

PROPERTIES OF AA6061 ALUMINUM ALLOY REINFORCED WITH DIFFERENT INTERMETALLICS AND CERAMICS PARTICLES

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Abstract: Aluminum alloys have been increasingly applied as a structural material in composite materials using metal matrix due to their excellent mechanical properties and low weight. The reinforcement are of fundamental importance in composite materials, owing to the their responsibility to support stresses acting on the metal matrix. Therefore, ceramic reinforcements can be replaced by intermetallic components with high mechanical properties and good thermal stability. The intermetallic components react chemically with the matrix, characterized by strong interactions, which makes possible the development of the new families of materials. The composite materials using aluminum reinforced with nickel aluminides and ceramic were developed using techniques based on a combination of powder metallurgy and extrusion processes, which makes possible to obtain more dense materials under lower processing temperatures. The powders of AA6061 and Ni₃Al were manually mixed for 30 minutes, with different percentages of intermetallics and ceramics particles, 5 and 10% in weight. The composite powders were submitted to a hot extrusion process for 40 minutes at 540°C, and 385 MPa, with a reduction ratio of 25:1. This process insures extruded composites with a refined structure and a good distribution of the reinforcement particles. The material characterization were performed through structural analysis via scanning electron microscopy; mechanical behavior via tensile and hardening tests; and analysis of the fracture. The results show that the method used is effective to obtain composite materials with improved characteristics.

Keyword: Aluminium, composites, reinforcement, extrusion.

1. Introduction

The metal matrix composites, which were designed with the aim to conjugate the desired characteristics of two or more materials, constitute one of the most important research fields in materials science and engineering since the beginning of 60 decade. This fact is related to their potential for new applications once they can exhibit unique properties if compared with traditional materials.

The aluminum metal matrix composites, in particular the hardenable aluminum alloys matrix, such as AA2XXX, AA6XXX and AA7XXX groups, are used in applications where good mechanical characteristics and low specific weight are required. The applicability of these materials is based on the improvement of both mechanical properties at high temperatures and wear resistance, principally when compared with conventional allows without reinforcement. The industry related to transportation was the first to use these materials, where many components made from them are used in automotive industry (Hehmann, 1994; Lindroos, 1995 and Raganath, 1997).

Investigations associated to obtainment of aluminum-based composites by powder metallurgy have been developed rapidly lately, in view of the fact that the obtainment of metal matrix composites by powder metallurgy offers innumerable advantages over casting metallurgy, making possible not only to improve the existing properties but also conferring new properties. The temperatures involved during the material production by powder metallurgy are lower which promotes a less interaction between the materials, minimizing interfacial reactions and making possible to reach superior mechanical properties. The use of powder metallurgy to fabricate metal matrix composites also allows controlling the volumetric fraction of reinforcement in a relatively large proportion and produces homogeneity on the reinforcement distribution.

Among all processes that have been developed to improve the characteristics of aluminum and its alloys, the mechanical alloying process has received more attention.

The reinforcements usually investigated and utilized to compose the composites materials are alumina or silicon carbide in the form short or long fibers and particles, because they present elevate hardness, thermal stability and relatively low weight. However, in last years appeared new reinforcement candidates such as nitrates, borates, other oxides and carbonates. In the mean time, materials as intermetallic compounds of out standing mechanical properties and good thermal stability were developed making them a powerful material to be used in this kind of composites (Harris, 1995 and Da Costa, 1998).

The titanium aluminides, Ti₃Al e TiAl, have been considered one of most important reinforcement candidates because they exhibit low density and excellent mechanical properties, principally at high temperatures. Their main use is centered in the aerospace industry, specially in turbine elements that are submitted to high temperatures, in substitution to nickel superalloys, and with an important economy in weight. The utilization of these reinforcements

came from the possibility to make use low density materials and that permit to produce aluminum composites with good wear resistance (Amigo, 1999, Busquet, 2000 and De Carvalho, 2002).

The main aim of this work is to investigate different kinds of reinforcements, such as intermetallic, carbides, nitrates and borates, with distinct morphologies on the properties of aluminum-based composites. The reinforcement structural characterization was done by optical and electronic microcopies and the mechanical properties were determined by tensile strength tests.

2. Materials and Methods

The AA606 aluminum alloy 1, with low and high magnesium content, was used as a metallic matrix and its chemical composition is showed in table 1. This alloy was fabricated using atomization technique by ALPOCO/England Company. The intermetallic reinforcements were obtained by rapid solidification technique (RST) and milling of 5% of B_4C , TiAl, Ti_3Al , TiB_2 , SiC_W and 10% of TiAl, Ti_3Al , TiB_2 , TiN and Si_3N_4 , in order to obtain the composites.

The mixture of reinforcements and matrix was realized by manual mixing during 20 minutes and the consolidation of them was done by hot extrusion process in a temperature of 530 °C under a maximum pressure of 350 MPa.

Fractographic analyses of composites were performed after tensile strength tests. This study emphasizes the rupture conditions involved depending on the kind of reinforcement utilized.

Table 1 – Chemical Composition of AA6061 alloy used as matrix.

AA6061 with low magnesium content		AA6061 with high magnesium content
Elements	%	%
Fe	0,66	0,04
Si	0,74	0,63
Mg	0,19	1,04
Cu	1,0	0,23
Cr	0,22	0,21
Others	<0,3	<0,3
Granulometry	+ 75 μ m = 0,23% - 75 μ m = 99,77%	+ 75 μ m = 0,5% - 75 μ m = 99,50%

3. Experimental Results

The extrusion process was efficient in the sense that permitted the fabrication of a product of good cohesion and free of porosity, independent of the reinforcement quantity added. In general, the reinforcement distribution in the matrix was homogeneous as shown in figures 1 and 2 with the exception of the material reinforced with Si_3N_4 and SiC , that we could observe particles agglomeration in certain regions. The Si_3N_4 particles agglomeration is probably related to the process employed for their obtainment that resulted in an extremely fine powder. On the other side, SiC being in the form of short fibers (whiskers) facilitated the clusters formation due to the method used for mixing, which influenced on the maximum resistance as observed in the fractography studies, figure 4.

It was possible to observed by means of the microstructural analysis that the particles morphology is related to technique used for their fabrication. The particles produced by the rapid solidification technique have a spherical form (see fig. 1a), while the particles produced by milling have irregular morphology (see fig. 1b) and the whiskers have a bigger relation between length and diameter (fig.1c).

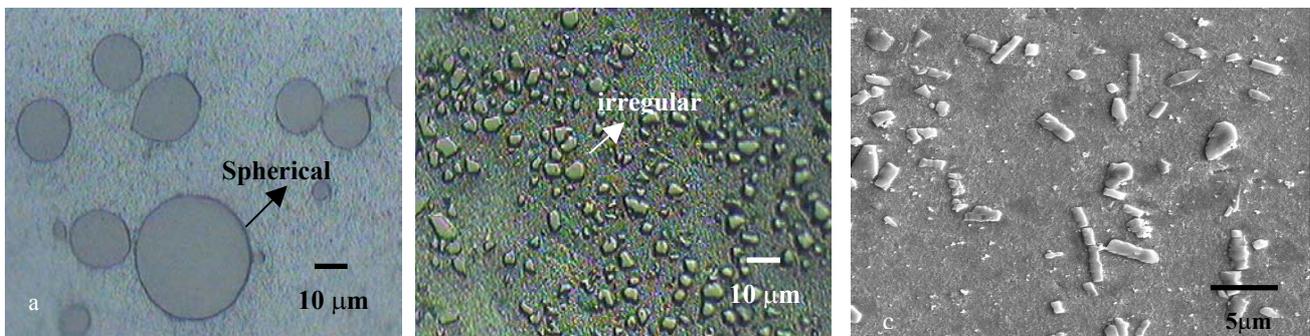


Fig. 1- (a) AA6061 +10% of TiAl composite. (b) AA6061+10% of TiB_2 composite. (b) AA6061 + 5% of SiC_W composite.

The reinforcement distribution that is going to determine the properties isotropy is directly influenced by the kind and size of particles. In general, the TiAl, Ti₃Al and TiB₂ were homogeneously distributed, while Si₃N₄ and SiC_w clustered. In the case of Si₃N₄, this fact is associated to the presence of fine particles and in the case of SiC_w to their morphology (short fibers) that makes difficult to achieve a homogeneous distribution.

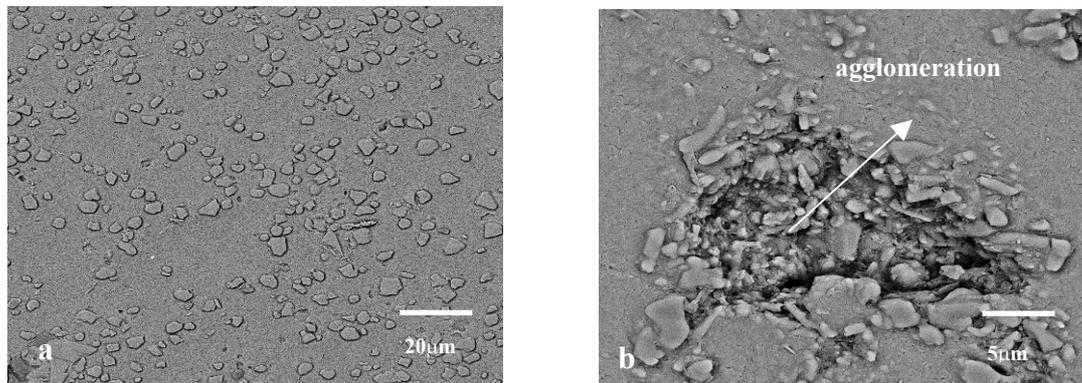


Fig. 2- Scanning electron microscopy image of composites. (a) AA6061 + 5% de TiB₂ and (B) , AA6061+10% de Si₃N₄.

The matrix fracture of all composites presented a clear appearance of ductile fracture, with great quantity of caverns that are typical of this type of fracture.

It was possible to observe that the presence of reinforcements modified this behavior, mainly at the interface between matrix and reinforcement. A reinforcement obtained by rapid solidification technique presents a spherical morphology, making easier the rupture in the matrix surrounding the particle, which means that the particle remains intact. When the reinforcement is produced by other technique, in our case milling, they present a irregular morphology, the tendency observed is that the matrix and particle have a mechanical interaction due to higher particle specific surface. The figure 3 makes evident this behavior.

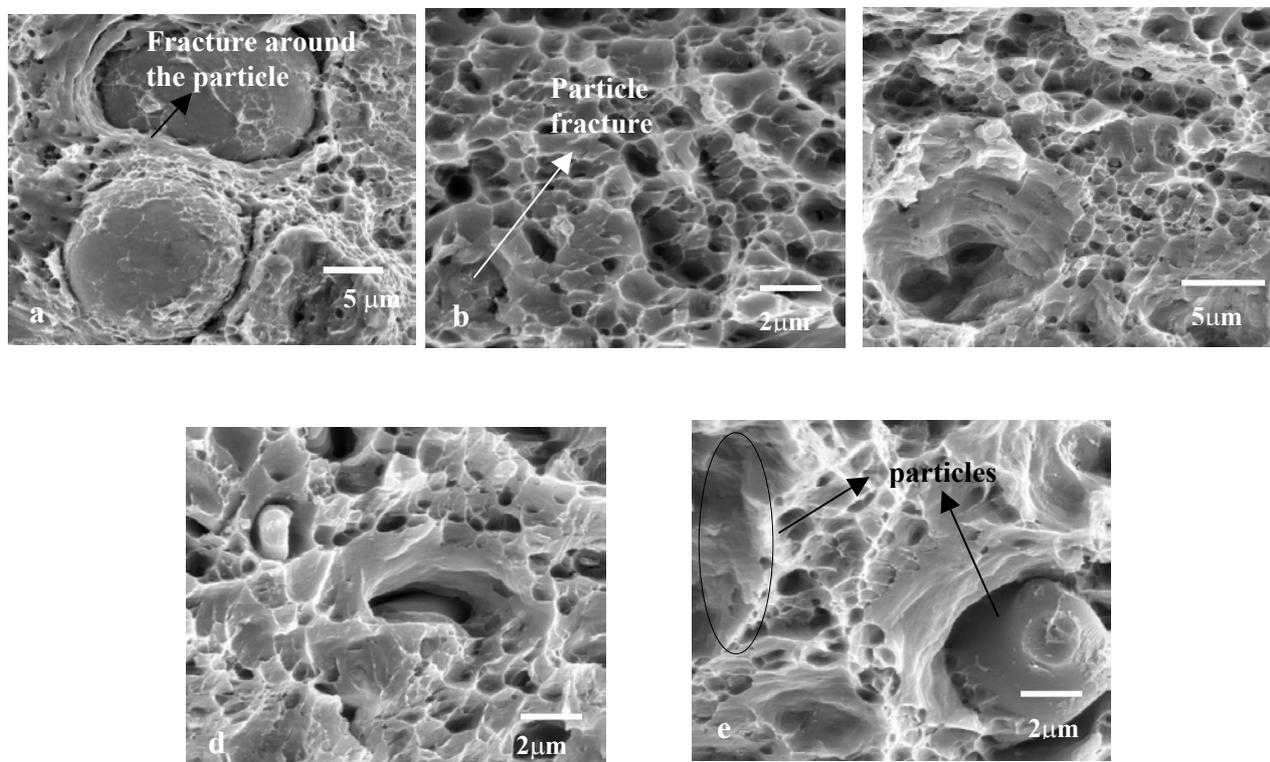


Fig. 3 – Scanning electron microscopy image of composites: (a) AA6061: + 10% de TiAl, (b) AA6061+ 10%TiN. (c) AA6061+ 10%de B₄C. (d) AA6061 + 10% TiB₂. (e) AA6061 + 5% de Tib₂.

The materials reinforced with Si_3N_4 and SiC_W had a distinct behavior if compared with the others once they present a heterogeneous distribution with clustering formation in certain regions and the rupture starts mainly at the reinforcement, while the fracture in the others regions of the composite is ductile.

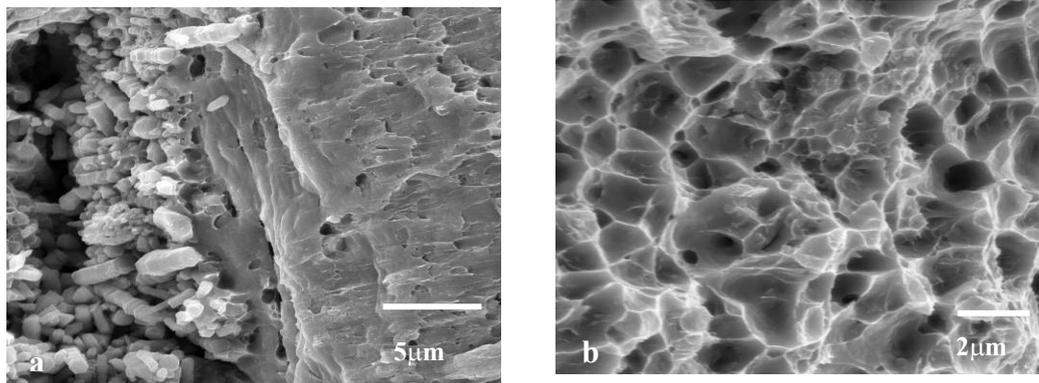


Fig. 4 – Scanning electron microscopy image of AA6061+5% de SiC_W composite. (a) Region showing a reinforcement accumulation. (b) Region showing a homogeneous distribution of particles, performing a typical rupture.

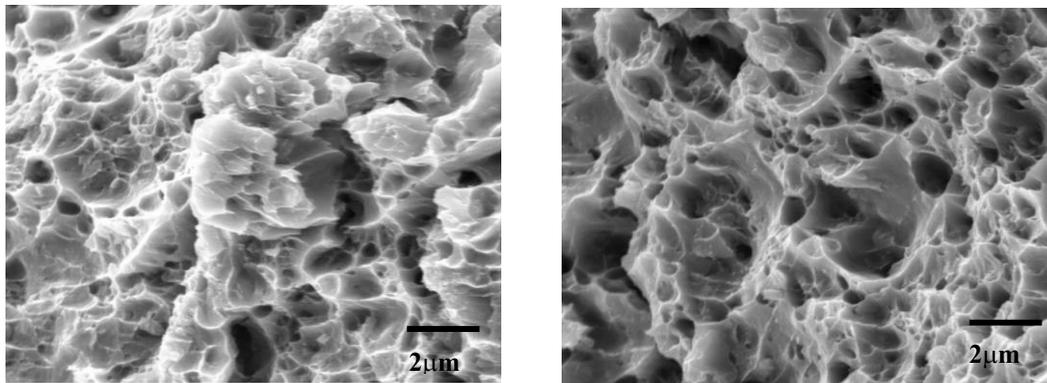


Fig. 5 – Scanning electron microscopy image of AA6061 + 10% de Si_3N_4 composites.

The results of tensile strength tests showed in figure 5, reveals that the mechanical resistance is influenced by the reinforcement morphology and the quantity that they are added.

The composite that presented the lowest mechanical resistance was the one reinforced with 5% of SiC_W . This behavior can be attributed to the poor reinforcement distribution, which formed clusters that acting as big defects and as a consequence make easy the material fracture. On the other hand, the composite reinforced with Si_3N_4 that also presented a particle heterogeneous distribution, exhibited high mechanical resistance. This behavior can be attributed to the presence of fine particles, which improved the rupture tensile. These results can be improved if a homogeneous distribution is reached, by an assisted mixture.

Among all, the material that performed the best resistance was the AA6061 with 10% of TiAl obtained by rapid solidification technique by the fact that occurred a interfacial reaction between the particle and matrix.

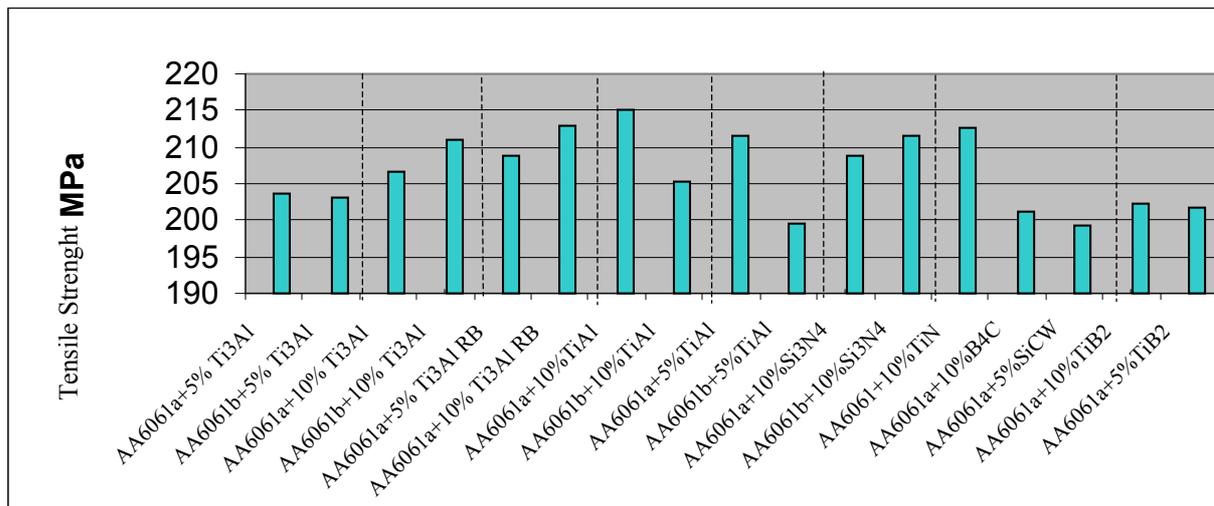


Fig 6 – Graphic showing tensile strength of composites.

4. Conclusions

- The conditions utilized in the consolidation process by extrusion made possibility to produce a cohesive product with low fabrication cost once alloys to utilize conventional technique for aluminum.
- The microstructural analyses showed a homogeneous distribution of intermetallic reinforcement in the AA6061 aluminum matrix. The exception was the matrix reinforced with Si_3N_4 and SiC_w , which is attributed to the process used for their production.
- 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 depending on the processes utilized for their production at the interface, which is characteristic of materials obtained by rapid solidification technique or at the reinforcement with is characteristics of materials produce by milling.
- The materials reinforced with Si_3N_4 , presented low mechanical resistance due the formation of particle clusters resulting from a irregular reinforcements. The fracture started in these defects, but in the borders the fracture was ductile.
- If the reinforcement morphology is considered, the mechanical resistance is a slight superior when a reinforcement of irregular morphology is used. The increase on the tensile strength is proportional to the quantity of reinforcement added.

5. References

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