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Microstructural Characterization in Aluminum-Graphite Composites Produced by Mechanical Milling and Hot Extrusion

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Aluminum alloys have a great diversity of industrial applications because of their low density and good workability, but the use of these alloys is limited due to their relatively low yield stress. Recently, the interest to increase aluminum strength for applications in the aerospace and aeronautics industries has motivated the study of aluminum matrix composites (AMC) which could present better mechanical properties at both, medium (473 K) and room temperatures.
The raw powder materials used were Al (99.5 % purity, -325 meshes in size) and graphite nanoparticles. The selected graphite content was 0.0, 0.25, 0.50, 0.75, and 1.0 wt. %. Each mixture was mechanically milled in a high energy SIMOLOYER mill for 2 hrs in an argon atmosphere.
Consolidated bulk products (4 cm of diameter ϕ) were prepared by pressing the milled powder at ~950 MPa for two minutes under uniaxial load. Pressed samples were next sintered under vacuum for 3 hrs at 823 K with a heating rate of 50 K/min.
Sintered products were held for 0.5 h at 823 K and hot extruded into a rod of 10 mm diameter by using indirect extrusion and an extrusion ratio of 16. Table I shows the sample identification, composition and experimental conditions used.
Tension and compression tests were done in an INSTRON testing machine at room temperature and at constant displacement rate of 0.016 mm/s. The yield stress was measured at the elastic limit. The microstructural characterization was done by Transmission Electron Microscopy (TEM) in a Philips CM 200 equipped with EDS and PEELS analyzers.

Figure 1 shows the σ vs ε tension curves of the aluminum graphite microcomposites samples tested in the extrusion direction as a function of graphite content. All samples follow a milling-sintering-extrusion sequence, with exception of Al_p sample, which was only sintered and extruded. From this Figure it is evident the increment of the resistance upholding the ductility in all the samples.
Figures 2 and 3 present σ_y and σ_{max} values found in present work. From these Figures it is manifest the important effect of graphite content in mechanical properties; both, σ_y and σ_{max} present a positive slope as a function of graphite content. σ_y variation was from 11.4 to 15.11 kg/mm^2 which correspond to an increment of about 34 %, and for σ_{max} increment was around 28 %. This is an important enhancement of the mechanical resistance, considering also that the ductility of the samples was kept, as it is shown in Figure 1.
Figure 4 shows a representative microstructure found in Al_p sample in the as-extruded condition. In this sample was observed the presence of both, equiaxial and deformed grains, due to partial recrystallization during hot extrusion. Figure 5 shows a representative view of reinforcement nanoparticles, which present sizes close to 50 nm and their distribution, is at random. Previous analysis showed the presence of aluminum and graphite in these particles; however, Al could be from matrix or by carbide formation. Deep characterization of these nanoparticles is carried-out at this moment. Additionally, Figure 6 shows a nanofiber found in Al_{100} composite, lengths of about 800 nm and diameter lower than 200 nm were observed.

Table I.- Identification in samples, composition and experimental conditions

Identification	Composition	Milled	Extruded
Al_p	Pure Aluminum	---	X
Al_m	Pure Aluminum	X	X
Al_{25}	Al-0.25 % C	X	X
Al_{50}	Al-0.50 % C	X	X
Al_{75}	Al-0.75 % C	X	X
Al_{100}	Al-1.00 % C	X	X

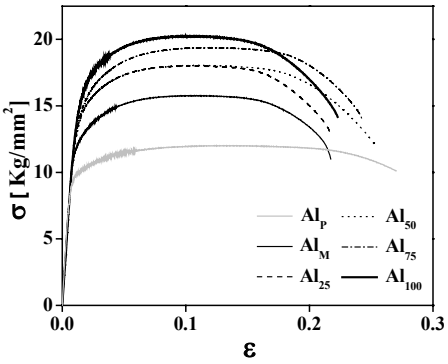

Figure 1.- σ vs ε curves from all samples tested in the extrusion direction.

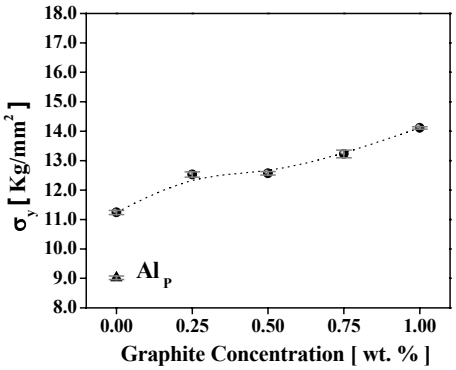

Figure 2.- σ_y as a function of graphite contents.

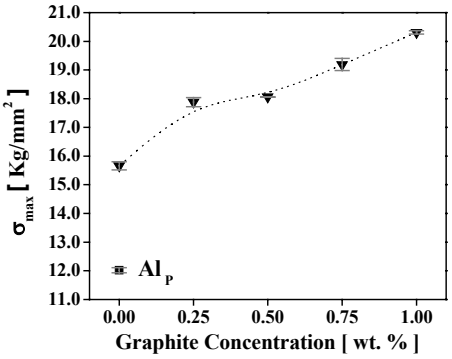

Figure 3.- σ_{max} as a function of graphite contents.

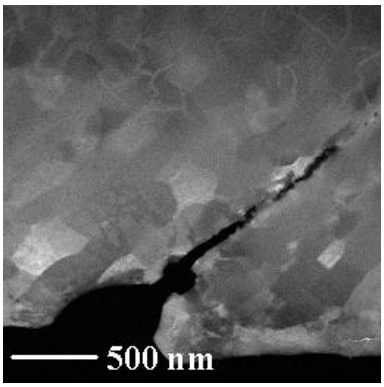

Figure 4.- TEM micrograph from pure aluminum (Al_p sample). Notice the partial recrystallization.

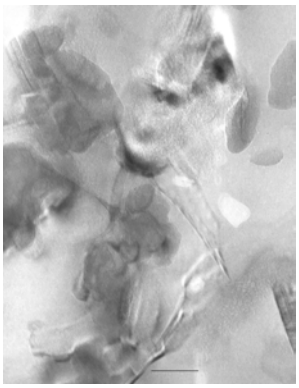

Figure 5.- nanoparticles found in Al_{100} composites. Particles size is lower than 100 nm.

Figure 6.- Al-O-C nanofibers found in Al_{100} composites. Nanofibers present amorphous structure.

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