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Microstructure and mechanical properties of an Al–12.7Si–0.7Mg alloy processed by extrusion and heat treatment

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ABSTRACT

Direct chill (DC) cast Al–12.7Si–0.7Mg alloy without chemical modification was hot extruded and subsequently heat-treated under various conditions. The microstructure and tensile properties of the extruded profile were investigated aiming at understanding the strengthening mechanisms. The results show that the refined microstructure characterized by fine Si particles uniformly distributed in the Al matrix of fine equiaxed grains was promoted by hot extrusion. The alloy after T6 treatment exhibits good ductility and much higher proof strength as well as tensile strength compared to 6063 alloy in general. The strengthening was attributed to be the combining effect of particle, grain boundary and precipitation strengthening.

1. Introduction

6xxx Al–Mg–Si aluminum alloys formed a large family in wrought aluminum alloys and received considerable interests as structural materials for their medium strength, excellent formability, weld ability, corrosion resistance and low cost [1]. The main alloying elements in 6xxx series alloys are Si and Mg, which form Mg_2Si phase in the equilibrium state and a series of transient phases as precipitation during aging treatment following solution treatment. The latter non-equilibrium precipitations contribute mainly to the strengthening of this alloy family [2–4].

Al–Si alloys with addition of Mg make a big group of cast aluminum alloys for structural purpose. As in the 6xxx alloys, Mg in the cast Al–Si alloys is taken in advantages to strength the alloys through precipitation hardening. However, application of wrought Al–Si alloys bearing Mg as structural materials has not been seen in literature. The reason is generally believed to be drawn from the fact that, in ingot metallurgy, in the cast Al–Si alloys with higher Si content; the brittle primary and/or eutectic Si phase usually make further deformation difficult [5,6].

The work of Guiglionda and Poole [7] on the Sr modified Al–12Si alloy with less amount of Fe showed that hot rolling could be easily performed provided that, prior to deformation, fibrous eutectic Si phases must be transformed into fine particles through sphericallization treatment. Yu at al. [8] showed that in a direct chill (DC) cast Al–15Si alloy, eutectic Si can be modified to be fibrous by direct chilling, just as that in the chemically modified Al–Si alloys. It is thus expected that on the condition one overcome the deformation problem associated with DC cast Al–Si alloys with addition of Mg, precipitation effect of Mg and Si should make the wrought alloys attractive for structural materials from the viewpoint of, al least, strength promotion.

In this work, DC casting without chemical modification was employed to generate an Al–12.7Si–0.7Mg billet. Hot extrusion was performed following pre-heat-treatment to produce profiles which were subsequently subjected to solution and aging treatment. The microstructure and mechanical properties were investigated to evaluate the possible mechanisms contributable to the strengthening of the alloys.

2. Material and methods

A DC cast Al–Si–Mg alloy billet of 110 mm in diameter was produced, without chemical modification, with a pouring temperature of 700 °C and casting velocity of 3 mm/s. The chemical composition of the alloy is given in Table 1. The billet was extruded into a profile of 4 mm in thickness at 470 °C, after pre-heat-treatment at the same temperature for 2 h. The extrusion ratio is 15:1 and the ram speed was set at 10.5 mm/s during extrusion.

The specimens for tensile test were cut from the extrusion profiles along the longitudinal direction. A portion of the tensile specimens were processed to T4 (solution treatment + natural

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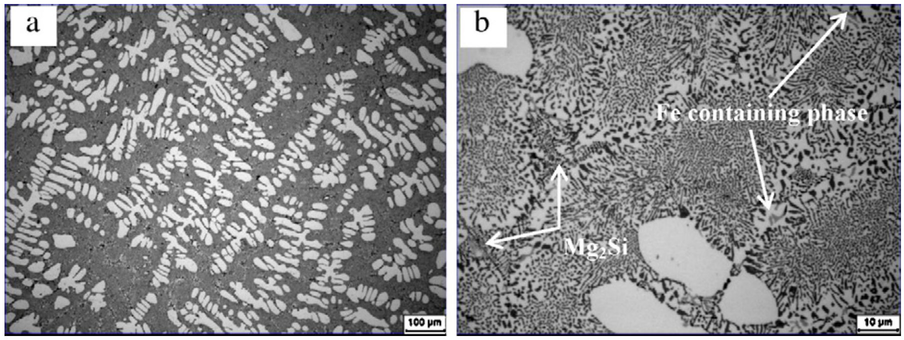

Fig. 1. Optical micrographs of the DC cast Al–12.7Si–0.7Mg alloy showing (a) fully developed Al dendrites and (b) fine eutectics.

Table 1
Chemical composition (wt. %) of the Al–Si–Mg alloy.

Elements			
Si	Mg	Fe	Al
12.7	0.7	0.2	Bal.

aging) and T6 (solution treatment + artificial aging) tempers. The solution treatment was performed at 540 °C for 90 min in a salt bath and quenched into water at room temperature. Artificial aging was carried out at 180 °C for a period of 1, 2, 3 h respectively in a Muffle furnace. Mechanical tests were performed on a SANS testing machine at a cross-head speed of 1 mm/min. The mechanical data for T1 (as extruded), T4 and T6 conditions were the average for three specimens which were wire electric discharge machining machined corresponding to ASTM standard E8. Elongation was measured as the engineering strain at fracture.

The samples for optical observation were prepared following standard metallographic methods. An optical microscope (Leica DMI 5000 M) was used for this purpose. Quantitative analysis was carried out to investigate the Si particle size and matrix grain size by using Image-Pro Plus image analysis software. The grain size of the Al matrix was measured by the linear intercept method. The transmission electron microscopy (TEM) samples were thinned to 50 μm by mechanical polishing and punched into 3 mm disks prior to the TEM experiments. Thin foils for TEM studies were twin jet electropolished in a solution of 30% nitric acid in Methanol at −20 °C. Conventional TEM observations and selective area electron diffraction (SAED) were performed using a FEI Tecnai F20 electron microscope operated at 200 KV.

3. Results and discussion

3.1. Microstructure

Direct chill (DC) casting of Al–12.7Si–0.7Mg without chemical modification, not only produce a solidification microstructure with fine eutectic Si phase but also with fine intermetallic phases. Fig. 1 shows the microstructure of the DC cast Al–12.7Si–0.7Mg alloy. As can be seen, the as-cast microstructure consists of fully developed Al dendrites and fine eutectics among the Al dendrites. The high-magnification micrograph in Fig. 1b reveals that the eutectic microstructure of the alloy was extremely refined, containing closely spaced fibrous silicon and intermetallics phases precipitated in the interdendritic regions. The black Chinese script-like Mg_2Si phases are clearly discernable. The block-like and needle-like Fe-containing phase appears in the form of small grey particles.

The microstructures of longitudinal (along the extrusion direction) section and cross-section (transverse to the extrusion direction) of the extruded alloy were shown in Fig. 2a and b, respectively. It contains uniformly distributed silicon particles in the Al matrix of fine equiaxed grains. The fibrous eutectic Si in as-cast alloy was spherodized during pre-heat-treatment [7]. Hot extrusion resulted in a uniform distribution of fine Si particles, as well as other second phase particles, on the Al matrix of fine equiaxed grains via dynamic recrystallization. The averaged grain size of the Al matrix on the longitudinal section of the extruded alloy is 6.1 μm. On this section the averaged size of Si particles is 3.1 μm. Air-quenching from the extruding press should have produced a fine dispersion of Mg_2Si precipitates which can hardly be resolved at the overview magnifications.

The microstructures of the extruded profile on its longitudinal section after solution treatment and artificial aging are shown in Fig. 3a and b, respectively. After solution treatment at 540 °C for 90 min and artificial aging 180 °C for various times, the averaged Si particle size and Al grain size was increased to 3.3 μm and 7.2 μm, respectively. It is also noticed that the Si particles were gradually rounded and their aspect ratio were decreased in average. It is worthy to notice that the solution treatment at such a high temperature and such long time did not change the size of the Si particles and the Al matrix grains in a considerable manner. The normal grain growth of Al matrix and the coarsening of the Si particles at high temperature might be restrained by mutual reactions. In this regard,

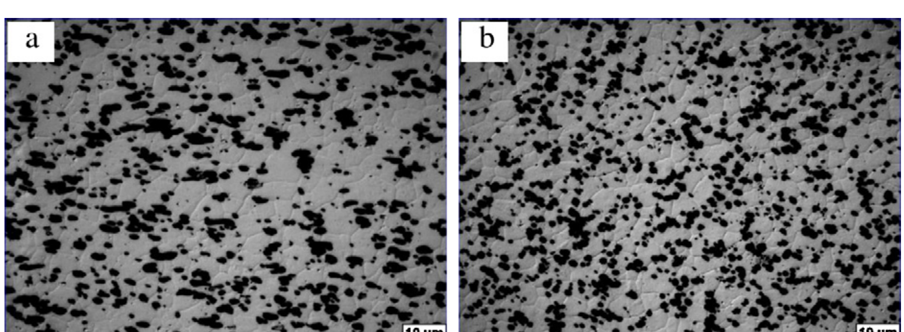

Fig. 2. Optical micrographs of extruded Al–12.7Si–0.7Mg alloy: (a) longitudinal section, (b) cross-section.