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DOI: 10.1017/S1431927606064531

Microsc Microanal 12(Supp 2), 2006

Microstructural and Mechanical Characterization of Aluminum Reinforced with Silver Nanoparticles

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Aluminum alloys have a great diversity of industrial applications because of their low density and good workability, but their use is limited by their relatively low yield strength. It is well known now that aluminum, aluminum alloys, and aluminum composites can be strengthened by dispersing hard particles such as carbides, oxides or nitrides into the aluminum matrix by using different techniques.
Al (99.5 % purity, -200 meshes in size) and silver nanoparticles covered with carbon with average size of 10 nm (Figure 1), here forward "Ag-C NP", were used as raw powder materials. The Ag-C NP, a product obtained from NANOTECHNOLOGIES, Inc. (Austin, TX), are produced by arc discharge and stabilized with carbon from a hydrocarbon source. Aluminum-based composites with content of 0.0, 0.25, 0.50, 0.75, and 1.0 wt. % Ag-C NP were made by mixing followed mechanical milling in a high energy SIMOLOYER mill for 2 h under argon atmosphere. The milling ball-to-powder weight ratio was set at 20 to 1. Milled products were sintered and extruded at 823 K under protective atmosphere.

Figure 1 shows representative SEM (1a) and TEM (1b) images of the Ag-C NP in the as-received condition. Note in figure 1b the nano-size of the particles and the grayish contrast that surrounds them, which correspond to carbon. Figure 2 shows conventional TEM bright field images of the Al sample with 1% of Ag-C NP. The contrast corresponds to bend contours, grain boundaries and dislocations.
As part of the contrast, there is also a continuous distribution of dark spots. A detailed analysis of these dark spots indicates that there are particles of two sizes mainly: ones in the range of 100 nm and others one in the range of 10 nm.
Figure 3 shows the HRTEM images of the Ag particles. This type of contrast has been very well analyzed in our group's TEM work, and it corresponds to the icosahedral and decahedral shaped particles. Observe also in these images the grayish annular contrast that surrounds the particles. The crystalline lines observed in the matrix correspond to the Al lattice.
Figure 4 shows the micro-hardness for the composites at different concentrations. It is worth noting that hardness increases as the Ag-C NP content increases, reaching the maximum value of 59.55 VHN in the composite with 1.0 wt. %. These values can be compared with those reported for bulk pure aluminum in as-annealed condition (~23 HVN). An important increase in hardness is also registered, including for "pure aluminum" which is 1.5 to 2 times higher than 23 HVN.

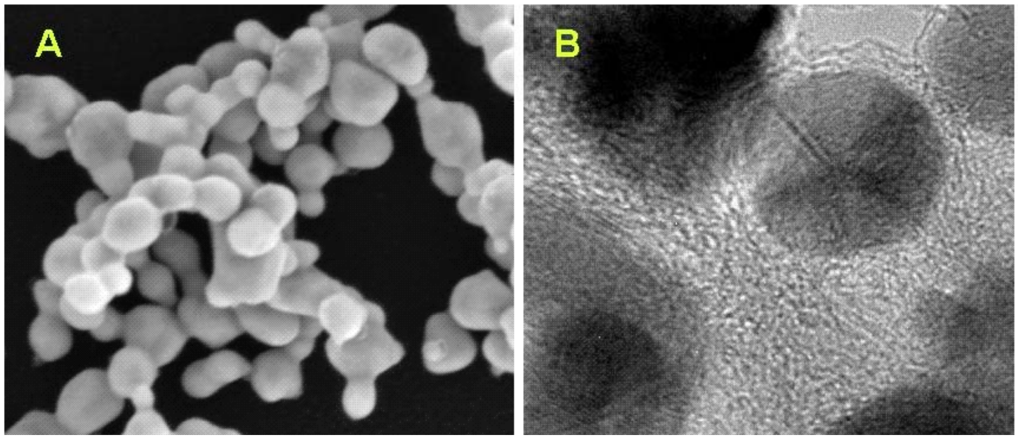

Figure 1.- Ag-C NP before processing. a) SEM image, b) HRTEM image. The carbon layer covering the particles is clearly observed in (b).

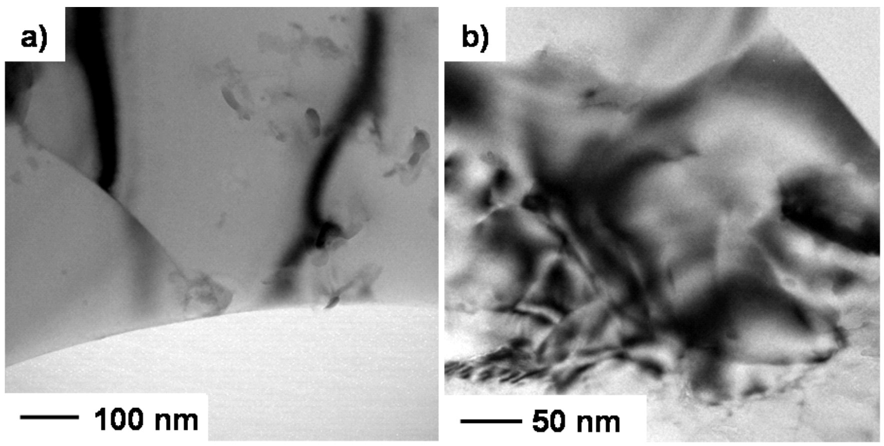

Figure 2.- TEM bright field image of an Al-based composite. Additional to the bend contours and grain boundaries in (a) note that there is a continuous distribution of dark spots which correspond to Fe particles, better observed in (b).

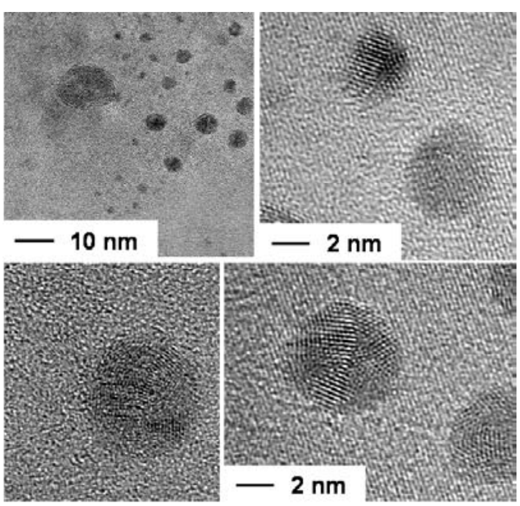

Figure 3.- TEM bright field image of the smaller particles (Ag-C) shown in figure 2 and HRTEM images of three of these particles.

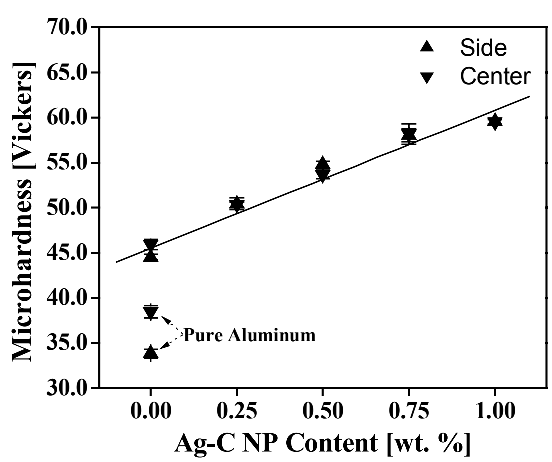

Figure 4.- Micro-hardness in extruded samples as a function of the Ag-C NP content. Data for pure aluminum are included for comparison.