Formation of nanocomposites of Al_{7075} alloy and silver nanoparticles by powder metallurgy

Conformación de nanocompósitos de aleación Al_{7075} y nanopartículas de plata mediante metalurgia de polvos

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Resumen

Nanocompósitos de aleación de Aluminio 7075 (Al_{7075}) y nanopartículas de plata recubierta con carbono (Ag-C NP) fueron procesados por la técnica de metalurgia de polvos. El análisis del polvo muestra que las nanopartículas de plata tienen un efecto en la reducción del tamaño de partícula del polvo; las propiedades mecánicas de los nanocompósitos se obtuvieron mediante ensayos de tensión y éstas se determinaron en función del tiempo de molienda y del contenido de nanopartículas. Se observó que las propiedades aumentan a un valor máximo y luego decrecen.

Abstract

Nanocomposites of 7075 aluminum alloy (Al_{7075}) and silver nanoparticles coated with carbon (Ag-C NP) were processed by the powder metallurgy technique. The analysis of the powder show that silver nanoparticles had an effect in the comminuting of the powder particle size; mechanical properties of nanocomposites were obtained by tension tests and reported as a function of the milling time and nanoparticles content. It has been found that the properties increase to a maximum value and then they fall.

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Abstract

Nanocomposites of 7075 aluminum alloy (Al_{7075}) and silver nanoparticles coated with carbon (Ag-C NP) were processed by the powder metallurgy technique. The analysis of the powder show that silver nanoparticles had an effect in the comminuting of the powder particle size; mechanical properties of nanocomposites were obtained by tension tests and reported as a function of the milling time and nanoparticles content. It has been found that the properties increase to a maximum value and then they fall.

Introduction

The use of aluminum is becoming more important every day; however its wider application is limited due to its low mechanical strength. Aluminum alloys improve their resistance depending on the alloying elements. 7000 series aluminum alloys, containing Zn as the principal alloying element, provide the highest strength of any commercial series. The 7075 aluminum alloy (Al_{7075}) is widely used in aircrafts [1]. Nevertheless, its mechanical strength is not enough. One way to increase its mechanical properties without affecting its low density, is introducing second phase particles into the aluminum matrix. The generation of these materials can be done by different techniques. A composite is an emerging way to combine two materials with different properties to generate a new material with better properties. Mechanical milling (MM), a special powder metallurgy method, allows the production of these composites [2]. To ensure the properties enhancement obtained in a nanocomposite, the nanoparticles must be finely and

homogenously distributed into the metal matrix [3]. The present study is focused on the production of nanocomposites of Al_{7075} reinforced with carbon coated silver nanoparticles (Ag-C NP), as well as their properties evaluation. Microstructural and mechanical characterization is discussed.

Experimental

Aluminum 7075 Alloy (Al_{7075}) in the T6 condition and silver nanoparticles coated with carbon (Ag-C NP) were the starting materials. To reduce the hardness of the base alloy, this was annealed for 24 h at 698 K and machine tooled to produce burrs with a size between 1 and 7 mm. Ag-C NP with a size between 10 and 20 nm are a product of Nanotechnologies, Inc. (Austin, TX). The composites were produced by mixing and MM of Al_{7075} and Ag-C NP in different concentrations, from 0.5 to 2.0 wt.% of nanoparticles, based on previous works [4-6], and 5, 10 and 15 h of milling. For comparison purposes, an unreinforced alloy was milled under the same milling times. To perform the MM, a high-energy mill (SPEX-8000M) was used. The milling device and the milling media used in the experiments were made from hardened steel; the milling ball-to-powder weight ratio was 4 and the total sample weight was 10 g for all the samples; methanol was added as a process control agent (PCA) in amounts of 3 ml. To avoid oxidation of the powder mixture during the milling process, a static argon atmosphere was used in all runs. The as-milled products were cold compacted under uniaxial load pressure of 450 MPa for 2 minutes. Samples of 4 mm in diameter were obtained and then sintered under argon atmosphere by heating during 2 h at 473 K, then heating for 4 h at 733 K and finally heating for 18 h at 748 K; the cooling was done in the furnace. The sintered products were hot extruded at 773 K using indirect extrusion with an extrusion ratio of 25:1, to produce bars of 10 mm in diameter and 500 mm in length. The microstructural characterization of powders and extruded samples was carried out by using an optical microscope Olympus CK40M and a scanning electron microscope JEOL JSM7401F operated at 5 and 10 kV. The mechanical tests were performed using a Shimadzu Autograph AGI universal testing machine with a load cell of 250 kN and a head displacement of 0.066 mm/s; the samples were machined according to the ASTM E8M standard.

Results and discussion

Morphological analysis

Figure 1 shows the effect of MM on the microstructure of the Al_{7075} alloy powder. A decrease in the powder particles size can be observed as the milling times increases. A deeper analysis of this decrease was made elsewhere [7].

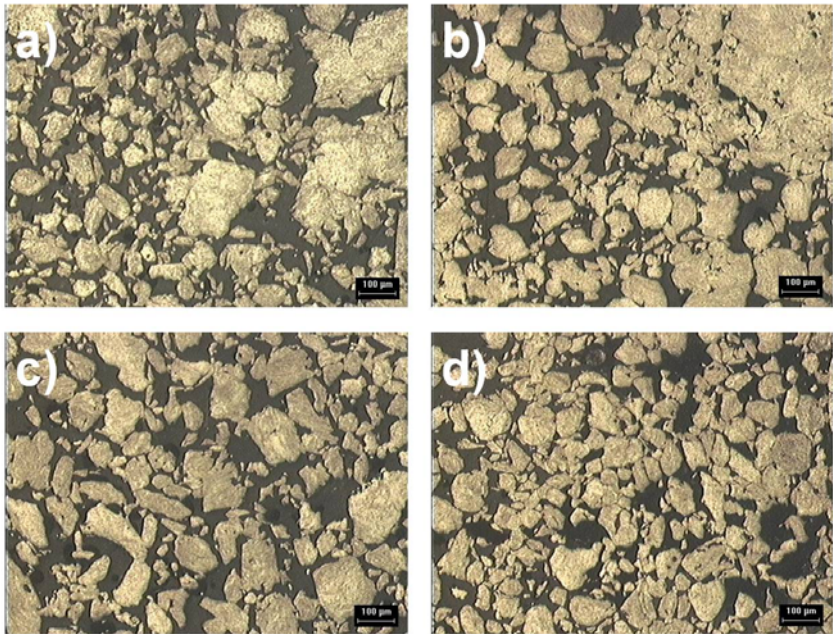

Figure 1. Powder morphology evolution of the Al_{7075} alloy as a function of the milling time: a) 5h, b) 10h, c) 15h and d) 20 h.

Figure 2 presents the effect of MM on the microstructure of the as-milled Al_{7075}-Ag-C NP nanocomposite milled for 5 h. It can be seen that the powder particle size decreases as the silver nanoparticles content increases. For 0.0, 0.5, and 1.0 wt.% of nanoparticles (Figs. 2a, 2b and 2c) the particles have similar sizes, but in the case of 1.5 and 2.0 wt.% of nanoparticles (Figs. 2d and 2e), a smaller particles agglomeration can be seen.

Figure 3 shows some SEM micrographs of the Al_{7075}-Ag-C NP nanocomposite milled for 5, 10 and 15 h and with 2.0 wt.% of nanoparticles (Figs. 3a, 3b and 3c, respectively) and for 20 h and without silver nanoparticles (Fig. 3d). In the former cases, it can be observed that the powder particle size decreases as the milling time increases, but in the last case the particle size decrement is not outstanding.

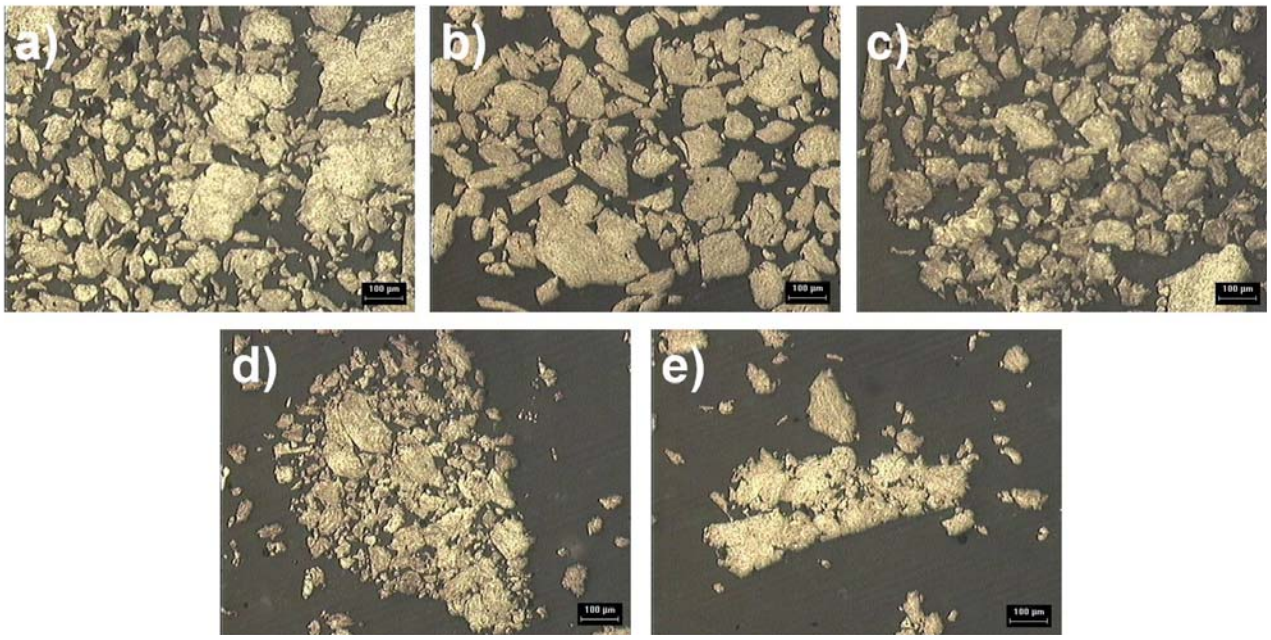

Figure 2. Powder morphology evolution of the Al_{7075}–Ag-C NP nanocomposites as a function of silver nanoparticles content, with 5 h of milling: a) 0.0, b) 0.5, c) 1.0, d) 1.5 and e) 2.0 wt.% of Ag-C NP.

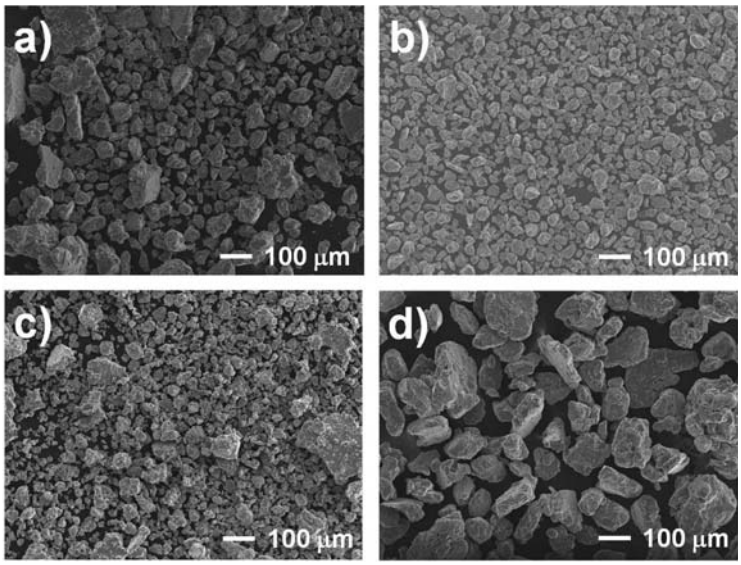

Figure 3. Powder morphology evolution of the Al_{7075}–Ag-C NP nanocomposites after MM with: a) 5h and 2.0 wt.%, b) 10 h and 2.0 wt.%, c) 15 h and 2.0 wt.%, and d) 20 h and 0.0 wt.% of Ag-C NP.

Figure 4 shows some SEM micrographs of the extruded Al_{7075}-Ag-C NP nanocomposites. Fig. 4a corresponds to the alloy without silver nanoparticles and 10 h of milling; this sample has a structure consisting of an aluminum matrix. The nanocomposite milled for 10 h and containing 1.5 wt.% of nanoparticles (Fig. 4b), presents an aluminum matrix with 20 nm-sized bright

particles, which correspond to the silver nanoparticles; these particles are well embedded into the aluminum matrix. Furthermore, it can be noted that these particles are covered by a layer of material that appears lighter than the aluminum matrix; a more detailed analysis [8] showed that this material matches to the $MgZn_2$ phase. Figure 4c corresponds to the nanocomposite containing 2.0 wt.% of Ag-C NP and milled for 10 h. It can be seen that the particles are also well embedded into the aluminum matrix, but their size is around 100 nm; this observation suggests that the nanoparticles coalesce into larger particles during the mechanical milling.

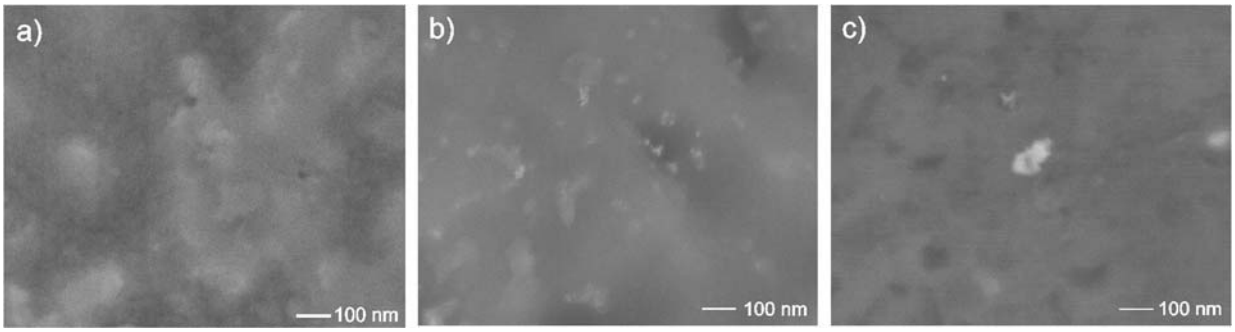

Figure 4. Morphological evolution of the extruded Al_{7075}–Ag-C NP nanocomposite after a) 10 h and 0.0 wt.% of Ag-C NP, b) 10 h and 1.5 wt.% of Ag-C NP, and c) 10 h and 2.0 wt.% of Ag-C NP.

Mechanical properties analysis

Tensile test were carried out for all the composites obtained, three specimens for each extruded bar were tested to evaluated the mechanical properties. Figure 5 shows the stress-strain curve of the extruded Al_{7075} alloy, previously milled for 5 h. Table I summarizes the results of the data obtained for the Al_{7075} alloy without addition of silver nanoparticles, with different milling times. The ultimate tensile strength (UTS) values increase up to a maximum value for 10 h of milling and decrease for higher milling times; this is most evident in the yield stress (σ_y) values. These variations are due to the mechanical deformation introduced to the material during the mechanical milling. All values obtained are higher than those of pure Al (σ_y = 91.8 MPa, UTS = 117.1 MPa) and Al_{7075} alloy (σ_y = 96.5 MPa, UTS = 221 MPa) [9].

With addition of nanoparticles, the values of yield stress (Table II) and ultimate tensile strength (Table III) increase as the nanoparticles content and milling time increase, with a maximum at 1.5 wt.% of nanoparticles; later additions of nanoparticles provoke the properties decrease, although they are higher than those obtained for the alloy without nanoparticles addition. The mechanical properties increase is due to *i)* the mechanical deformation introduced into the

material during the MM, which produces a decrease in the crystal size [2], and *ii)* the presence of silver nanoparticles that act, on the one hand, as PCA refining the crystal size [10], and on the other hand, their homogeneous dispersion throughout the matrix act as obstacles to the dislocations movement during the plastic deformation [8].

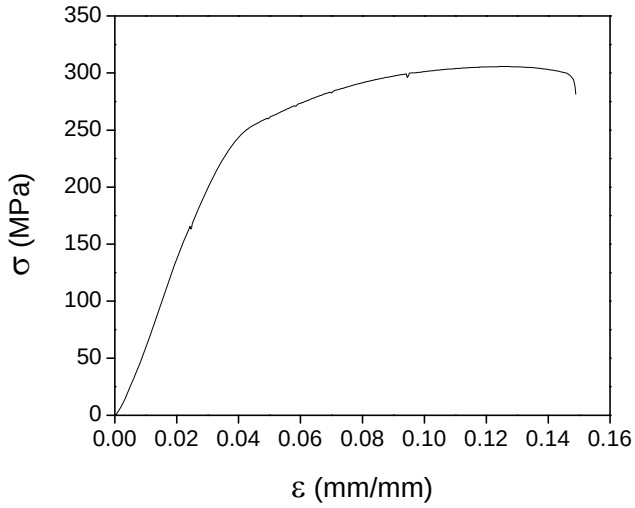

Figure 5. Stress–strain curve of the Al_{7075} alloy milled for 5 h and tested in the extrusion direction.

The mechanical properties decrease after 15 h of milling could be due to the energy absorbed by the material during the MM, bringing on the nanoparticles agglomeration to form clusters of larger sizes, which reduce the amount of particles dispersed into the matrix; after the MM, the energy can be released to allow the crystal size growth. These two effects let the dislocations to move freely into the matrix, which is why smaller stresses are required to strain the material. It will be worthwhile to investigate deeply to understand this phenomenon.

Table I. Yield stress (σ_y) and ultimate tensile strength (UTS) of the Al_{7075} alloy at different milling time.

Time (h)	σ_y (MPa)	SD	UTS (MPa)	SD
0	229.3	33.7	327.1	36.3
5	206.0	12.4	305.0	19.1
10	253.0	21.2	332.2	48.6
15	175.5	19.1	239.0	6.6
20	169.5	23.2	239.9	18.7

Table II. Yield stress (σ_y) of the Al_{7075}–Ag-C NP nanocomposites at different milling time.

	σ_y (MPa)					
Ag-C NP (wt.%)	**5 h**	**SD**	**10 h**	**SD**	**15 h**	**SD**
0.0	206.0	12.4	253.0	21.2	175.5	19.1
0.5	210.7	11.3	242.4	2.7	192.3	67.6
1.0	248.1	8.4	265.0	2.4	204.0	32.1
1.5	290.7	10.3	272.8	15.2	254.5	33.2
2.0	242.9	28.5	207.9	6.4	231.3	25.4

Table III. Ultimate tensile strength (UTS) of the Al_{7075}–Ag-C NP nanocomposite at different milling time.

	UTS (MPa)					
Ag-C NP (wt.%)	**5 h**	**SD**	**10 h**	**SD**	**15 h**	**SD**
0.0	305.0	19.1	332.2	48.6	239.0	6.6
0.5	358.0	6.3	347.8	7.8	281.6	57.2
1.0	328.9	10.0	375.1	26.4	337.2	17.1
1.5	400.5	16.3	396.5	9.3	356.0	21.3
2.0	353.7	18.6	323.8	0.5	353.9	22.5

Conclusions

Nanocomposites of Al_{7075} and silver nanoparticles were processed by mechanical milling and indirect hot extrusion. The powder particles size is affected by the milling time and by the presence of silver nanoparticles. The mechanical properties of the nanocomposites are improved up to a maximum content of silver nanoparticles and milling time, then these properties go down. The increment in mechanical properties is due to the homogeneous distribution of silver nanoparticles. The best results of nanocomposites mechanical properties were obtained with 10 h of milling and 1.0 and 1.5 wt.% of nanoparticles.

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