Titanium and aluminium composites materials reinforced by Ti-Al compounds

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Abstract: There are very differents studies about interactions between titanium and aluminium. In this paper differents composites materials obtained by powder metallurgy rout are studied. Composites materials are obtained reinforcing titanium matrix with Ti-Al compounds, and aluminium matrix with Ti-Al too.

Titanium matrix composites are milled with differents percentages of reinforcements in a balls mill; the mixture are pressed in a uniaxial press and sintered in a vacuum furnace at differents temperatures.

Aluminium matrix composites are milled with differents percentages of reinforcements in a balls mill too, and extruded in a uniaxial press with a 25:1 extrusion rate, obtaining 5 mm diameter samples.

Mechanical properties and the reinforce particles influence in the different matrix are studied. In addition samples are observed by optical and electronic microscopy to study his microstructure and the reactivity between the reinforcement and the matrix is studied too.

Introduction

Metal matrix composites (MMCs) are currently being explored because of their superior properties as compared to those of most conventional materials. MMCs exhibit a high specific strength, stiffness and wear resistance. However, discontinuously MMCs have lower ductility and fracture toughness than the unreinforced alloys [1,2]. The employ of intermetallic particles (nickel or titanium aluminides) as suitable reinforcements for aluminium and titanium alloys was proposed at least 22 years ago [3,4].

At the present, the two major obstacles to the application of such materials are high cost and chemical reaction at reinforcement/matrix interfaces during materials processing and service at elevated temperatures [5,6]. Systematic studies on the mechanical response of various commercial MMCs as a function of material, processing or loading parameters are still meaningful. The deformation and fracture modes of MMCs can be controlled by a number of material and processing parameters [7,8] such as the type, shape, aspect ratio, volume fraction, orientation and distribution of the reinforcements, as well as the matrix interfaces properties. Most of these parameters will be strongly influenced by the processing and thermal treatment history.

Various authors have studied microstructure/mechanical property relationships for discontinuously reinforced aluminium. The effects of the reinforcements on the mechanical

properties of the aluminium alloys are in general beneficial compared with the properties of the matrix. However, the elongation is adversely affected due mainly to the higher number of nucleation sites present for the cracks to form [8,9,10].

On the other hand, titanium and its alloys stand out primarily due to their specific strength and excellent corrosion resistance. This explains their early success in the aerospace and chemical industries, but other markets such as architecture, chemical processing, medicine, power generation, marine and offshore, sports and leisure, and transportation are seeing increased application of titanium [11,12]. At higher temperatures the specific strength of titanium alloys is particularly attractive. However, the maximum application temperature is limited by their oxidation behaviour.

The titanium aluminides, TiAl, have been considered one of most important reinforcement candidates because they exhibit low density and excellent mechanical properties, principally at high temperatures. The utilization of these reinforcements came from the possibility to make use low density materials and that permit to produce aluminum or titanium composites with good wear resistance [7,11,12].

As compared with casting procedure, in addition to its inherent economic benefits, PM procedure has the advantage of greatly reduced particle/matrix interfacial reaction and more homogeneous particle distribution in the matrix [13,14].

In this work we intend to put together the benefits of titanium and aluminium as matrix and the TiAl compounds as reinforcements to develop materials with improved properties. The reinforcement structural characterization was done by optical and electronic microcopies and the mechanical properties were determined by tensile and flexural strength tests.

Materials and Methods

In this work two different materials in powder state are used as matrix. Firstly, AA6061 aluminum alloy with a 1.04% Mg and 0.63% Si, obtained by atomisation of the molten metal by argon and The Aluminium Powder Co. Ltd. supplied it. Secondly, titanium powder (99.5) quality 3 powder, about 325 mesh with polygonal shape, supplied by Crucible-Research, obtained by hydride and dehydride process (figure 1). The matrix powder has been reinforced by TiAl powders, supplied by Crucible-Research, is a Ti-48Al-2Cr-2Nb alloy, with spherical shape and about 325 mesh, obtained by atomisation process (figure 2).

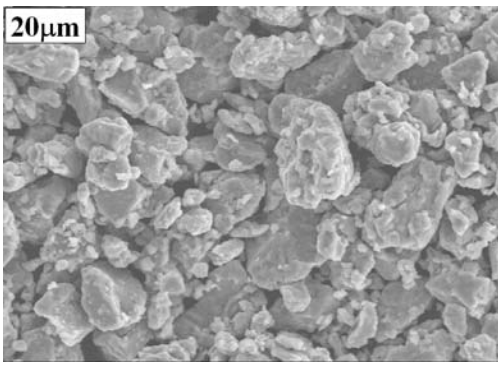

Fig. 1 - Ti powder SEM image

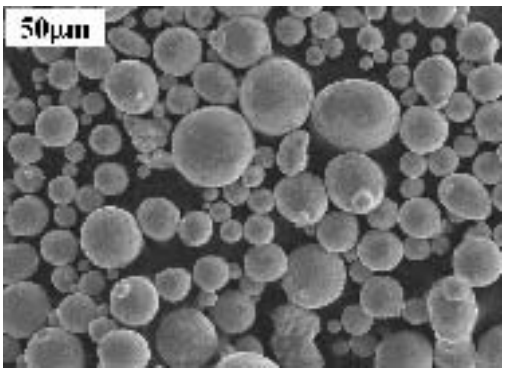

Fig. 2 - TiAl powder SEM image

Different metal matrix composites are obtained by mixing titanium or aluminium powder with different percentages of reinforcing particles. The mixtures obtained are aluminium with 5, 10 and 15% in volume of TiAl and titanium with 10, 20 and 40% in vol. pct. of TiAl.

Samples were obtained by P/M route: powders were mechanically blended in an

alumina lab mixer for 2 h at 90 rpm (1.5 s^{-1}). The obtained mixture was uniaxially cold compacted by slowly increasing pressure up 250 MPa for the aluminium matrix composites and 680 MPa for the titanium matrix composites and 86% of density were achieved. The aluminium matrix composites, after graphite lubrication and a ram speed of 2 m/s, were hot extruded at 530 °C (803 K) with a ratio of 25:1.

After the compaction process of the titanium matrix composites, the green samples have been sintered in a tubular vacuum furnace, Carbolite model HVT/15/75/450. Samples are sintered at different temperatures in a range from 1180ºC to 1220ºC. The sintering cycle is defined by a heating rate of 15ºC/min (0.25 K/s), permanence at final temperature for 1 hour, and cooling in the furnace to room temperature. The sintering process has been realised in vacuum of about 10^{-4} bar.

Powdered materials have been characterized by scanning electron microscopy, Jeol 6300, and particle shape, size and surfaces are studied. A particle size analyser has been used to study particle size distribution and dispersion, Mastersizer 2000 from Malvern Instruments. Fractographic analyses of composites were performed after tensile and flexural strength tests. Different titanium matrix composites are obtained by mixing titanium powder with different percentages of reinforcing particles. The mixtures obtained are titanium with 10%, 20% and 40% in vol. pct. of TiAl.

Experimental Results

The aluminium alloy, AA6061, show an evolution of tensile parameters as a function of precipitation state of the alloy. It was found that the ultimate tensile strength increase increases from 198 MPa for the extrusion condition up to 330 MPa after the aging treatment as a consequence of the presence of small intermetallic precipitates. Coherent precipitates increase the material flow strength trough the well-known mechanism of dislocation–precipitate interaction. It was also appreciated a slight reduction of elongation value. AMCs studied achieved similar tendencies.

Fig. 3 – Ultimate strength evolution with volume fraction of TiAl in AA6061 matrix composites for the extrusion condition.

The volume fraction of TiAl particles was found to have significant effect on tensile properties of aluminium alloys. This is illustrated in figure 3, which shows the variation of the ultimate strength with volume fraction of TiAl reinforcement particles that slightly increases with volume fraction of composite, until reinforcement content of 10% of intermetallic particles. After that, lower values are achieved by 15% volume fraction. The addition of the intermetallic particles improves the strength mainly by the load transfer from the matrix to the

reinforcement due to the differences in the elastic constants. Offset yield strength was found to decrease with the increase of reinforcement addition. The low values correspond to 15% volume fraction of reinforcement. The same behaviour was observed for the elongation parameter. It can be explained by follows: during powder metallurgy processes, are produced intermetallic and oxide particles that act like stress-concentrators and decrease ductility and toughness.

Some fractographic analysis were performed on fractured samples, figure 4. The composite fracture surfaces exhibited microscopically a ductile appearance by means of matrix/ reinforcement interface (dimples), and a fragile fracture of the particulates. The dimples were due to the aluminium matrix fracture. It was also observed, that fracture did not growth by particles that remain its initial shape after fracture. The fracture grows by the matrix/reinforcement interfaces.

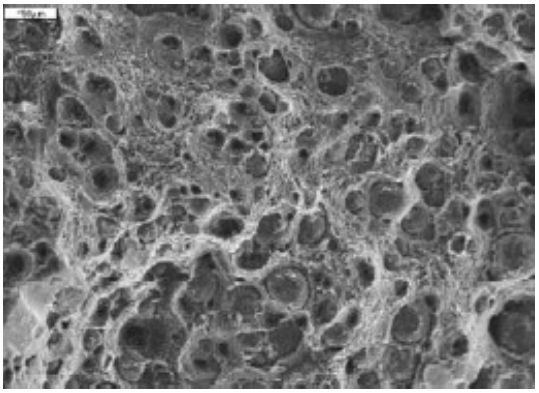

Fig. 4 – Fracture surface of AMC with 10% TiAl for the extrusion condition.

The composites obtained with titanium matrix show that there density decrease with reinforcement fraction. Figure 5 shows the density comparison between titanium samples and titanium reinforced with TiAl in relation to different sintering temperatures. At least, for a given amount of reinforcement increasing sintering temperature attains higher densification.

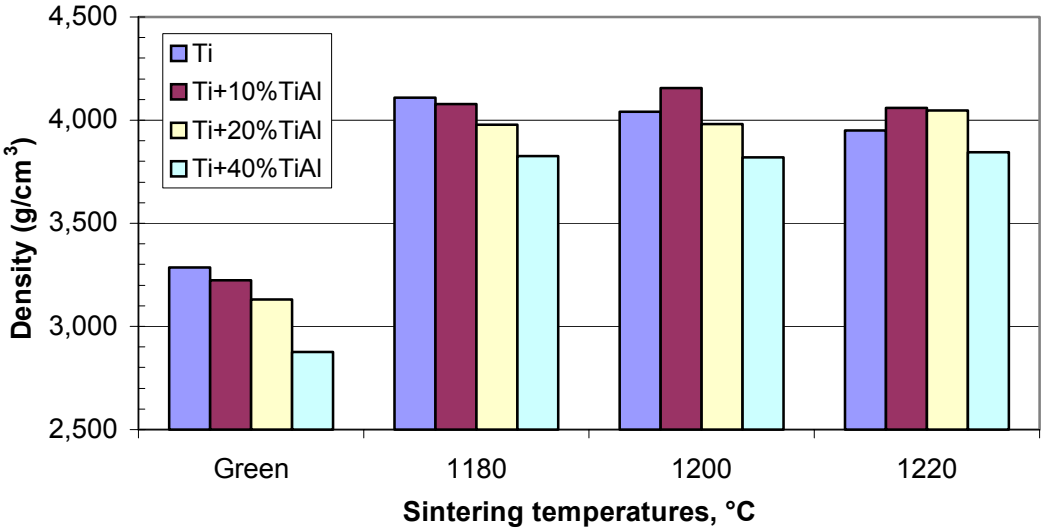

Fig. 5 - Density of the titanium samples reinforced by TiAl according to different sintering temperatures

Mechanical properties were studied by flexion and hardness tests. On figure 6 flexural strength is presented in relation to reinforcement content and sintering temperature. TiAl reinforced titanium samples have reached better flexural strength than unreinforced titanium in some conditions. In fact, there is a meaningful increase with a 10% of reinforcement although increasing this value produces an opposite effect.

Regarding hardness different results have been observed. Figure 7 shows that composite materials reinforced with TiAl have higher hardness than titanium matrix in some cases. In relation to titanium samples, a maximum in hardness is reached at a sintering temperature of 1200ºC in this case.

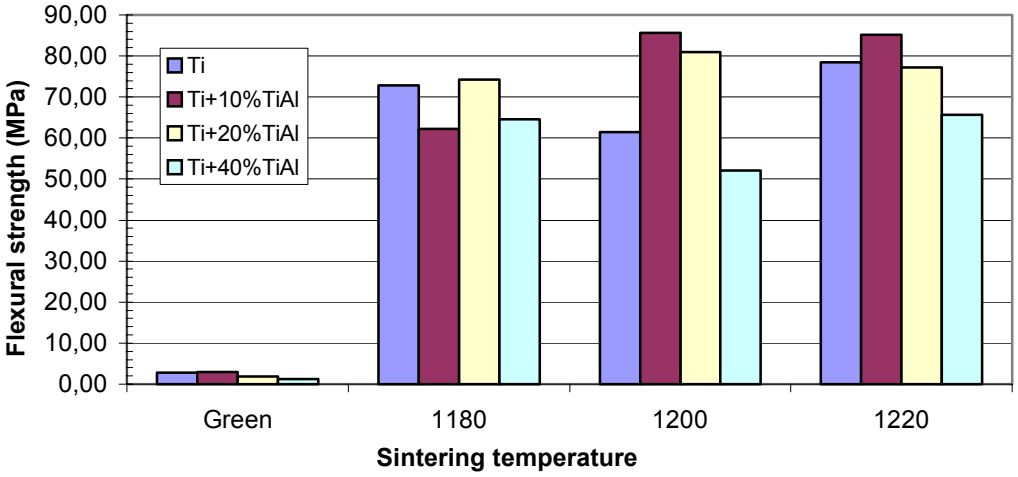

Fig. 6 - Flexural strength in Ti and in Ti+%TiAl samples according to different sintering temperatures.

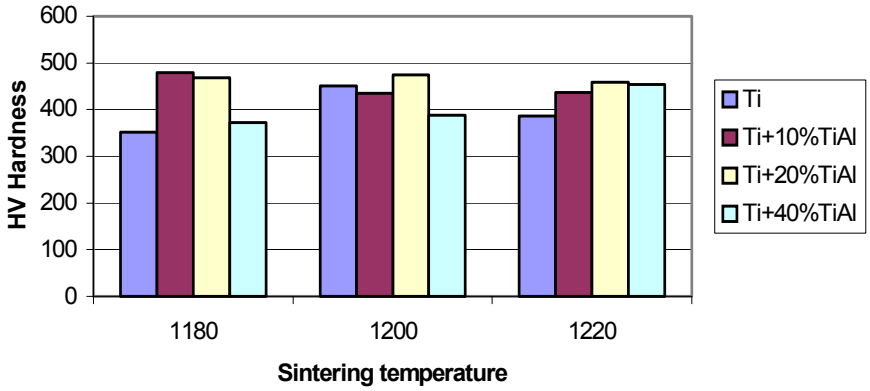

Fig. 7 - Graph showing Vickers hardness results.

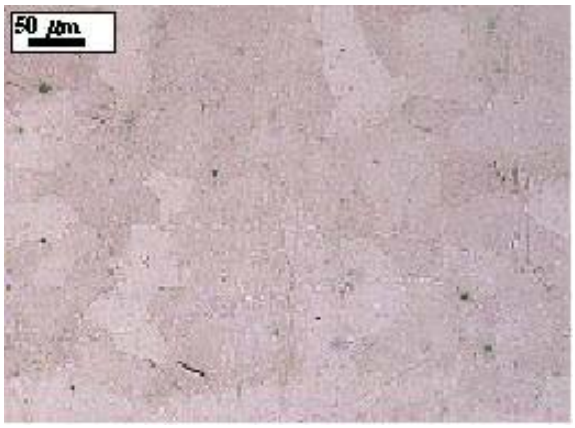

Fig. 8 - Pure titanium sample sintered at 1220ºC observed by optical microscopy, 100x

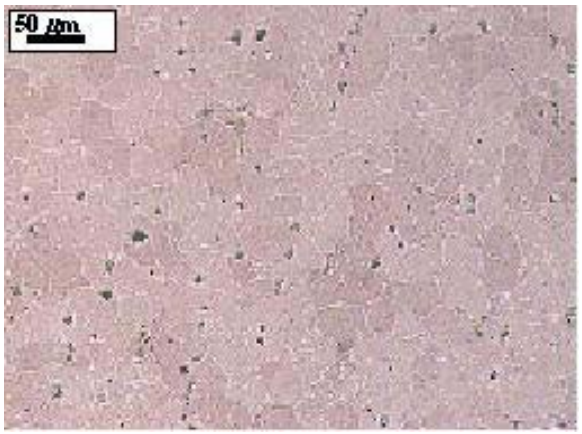

Fig. 9 - Titanium reinforced with 10%TiAl and sintered at 1180ºC sample observed by optical microscopy, 100x

Microstructural characterization has been made by means of optical and electron microscopy. On figure 8, pure titanium sintered at 1220ºC is observed by optical microscopy. The image shows the presence of α phase grains, which have quite equiaxed shape. The mean grain diameter is about 70 µm and a very low porosity is observed in this case. Figure 9 shows the microstructure of titanium with 10%TiAl, sintered at 1180ºC. Grain boundary can be observed very clear, there exist a completely reaction between the reinforcement and the

matrix, and probably this grain boundary is Ti_3Al reaction product. In this case the grains have more irregular shape, and grain size is smaller than in figure 8.

Conclusions

- The conditions utilized in the consolidation process by extrusion of AMCs made possibility to produce, with low fabrication cost, a cohesive product utilizing conventional technique for aluminum.
- Ultimate tensile strength slightly increases with volume fraction of composite, until reinforcement content of 10% TiAl and goes down after this reinforcement content. Offset yield decrease with whenever reinforcement addition as well as elongation.
- The fractographic studies demonstrated the conditions involved in the materials rupture, showing the characteristics of ductile fracture in the aluminum matrix. In the case of composites, the rupture occurs mainly by the matrix/reinforcement interface.
- Powder metallurgy is a simple and good route to obtain composites materials with titanium matrix.
- Titanium reinforced by TiAl particles as composite material, is more resistant than titanium pure material in some cases, mainly at 1200°Cwhere Ti+10% TiAl have got a 40% more of flexural strength and similar hardness.

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