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The effects of neodymium addition on the intermetallic microstructure and mechanical properties of Al-7Si-0.3Mg-0.3Fe alloys

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ABSTRACT

The effects of neodymium (Nd) addition (0, 0.03, 0.06 and 0.09 wt.%) on the intermetallic microstructure and mechanical properties of Al-7Si-0.3Mg-0.3Fe (wt.%) alloys were investigated in this study. The microstructures of the intermetallic compounds in the alloys were observed by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The Nd-rich particles gradually coarsened with increase of Nd addition and attached to the β-AlFeSi phase surface. Besides, the larger Nd-rich particles in the alloys decreased in size and became spherical after T6 heat treatment. In addition, the Nd addition could influence the amount of the π-AlSiMgFe phase by affecting the undercooling of the quaternary eutectic reaction (Liq. → $Al + Si + Mg_2Si + Al_8FeMg_3Si_6$). The amount of the π-AlSiMgFe phase increased when a little (0.03 wt.%) Nd was added, however with the further increasing Nd content, the larger Nd-rich particles often tightly attached on the β-AlFeSi phase surface and reduced the amount of the π-AlSiMgFe phase. Furthermore, the 0.03Nd as-cast alloy had the optimal conditions for the formation of the π-AlSiMgFe and the spherical Nd-rich particles with the ultimate tensile strength about 302 MPa and elongation about 3.1% after T6 heat treatment.

1. Introduction

Al-Si-Mg alloys have been extensively applied in industry, especially in the aerospace and automotive industries, due to their excellent properties, including castability, machinability, corrosion resistance and integrated mechanical properties [1–4]. Alloying has a great potential to improve the performance of the alloys [5–8]. Rare earth elements (REEs) are added to alloys to modify eutectic silicon from a coarse, plate-like structure to a fine, fibrous structure. In addition, REEs can effectively degas and remove slag, which is environmentally friendly.

Most studies on the effects of REEs mainly focused on the modification of eutectic silicon [9–12]. However, REEs not only modify eutectic silicon, but also remove iron, which decreases the harmfulness of iron-rich intermetallics. Chen et al. [13] noted that REEs gathered on the grain boundary and refined the iron-rich intermetallics. Fu et al. [14] studied the effect of Ce-rich mixed REE addition on iron-rich impurity phases in pure Al. The results suggested that the coarse iron-rich intermetallics transformed into small-sphere and short-stick complex compounds after the addition of REEs. Shi et al. [15] investigated the modification efficiency of Er in A356 alloy. They determined that a 0.3 wt.% addition of Er resulted in the best modification of eutectic Si, and after T6 heat treatment the needle-like β-AlFeSi phase was eliminated. Wan et al. [16] systematically studied the effect of yttrium (Y) additions on the microstructure and tensile properties of recycled Al–7Si–0.3Mg–1.0Fe casting alloys. Upon the addition of Y, the acicular β-AlFeSi phases were remarkably refined, and the volume fraction of the β-AlFeSi phase decreased.

Nd modification of eutectic silicon has been reported to improve their properties. For example, Xu et al. [17,18] believed that an Al-P-Ti-TiC modifier with a Nd/Nd_2O_3 addition could modify eutectic silicon and primary silicon in an Al-20 wt.%Si alloy. Tan et al. [19] believed that the eutectic silicon in ZL101 alloy could be modified by the addition of Nd (above 0.3 wt%). In addition, Wang et al. [20] investigated the influence of the Nd content on corrosion in an Al-

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5Mg alloy. Their study revealed that the addition of Nd decreased the intergranular corrosion and increased the hardness of the alloy. Additionally, Han et al. [21] investigated the effects of Nd addition on the microstructure and mechanical properties in the Al-Si-Cu-Ni-Mg alloy. The tensile properties were improved at elevated temperature when 0.2 wt.% Nd was added. However, the present studies still lack detailed investigations on Nd as a neutralizer for iron-rich intermetallics, and the information on the morphology of RE-rich particles is lacking. In the current work, the effects of Nd addition on the transformation of the Nd-rich particle morphology and the formation of iron-rich intermetallics in Al-7Si-0.3Mg-0.3Fe alloy were investigated. Furthermore, the mechanical properties of the as-cast and T6 heat treatment alloys were also examined.

2. Experimental procedures

2.1. Material preparation

A series of Al-7Si-0.3Mg-0.3Fe alloys with different Nd contents (0, 0.03, 0.06, and 0.09, wt.%) were prepared by melting together commercial pure Al (99.9% purity), pure Mg (99.99% purity), Al-20Si master alloy, Al-10Fe master alloy, and Al-20Nd master alloy at appropriate ratios. All the raw materials were preheated at 250 °C to remove water and oil. First, the pure Al, Al-10Fe master alloy and Al-20Si master alloy were melted at 800 °C. To reduce the burning loss of Mg and Nd, the pure Mg and Al-20Nd master alloy were added into the melt when the temperature of the melt was decreased to 690 °C. And then, the melt was stirred and held at 690 °C for 20 min to ensure a homogeneous distribution of the elements. The melt was refined at 690 °C before it was poured into a permanent mould, which was preheated at 250 °C. To reduce the impact of casting defects, the samples were obtained at a distance approximately 10 mm from the bottom, as shown in Fig. 1. The chemical compositions of the alloys were determined by X-ray fluorescence (XRF, XRF-1800). Considering the trace addition of Nd, the contents of Nd were detected by inductively coupled plasma optical emission spectrometry (ICP-OES, PE4300DV). Table 1 lists the chemical compositions and designations of the alloys. The heat-treated samples were treated using a standard T6 schedule. The solution treatment was firstly performed at 540 ± 5 °C for 8 h, and then quenched into hot water at 80 °C. The aging treatment was carried out at 160 ± 5 °C for 6 h, and the samples were finally cooled in air.

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

Alloy	Si	Mg	Fe	Nd	Al
0Nd	6.80	0.32	0.31	N.D.*	Balance
0.03Nd	6.89	0.29	0.33	0.025	Balance
0.06Nd	7.14	0.30	0.28	0.057	Balance
0.09Nd	6.95	0.35	0.31	0.085	Balance

N.D.*: Not detectable.

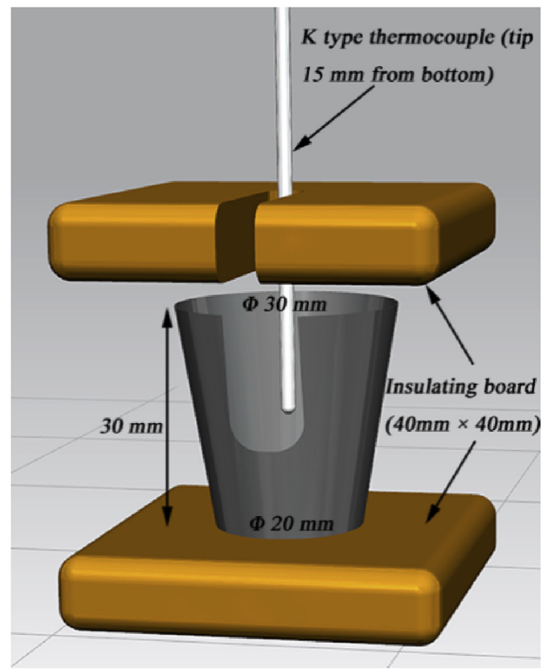

Fig. 2. A schematic of the experimental setup for the thermal analysis.

2.2. Thermal analysis

The thermal analysis was carried out in a stainless-steel cup with a ceramic crucible, and the experimental setup for the thermal analysis is shown in Fig. 2. Before pouring the melt into the permanent mould, the melt was first poured into the stainless-steel

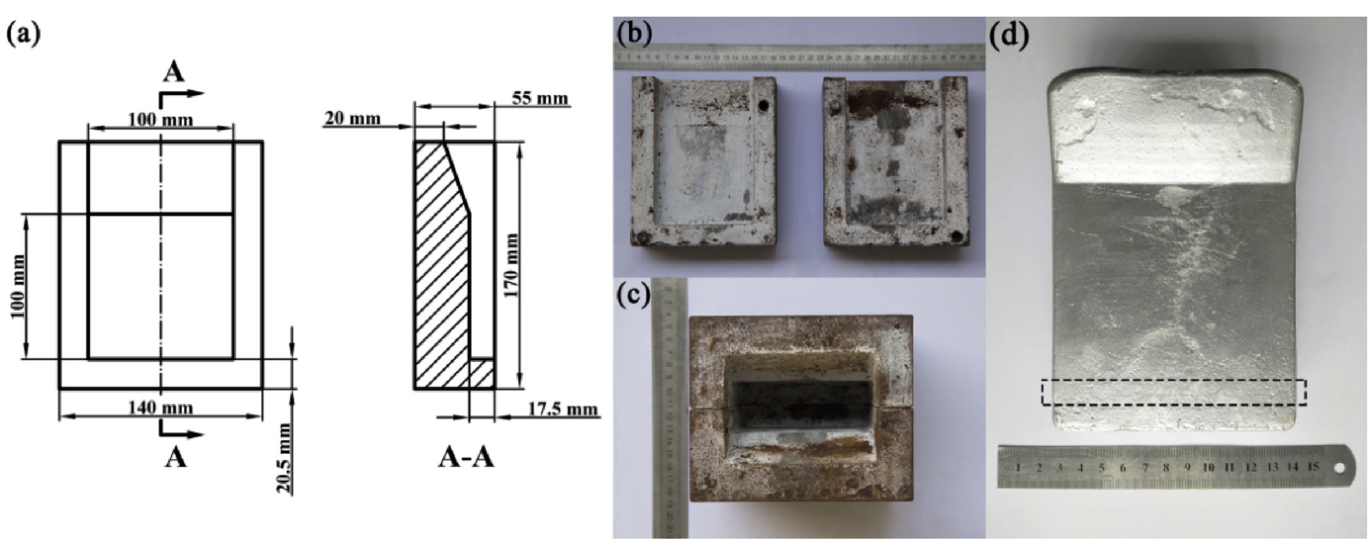

Fig. 1. (a) Schematic diagram of the half mould, (b and c) photographs of the split moulds and the assembly, respectively, (d) sampling area (the dotted box area).