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JOURNAL OF RARE EARTHS, Vol. 34, No. 4, Apr. 2016, P. 420

JOURNAL OF RARE EARTHS

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Effect of cerium/lanthanum addition on microstructure and mechanical properties of Al7075 alloy *via* mechanical alloying and sintering

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Received 26 July 2015; revised 14 February 2016

Abstract: The effect of the Al-6Ce-3La (ACL) on the microstructural behavior of the Al7075 was investigated. Materials were synthesized by mechanical alloying with variation in the ACL content and milling time. Products were characterized and studied in the as-milled condition and mechanically evaluated after sintering. The synergetic effect of milling time and ACL content in the modified materials led to a reduction in the particle size. Results from electron microscopy showed a homogeneous dispersion of Ce/La phases up to 20 wt.% of ACL content after 10 h of milling. Mechanical evaluation under compressive test showed an improved performance for those alloys reinforced with 0.2 wt.% and 0.5 wt.% of ACL.

Keywords: mechanical alloying; rare earths; aluminum; microstructure; sintering

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Powder metallurgy (PM) and mechanical alloying (MA) are synthesis techniques of great interest in the scientific community. They are widely considered in the production of attractive materials for the transportation industry, where weight reduction implies the use of lighter materials with improved mechanical performance[1–6]. Aluminum alloys synthesized by MA display improved mechanical properties when they are compared with their respective monolithic alloys[2]. The dispersion of insoluble phases[7], and the extension in the solid solubility limits[4] are attractive characteristics investigated in aluminum and aluminum alloys where outstanding results in the mechanical behavior of the final products are constantly reported.

The extension of the solubility limits is an attractive opportunity to be considered for elements commonly used at low concentrations in the production of alloys and composites as has been the case of rare earths. Their use in the production of new materials has been considered by several research groupsp[8], and beneficial effects in the resultant mechanical behavior have been reported mainly by additions of Er[9], Sc[10], Ce[11–15] and La[15,16]. However those materials are limited by the rare earth concentration due to the use of ingot metallurgy (IM) in their production and solution limits imposed in the phase diagrams. The use of IM in the production of those materials is limited by the amount of rare earths that can be used in the new material content. This is due to the morphology and size of the crystallized phases.

Though the study of rare earth in the modification of aluminum alloys has been carried out mainly by IM routes[9–19], the research through powder metallurgy routes has been scarcely considered. In this case the use of MA in the synthesis of stronger aluminum alloys reinforced or modified by rare earths allows an increment in the rare earth concentration, beyond the limits established by IM[20,21]. A noticeable fragmentation in the constituent compounds in master alloys containing Ce and La has been observed after being mechanically milled for short time[22].

Thus, in this research, the effect of MA in the dispersion of Ce and La was studied by the addition of a master alloy into a commercial Al7075 aluminum alloy. The microstructural behavior was analyzed in the as-milled condition for the resultant alloy modified by La and Ce with a limit concentration of 20.0 wt.%, as well as milled for different milling time.

1 Experimental

The Al7075 aluminum alloy (chemical composition listed in Table 1), was modified by addition of a commercial Al-6Ce-3La (ACL) master alloy. The addition of the ACL alloy was by means of MA according to the concentrations and milling time given in Table 2. Metal chips from the master alloy and the Al7075 were mechanically alloyed using a high energy mill SPEX 8000 M. The mass of the material was 8.5 g and of a

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DOI: 10.1016/S1002-0721(16)60043-1

Table 1 Chemical composition (wt.%) of the Al7075

Alloying element	Si	Fe	Mg	Ti	Cu	Mn	Zn	Cr	Al
wt.%	0.0938	0.193	2.83	0.201	1.62	0.0305	6.1	0.182	Bal.
±	0.0013	0.002	0.01	0.0002	0.01	0.0003	0.01	0.0004	

Table 2 Sample identification according to the ACL content

Milling time/h	ACL content/wt.%							
	0	0.2	0.5	1	2	5	10	20
5	5A	5B	5C	5D	5E	5F	5G	5H
10	10A	10B	10C	10D	10E	10F	10G	10H

ball-to-material ratio of 5:1. Milling runs were performed with methanol as process control agent (PCA). Argon was used as inert atmosphere.

For microstructural analyses, powders were hot mounted in bakelite and then ground and polished by conventional metallographic techniques. The analyses of the microstructure and the morphology evolution of the as-milled powders were carried by scanning electron microscopy (SEM) in a JEOL model JSM5800-LV operated at 15 kV. Deeper analyses of the microstructure of the as-milled powders were performed by transmission electron microscopy (TEM), in a JEOL model JEM 2200FS. Specimens for TEM were prepared by focusing ion beam (FIB) in a JEOL model JEM-9320FIB.

X-ray diffraction (XRD) analyses were carried out in a Panalytical X'pertPRO diffractometer with Cu Kα radiation. Analysis of particle size distribution was measured by the laser diffraction and scattering method using a Mastersizer-2000 particle size analyzer. Measurement of the mass and the geometry of cold consolidated samples was used to estimate the density of the products in the as-milled condition. For this purpose powders were cold consolidated under 850 MPA for 1 min into a die with inner diameter of 6.35 mm. Three samples were obtained and measured for each composition.

Composites were sintered at 550 ºC during 2 h under argon atmosphere and then mechanically evaluated by compressive test. The mechanical behavior of the specimens was measured using an Instron testing machine at room temperature and at a constant overhead displacement rate of 0.016 mm/s. The yield stress was measured at the elastic limit. Two height-to-diameter (*h*:*Ø*) ratios were used (0.8 and 2.0), in accordance with ASTM E9 standards.

2 Results and discussion

Fig. 1 shows a backscattered SEM micrograph of the cross-section of the ACL master alloy in the as-received condition. A bright phase in a large needle-like morphology can be observed, which EDS analysis shows La and Ce as constitutive elements. The sharp ends observed in the Ce/La phase morphology suggest a stress concentration behavior, which negatively affects the mechanical behavior of the modified alloy. However, this microstructure can be modified by milling process. The use of MA in the fragmentation of the Ce/La phases has shown positive results when the ACL master alloy has been milled for 5 and 10 h. Previous results showed this behavior for a maximum concentration of 0.2 wt.% of content in the modification of aluminum alloys[22]. In this regard, Table 3 shows the calculated contents of the ACL master alloy (shown in Fig. 1) employed in this study. The content of aluminum shows a variation less to 0.5%, whilst the maximum reduction of about 1.2% is found in the Zn content for an ACL concentration of 20.0 wt.%. Moreover, for this modified alloy, the contents of Ce and La are 1.2 wt.% and 0.6 wt.%, respectively.

The effect of ACL additions on the microstructure of the Al7075 is shown in Fig. 2 by means of backscattered SEM micrographs. Figs. 2(a, b) show

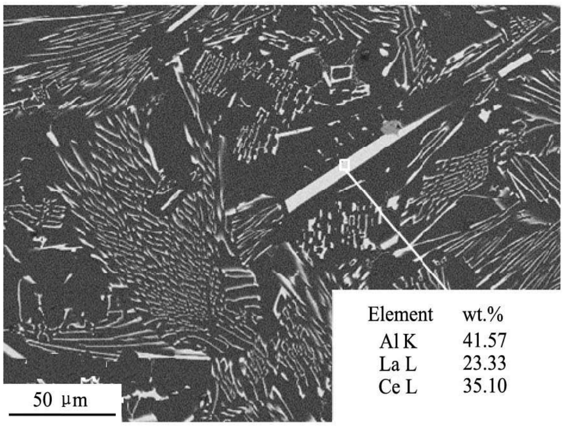

Fig. 1 Backscattered SEM micrograph of the cross- section of the ACL master alloy (the white square indicates the zone for the microanalysis shown in the figure)

Table 3 Calculated contents of the ACL master alloy in the Al7075 alloy

Content/wt.%	Si	Fe	Mg	Ti	Cu	Mn	Zn	Cr	Ce	La	Al
0	0.094	0.193	2.830	0.201	1.620	0.031	6.100	0.182	0.000	0.000	88.750
0.2	0.094	0.193	2.824	0.201	1.617	0.030	6.088	0.182	0.012	0.006	88.754
0.5	0.093	0.192	2.816	0.200	1.612	0.030	6.070	0.181	0.030	0.015	88.761
1	0.093	0.191	2.802	0.199	1.604	0.030	6.039	0.180	0.060	0.030	88.772
2	0.092	0.189	2.773	0.197	1.588	0.030	5.978	0.178	0.120	0.060	88.795
5	0.089	0.183	2.689	0.191	1.539	0.029	5.795	0.173	0.300	0.150	88.862
10	0.084	0.174	2.547	0.181	1.458	0.027	5.490	0.164	0.600	0.300	88.975
20	0.075	0.154	2.264	0.161	1.296	0.024	4.880	0.146	1.200	0.600	89.200