International Journal of Lightweight Materials and Manufacture 1 (2018) 108–114

Contents lists available at ScienceDirect

International Journal of Lightweight Materials and Manufacture

journal homepage: https://www.sciencedirect.com/journal/international-journal-of-lightweight-materials-and-manufacture

Original Article

Twin-roll casting 8011 aluminium alloy strips under ultrasonic energy field

Chen Shi [a, b, *], Ke Shen [a]

[a] College of Mechanical and Electrical Engineering, Central South University, Changsha 410083, People's Republic of China
[b] National Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha 410083, People's Republic of China

ARTICLE INFO

Article history:
Received 22 March 2018
Received in revised form
6 June 2018
Accepted 7 June 2018
Available online 13 June 2018

Keywords:
8011 aluminium alloy
Ultrasonic twin-roll casting
Microstructure
Precipitated phases
Mechanical properties
Texture

ABSTRACT

The ultrasonic energy field was applied during the twin-roll casting of 8011 aluminium alloy. The effects of ultrasonic vibration treatment on the microstructure and the mechanical properties of the 8011 strips were investigated by means of metallographic microscope observation, scanning electron microscope observation, electron backscattered diffraction and mechanical properties test. The average grain size of the strips decreased from ~90 μm to ~70 μm and the maximum density of texture decreased from 19.4 to 15. The content of Fe and Si in the precipitated phases decreased from 12.1% to 6.79%–6.4% and 1.78%, and the segregation phenomenon was restrained effectively. What's more, the mechanical properties of the strips were enhanced: the tensile strength, yield strength and elongation increased by 5.83%, 13.04% and 4.2%, respectively.

1. Introduction

8011 aluminium alloy is a common aluminum foil alloy with iron and silicon as the main alloying elements. It has been widely used in sealing packing of cosmetic bottles, beverage bottles and air conditioning aluminum foil because of its good deep drawing performance and low earing rate [1,2]. Twin-roll casting strips are the original blank of aluminum foil, and its microstructure and properties will cause genetic effects on the finished foil. Therefore, improving the microstructure and properties of the twin-roll casting strip blank is of practical significance for the subsequent production of aluminum foil. However, the strips prepared by conventional twin-roll casting method often have coarse grain, uneven structure and composition segregation, resulting in its decline in service performance [3,4]. In order to solve these defects, many previous studies introduced external energy fields (e.g., electromagnetic fields, pulsed current, ultrasound, or a combination of these) to improve the microstructure and properties of twin-roll casting strips [5–9].

Ultrasound is a high-energy sound wave that can generate cavitation effect and acoustic streaming effect when propagated in a metal melt; these effects can significantly improve the quality of the solidification structure [10]. Yu et al. [8] studied the effects of ultrasonic treatment on the microstructure and properties of twin-roll casting magnesium alloy sheet, and they found there were coarse grain and the α-Mg phase dendrites without ultrasonic treatment (UST) of the molten alloy, when ultrasound was applied during the twin-roll casting process, the grains were clearly refined and the mechanical properties were improved. Shi et al. [11] found there were an obvious segregation layer on longitudinal section and serious micro segregation of traditional twin-roll casting strips, while the segregation layer disappeared and micro segregation decreased obviously when introduced multi-energy field. Li et al. [12] also found similar phenomena such as grain refinement when they researched twin-roll casting 3003 aluminum alloy strips by applying ultrasonic/electromagnetic compound energy fields.

Although there are many existing studies on aluminum alloy twin-roll casting, research on application of ultrasonic vibration treatment to metal melt to improve the microstructure of 8011 aluminum alloy strips is rarely reported. And the previous works usually used titanium alloy radiators to transmit ultrasound to the

* Corresponding author. College of Mechanical and Electrical Engineering, Central South University, Changsha 410083, People's Republic of China.
E-mail address: shichen@csu.edu.cn (C. Shi).

Peer review under responsibility of Editorial Board of International Journal of Lightweight Materials and Manufacture.

https://doi.org/10.1016/j.ijlmm.2018.06.001

metal melt. However, their in-service performance was obviously weakened due to severe cavitation erosion [13]. As ceramic materials are stable and do not react with metal melts in high temperature environments, here, the effects of an ultrasonic energy field on the microstructure and properties of twin-roll casting 8011 strips were investigated using a ceramic radiator to introduce ultrasonic waves.

2. Experimental procedures and test method

2.1. Experimental procedures

The experimental material was the 8011 aluminium alloy with the chemical composition listed in Table 1.

The industrial experiment was carried out on a 800 mm × 1550 mm horizontal twin-roll casting unit in Xinren Aluminum Limited Company. The experiments were divided into two groups: one was conventional twin-roll casting and the other was a group with the same process parameters except applying ultrasonic vibration to metal melt in the twin-roll casting process. The schematic of ultrasonic vibration device and 8011 aluminum alloy ultrasonic twin-roll casting are shown in Fig. 1.

The technological parameters of the twin-roll casting unit were as follows: the roll gap was 6.4 mm, twin-roll casting speed was 0.86 m/min, pouring temperature measured by thermocouple was 698 °C, the flow of cooling water in the rolls was 80 L per minute and the temperature was 20 °C. The ultrasonic vibration device consisted of an ultrasonic generator, ultrasonic transducer, ultrasonic horn, and a ceramic radiator. The ceramic radiator was made of a Si_3N_4 ceramic and was connected to the end of an ultrasonic horn (made of TC4 Ti alloy) by bolt. The parameters of the ultrasonic equipment were as follows: the power of ultrasonic wave was 500 W and the frequency was 23 ± 0.2 kHz; the ceramic radiator was inserted below the surface of the liquid about 30 mm. The 8011 aluminum alloy twin-roll casting strips with the thickness of 6.5 mm, the width of 1320 mm and the weight of about 6500 kg was prepared.

2.2. Test method

Square samples with the dimensions of 10 mm × 10 mm were cut at the center of the aluminum alloy strips. According to GB/T 3246.2–2000, the samples were ground and polished in the MP-2B polishing machine, then rinsed with water and wiped with alcohol, and finally, the microstructure of the samples corroded about 25 s with 0.5% HF were observed using an OLYMPUS DSX500 metallurgical microscope (OLYMPUS Corporation, Japan). The morphology, size and distribution of the precipitated phase were observed using a Phenom fully automatic scanning electron microscope (Phenom-world BV, Holland), and the content of the alloying elements in the precipitated phases were analyzed by energy dispersive spectroscopy (EDS). According to GB/T 16865-2013, the standard tensile test samples were cut from the strips along the 0° direction (cast-rolling direction, RD), 45° direction and 90° direction (transverse cast-rolling direction, TD) using a wire cutting machine. The direction and dimensions (mm) of the standard tensile specimens are shown in Fig. 2. The mechanical properties of the samples were tested at room temperature using a MTS 810 universal material testing machine (MTS Systems Corporation, USA) with a strain rate of 2 mm/min, and the fracture morphology was observed using a Phenom fully automatic scanning electron microscope (Phenom-world BV, Holland).

Table 1
Chemical compositions of the 8011 aluminium alloy (wt-%).

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Content	0.5–0.9	0.6–1.0	<0.1	0.2	<0.05	0.05	0.1	Bal.

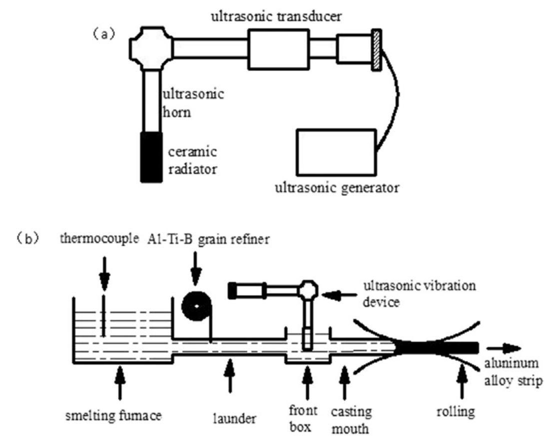

Fig. 1. The schematic of (a) ultrasonic vibration device and (b) 8011 aluminum alloy ultrasonic twin-roll casting.

3. Results and discussion

3.1. Effect of ultrasonic treatment on the microstructure of 8011 aluminum alloy twin-roll casting strips

Fig. 3 shows the metallographic structure of two kinds of twin-roll casting strips in rolling direction (RD), transverse direction (TD). Fig. 3a and c shows the metallographic structure of strips observed along the rolling direction, where it can be seen that the grains were elongated along the rolling direction due to the effect of rolling force. But the size, shape and uniformity of the grains were different: the grains of conventional twin-roll casting strips were coarse and uneven, while the grains of ultrasonic twin-roll casting strips were smaller with clear and smooth grain boundary, which indicated that applying ultrasonic vibration treatment to metal melt can make the deformation of original grain more uniform in the process of flattening and stretching. With regard to the metallographic structure in transverse direction, Fig. 3b and d shows that the grain size of conventional twin-roll casting strips were also bigger than that of ultrasonic twin-roll casting strips.

The microstructures of twin-roll casting strip surface are shown in the EBSD maps (Fig. 4), where it can be seen that the grains of ultrasonic twin-roll casting strips were smaller than those of conventional twin-roll casting strips, and the average grain size was refined from ~90 μm to less than ~70 μm with ultrasonic vibration treatment. Fig. 5 shows the ODFs of twin-roll casting strip surface. The main texture component of two kinds of twin-roll casting strips was rotated cube {001} <110>, but the strength of rotated cube texture of conventional strips was higher than that of ultrasonic strips. The maximum density of texture decreased from 19.4 to 15 after introducing the ultrasonic vibration treatment. The conventional strip had strong {211} <011> at (50°, 65°, 65°), and the ultrasonic strip had strong {111} <011> at (60°, 55°, 45°).

In general, the grains of ultrasonic twin-roll casting strips in three directions were smaller than those of conventional twin-roll casting strips, and its metallographic structure was more uniform. When the ultrasonic wave was propagated in the molten metal, the sound intensity appeared attenuation with the increase of the propagation distance due to the viscous force of the liquid, which led to form the sound pressure gradient along the direction of