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Microstructure and tensile properties of a continuous-cast Al–Li–Hf alloy

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Abstract

Bars of 37.5 mm diameter and length higher than 300 mm of an Al–(1.2 wt.%) Li–(0.8 wt.%) Hf alloy were produced by continuous casting in a caster machine. The density of the as-cast alloy was determined to be about 2.626 Mg/m^3. The microstructure and mechanical properties of the ingots were compared with those of a continuous cast aluminium ingot produced in the same machine. The yield and ultimate tensile strengths of the as-cast alloy were much higher than those of cast pure aluminum. The elongation of the former material was smaller than the latter material. The fracture surface of the as-cast alloy showed a ductile fracture mode. These tensile properties were also similar or superior to those of non-heat-treatable wrought aluminium alloys in the annealed condition.

The optical micrographs of the as-cast alloy showed columnar grain, elongated in the cast direction, and formed from the outer surface to the centre of ingot. Finer equiaxed grains were formed in the central part of the ingot. The MEB and MET micrographs showed that the microstructure of the as-cast alloy consisted mainly of granular α (Al-rich phase) grains containing colonies of dendrites or cells. These were outlined by a layer of solute-rich interdendritic zones.

Keywords: Continuous caster; Cast alloys; Al–Li–Hf alloys; Tensile properties; Microstructure

1. Introduction

As is well known, the casting practice has a marked influence on the mechanical properties of materials. The continuous casting process is associated with high cooling rates and thus, it has received much interest because it makes possible to refine microstructure, to reduce microsegregation and then to improve the mechanical properties [1–3]. This kind of process enables us to eliminate a part of the hot rolling process, saving energy. Besides, the continuous casters offer the possibility for processing special alloys. The topic of casting aluminum and aluminum-base alloys in a continuous mode has been reviewed in different works [1–4].

The property improvements of Al–Li alloys have been achieved by alloying additions [5–7]. The aging treatment of these alloys produces the formation of complex precipitates such as $Al_3(Li_xTM_{1-x})$ with TM = Hf, Zr and Ti. Hafnium has been also added to Al–Li alloys to increase its hardness, after aging [8]. Besides, an Al–1.2Li–1Hf alloy was prepared using powder metallurgy [9]. They carried out aging treatments for this alloy and observed good hardening response and good mechanical properties.

The goal of this work was to design an experimental system for continuous casting of aluminum and aluminum alloys based on theoretical models of heat transfer and to analyze the quality of macrostructure and microstructure, as well as the tensile properties of the continuous-cast Al–Li–Hf alloy ingot, compared with those of a continuous-cast aluminum.

2. Experimental procedure

Fig. 1 shows an schematic illustration of the bar continuous caster used in this work. The design of the direct-chill type continuous casting system was based on a theoretical models proposed by Hills and Moore [10], Szekely [11] and Indyk and Hadden [12]. The tundish and crucible were made of silicon carbide. The mold and false bottom were fabricated with pure copper. The main structure of the caster was constructed using a plain carbon steel. The pure alu-

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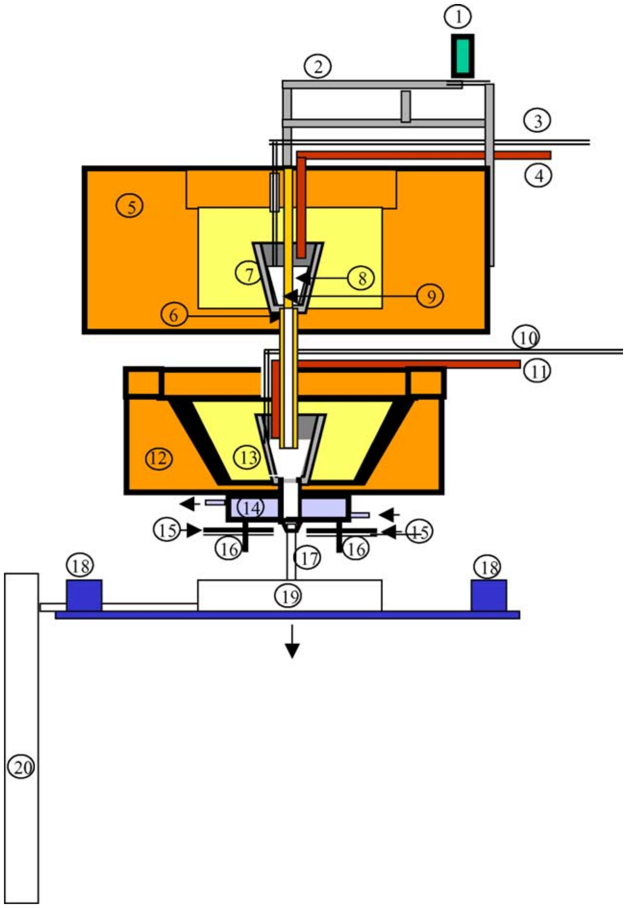

Fig. 1. Schematic illustration of continuous caster: (1) valve motor; (2) valve control of liquid metal; (3) thermocouple of melting furnace; (4) insert atmosphere conduct; (5) melting furnace; (6) liquid metal conduct; (7) melting crucible of silicon carbide; (8) liquid metal; (9) drain plug of liquid metal; (10) thermocouple of tundish; (11) insert atmospheric conduct; (12) kiln; (13) tundish; (14) mold; (15) water spray (secondary cooling); (16) protection flats; (17) false bottom; (18) cylindrical bushing; (19) water cooling receiver; (20) reservoir water.

minum and Al–(1.2 wt.%) Li–(1 wt.%) Hf alloy were continuous cast. Both materials were prepared from pure elements and melted using an electrical-resistance furnace under an argon atmosphere in a silicon carbide crucible. The casting speed and cooling rate were about 0.25 cm s^{-1} and 6 K s^{-1}, respectively. The continuous cast bars have the following dimensions: 300–350 mm length and 37.5 mm diameter. The chemical composition of the ingots was determined by atomic absorption chemical analysis and X-ray fluorescence spectrometry. Both bars were cut longitudinally and then prepared metallographically. These prepared surfaces were macroetched with a Keller's reagent at room temperature. The microstructures of the bottom, middle and top parts of the ingots were observed at 20 kV in a SEM equipped with a microanalysis system, after metallographical preparation and microetched with a Keller's reactive at room temperature. The Vickers hardness was determined on the ingots with a load of 100 g. The tension test specimens of 11 mm diameter and 90 mm length were prepared and tested at room temperature and cross-head speed of 1 mm min^{-1} with a Shimadzu tension test machine, according to the procedure of E-8 ASTM standard. The tension specimens were extracted from three parts of the ingot, bottom, middle and top. The fracture surfaces were observed with a SEM at 20 kV. The density of alloys was measured using the picnometer technique with pure water. The TEM specimens were prepared by the twin-jet electropolishing technique with an electrolyte composed of 33 vol.% nitric acid in methanol at −40 °C, and observed at 200 kV in a TEM equipped with an Energy-Dispersive X-Ray Spectroscopy, EDS, system.

Table 1
Chemical analysis of pure aluminium and Al–Li–Hf alloy

Material/composition	%Li	%Hf	%Fe
Pure Al	–	–	0.15
Al–Li–Hf	1.21	0.8	0.15

3. Results and discussion

3.1. Chemical composition, density and microstructure of ingots

Table 1 shows the chemical composition of both the pure aluminum and Al–Li–Hf alloy. Both materials showed the presence of iron. The mass density for the Al–1.2Li–0.8Hf alloy was determined to be about 2.626 Mg/m^3.

Fig. 2 shows the size and the good surface quality of the Al–1.2Li–0.8Hf alloy ingot.

Fig. 3 (a)–(c) show the macrostructure of the continuous-cast Al–1.2Li–0.8Hf alloy ingot for its top, middle and bottom parts, respectively. The bottom part was the first cast section. It can be noticed that it was composed of columnar grain, elongated in the cast direction, and formed from the outer surface to the center of ingot. Finer equiaxed grains were formed in the central part of ingot. This solidification pattern was similar to that found in the pure aluminum ingot, but this one revealed a grain size larger than that found in

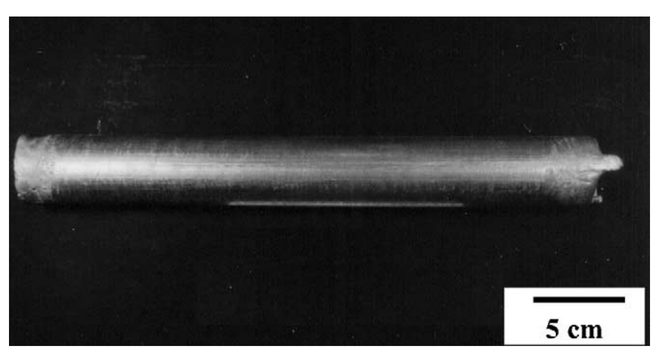

Fig. 2. Continuous cast ingot.