fabrication process. On the

other hand, an important thing that calls our attention is the fact that there is not an appreciable development of reaction layers at the matrix-reinforcement interface. It is only observed an increment in silicon content in the interface for the A2-A-Ti₃Al composite, although when considering the counts of the X-ray analysis it appears to be very small. Furthermore, it could be explained as a boundary precipitation of this element. On the contrary, in the A6-A-Ti₃Al composite there is not evidence at all of any reaction layer or precipitation of alloying elements at the interface.

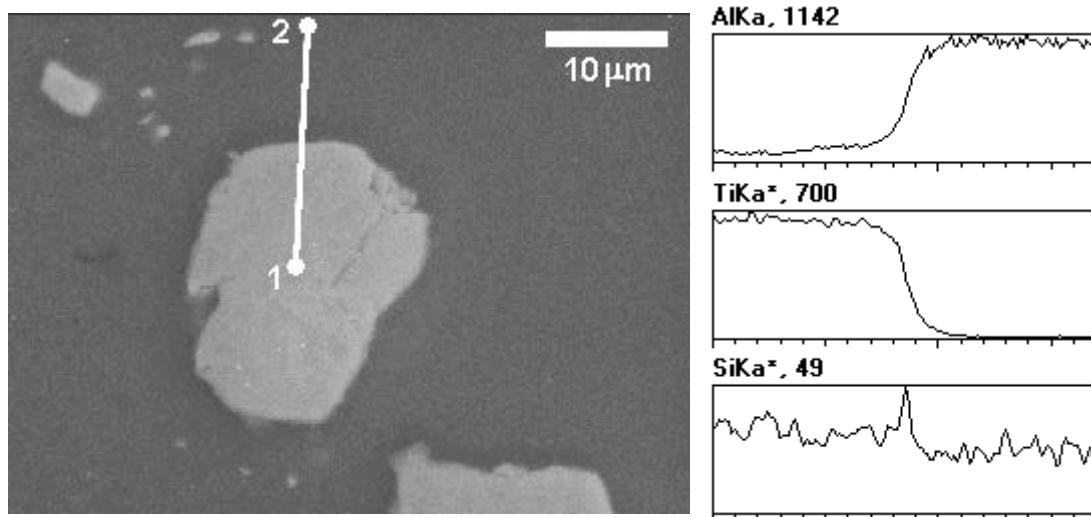


Fig. 4. SEM micrograph of A2-A-Ti₃Al, heat-treated 6 hours at 773K. It is not observed the formation of reaction phases at the interface, as shown by the X-ray line analysis. There is only a slight increment in the concentration Silicon.

It has to be pointed out that due to the fact that the spot size of the SEM electron beam is approximately 1 μm for the conditions of analysis (20 kV) and elements involved, this distance is the minimum resolution achievable by this technique. For this reason, the changes in element concentration shown by the profiles of the line analysis are not steep at the interface. Nevertheless, this technique has shown noticeable differences in stability between both intermetallics studied.

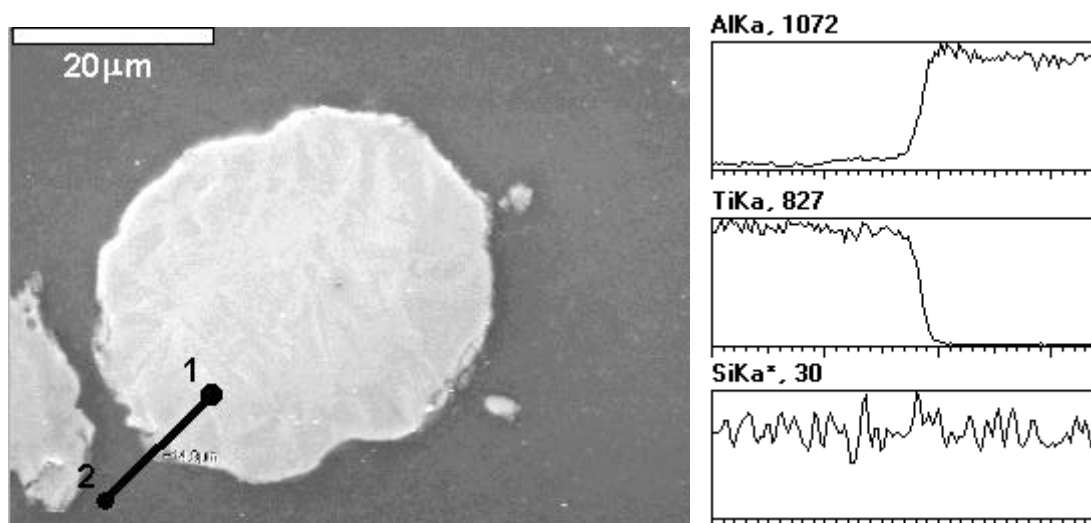


Fig. 5. SEM micrograph of A6-A-Ti₃Al, heat-treated 6 hours at 773K. Again, not appreciable interphases are developed at the interface.

To ascertain the degree of stability of Ti_3Al reinforcements in these composites, a heat treatment of 24 hours at 773K was performed. The results obtained for both Ti_3Al composites are similar, and could be summarised by figure 6 (in this case, for the A6-A- Ti_3Al one). It is observed the formation of a small reaction layer of about $2\text{ }\mu\text{m}$ thick, and an interesting feature is that in this case, there is silicon enrichment in this layer. In comparison to the role played by copper in the Ni_3Al reinforced composites, it has to be pointed out that in this case it has not any effect at all in the formation and/or development of these layers.

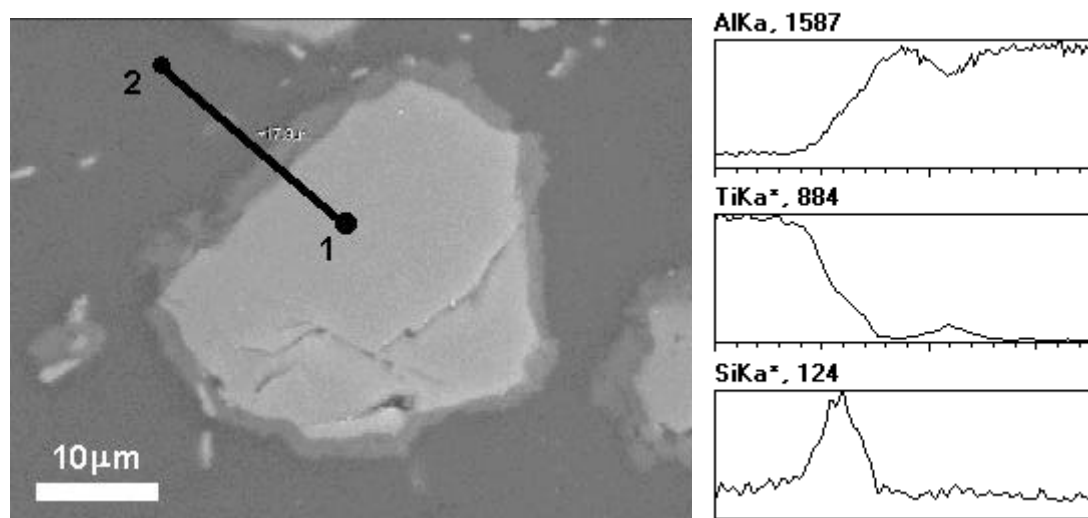


Fig. 6. SEM micrograph of A6-A- Ti_3Al , heat-treated 24 hours at 773K. The quantitative X-ray line analysis shows how in this case the interphase developed is enriched in Silicon from the aluminium alloy matrix.

CONCLUSIONS

In Ni_3Al intermetallic reinforced aluminium MMCs, both the processing technique of the alloy and the quantity of copper present influence the nature of the reaction layers formed between matrix and reinforcement.

A higher thermal stability of Ti_3Al intermetallic reinforced aluminium MMCs is attained in comparison to Ni_3Al reinforced one. This assures the no formation of deleterious reaction layers if solution treatments for the heat treatable matrix at high temperature are carried out.

In a first instance, copper plays an important role in the development of reaction layers in Ni_3Al reinforced materials, whereas silicon does when Ti_3Al is used as reinforcement.

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