Materials Characterization 127 (2017) 325–332

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Improvement of microstructure and properties in twin-roll casting 7075 sheet by lower casting speed and compound field

G. Chen [a], J.T. Li [a,b], Z.K. Yin [c], G.M. Xu [a,*]

[a] Key Laboratory of Electromagnetic Processing of Materials (Ministry of Education), Northeastern University, Shenyang 110819, PR China
[b] School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong, NSW 2500, Australia
[c] Department of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, PR China

ARTICLE INFO

Article history:
Received 18 November 2016
Accepted 12 March 2017
Available online 16 March 2017

Keywords:
7075 sheet
Twin-roll casting
Casting speed
Compound field
Segregation

ABSTRACT

Well-developed dendrites and severe macro and micro segregations in 7075 sheet produced by horizontal twin-roll casting (TRC) deteriorates the hot-workability and properties of the sheet, which makes an obstacle for the successful use of this technology. In this paper, lower casting speed and a pulsed electric-magnetostatic compound field are used to refine microstructure and abate segregation in TRC 7075 sheet. The dendrite arm space decreases from 20 μm to 8–13 μm and the micro-segregation degree of Mg, Zn and Cu decreases when casting speed decreases from 1.5 m/min to 0.75 m/min. The center macro-segregation belt disappears in the 0.75 m/min sheet. The as-cast structure and the dendritic segregation in the 0.75 m/min sheet are further refined and abated respectively by the compound field. The secondary dendrite arm size decreases to 5–8 μm in the field sheet. The 0.75 m/min sheet casted with the field shows better mechanical properties after homogenization and hot rolling. The optimization mechanism of lower casting speed and the field was discussed with the aid of classical solidification theory and electromagnetism.

1. Introduction

As a kind of ultra-high strength aluminum alloy, 7075 alloy is widely used in many fields like construction of plane structures, automotive components, sports and electronic industries due to its superior comprehensive properties, such as low density, high specific strength, toughness and resistance to fatigue [1–4]. The traditional method of producing 7075 sheet is direct chill (DC) casting followed by hot rolling [5], which has the disadvantage of complex process and high cost. Unlike this method, twin-roll casting (TRC) can produce sheet directly from melt and thus has the advantage of short procedure, energy saving and low cost [6]. However, severe segregation and well-developed columnar dendrites always occur in TRC 7075 sheet as a result of directional solidification as well as high content elements and wide solidification temperature range in the alloy [7]. These segregated phases often form a network-like structure and provide easy path for crack growth during hot plastic deformation at low temperatures [7]. They also cause partial melting due to eutectic reaction at high temperatures, which narrows the temperature and strain rate ranges for successful hot working [7].

During TRC of aluminum, process parameters such as pouring temperature and casting speed decide whether the sheet can be produced smoothly as well as the microstructure of the sheet. Sun et al. [8] pointed out that high casting speed tended to form macro-segregation in the TRC sheet center. Thus the metallurgical defects in the TRC 7075 sheet may be abated by adjusting the casting speed. Besides, as stated by Asai [9], applying electric current and magnetic field would induce an electromagnetic oscillation in the melt. As a result, the growing crystals can be shattered and refined and the segregation abated. What's more, compared with traditional refining methods, the application of magnetic field is completely free from contamination and the imposition of electric current is extremely clean, except for contamination from electrodes [9].

Several researches on 7075 sheet produced by TRC have been carried out recently. Wang et al. [10] studied the effects of microstructure of TRC 7075 sheet on its hot tensile behavior and found that large elongation over 200% was obtained at 450 °C under high strain rate of $1 \times 10^{-1}\ s^{-1}$. This large elongation was caused by the uniformly distributed small particles in TRC sheet casted at high solidification rate, which induced homogeneous recrystallized microstructure during the hot deformation. Su et al. [5,11–12] studied horizontal TRC of 7075 sheet. Electromagnetic fields were used during the process to abate both the micro and macro segregation and to refine the microstructure. However, in these works, the effects of casting parameters were not investigated

---

[*] Corresponding author.
E-mail address: xu_gm@epm.neu.edu.cn (G.M. Xu).

http://dx.doi.org/10.1016/j.matchar.2017.03.024
1044-5803/

and the function mechanism of the electromagnetic fields was not studied in detail.

In this paper, a 7075 sheet was produced by horizontal TRC. Different casting speeds were used to study their effects on the microstructure of the sheet. A compound field (pulsed electric field combined with magnetostatic field) was applied during casting to study its effects on the as-cast microstructure and elements segregation in the sheet. The paper aims at finding an effective way to abate the metallurgical defects in the 7075 TRC sheet and thus puts the technology into practice.

2. Experiment and Material

The TRC was carried out on a reversible horizontal twin-roll caster with two rollers 500 mm in diameter and 500 mm wide. The maximum rolling force was 1000 kN. Two roll gaps of 5 mm and 3.8 mm were used. The roller surface was smeared with graphite powder to avoid sticking. A refractory nozzle was used to direct melt into the roll gap. Two home-made coils were used to generate magnetostatic field in the roll-casting zone. One of the coils was put under the nozzle and the other at the exit side near the roll gap. The maximum vertical magnetic flux density in the cast-rolling zone was about 45 mT. The pulsed electric field (PEF) was generated with a pulse stabilized power supply. The peak value, frequency and duty ratio were set to 600 A, 20 Hz and 15%, respectively. One end of the PEF wire was inserted into melt and the other end was pressed on the sheet surface to form loop. The schematic diagram of TRC is shown in Fig. 1(a) and the corresponding sizes of roll-casting zone are in Fig. 1(b). 7075 alloy was smelted in a 20 kW resistance furnace by firstly melting commercially pure (99.9%) aluminum ingot. When the melt temperature reached 750 °C, commercially pure magnesium and zinc ingot and master alloys of Cu and Cr were put into the melt. The melt was hold at this temperature for 2 h. Then the melt was cooled to 680 °C and poured into the nozzle through a sluice. The chemical composition of the 7075 alloy in wt% was Al- 5.59Zn- 2.92Mg- 1.88Cu- 0.239Cr- 0.46Fe- 0.4Si. Two casting speeds of 0.75 m/min and 1.5 m/min were used when the roll gap was 5 mm and 3.8 mm, respectively. In the first casting, the magnetostatic field and PEF were applied on half of the sheet and the other half casted without external field. The width and thickness of the as-cast sheet were about 210 mm and 7 mm (or 5 mm), respectively.

Small pieces of 50 mm × 150 mm were cut from the as-cast sheets to be further treated. Firstly, the pieces were homogenized in a resistance furnace at 460 ± 5 °C for 12 h and furnace cooled to room temperature. Then the sheets were hot rolled at a temperature range of 410–430 °C to a final thickness of 1.5 mm followed by a stress relief annealing at 390 °C for 30 min. Metallographic specimens were cut from the as-cast and homogenized sheets respectively to study their microstructures. The samples were studied under a Leica DMI5000M optical microscopy (OM) after being ground, polished and then etched with 3 vol% HF aqueous solution for 15–20 s. To study the precipitated phases and elements segregation in the differently treated sheets, SSX-550 scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometry (EDS) was used. The dendritic segregation was investigated with the micro-segregation degree S_e using the following equation:

$$S_e = \frac{C_{\max} - C_{\min}}{C_0} \quad (1)$$

where $C_{\max}$, $C_{\min}$, C_0 are the maximum, minimum and average content of an element in the segregation zone respectively. The mechanical properties of the hot rolled sheets were investigated by tensile testing on a SHIMADZU AG-X universal testing machine at a speed of 2 mm/min (corresponding to a strain rate of 0.001 s^{-1}). The test samples were cut from the hot-rolled and annealed sheets along the rolling direction on a wire cutting machine. The gage length and width of the tensile sample were 34 mm and 10 mm, respectively. To make the test results as reliable as possible, three samples were prepared for each condition and the average values of the eigenvalues of the tensile curves were used in the analysis. The fracture morphology was studied on the SSX-550 SEM.

3. Results

3.1. Microstructures of the As-cast Sheet

Fig. 2 shows the transverse microstructure of as-cast sheet under different casting conditions. Fig. 2(a) and (b) show the near surface and center part in the 1.5 m/min sheet respectively. Well-developed dendrites can be seen in the near surface part and the size of the dendrite arms is not homogeneous and within a range of 15–25 μm. Besides, some coarse worm shaped segregations 30–50 μm wide and 100–200 μm long can be observed in the upper right corner. In the center part, a 20–80 μm wide macro-segregation belt is observed. Above the belt, some very fine dendrites appear and the crystal structure is heterogeneous. Fig. 2(c) and (e) show the near surface and center part of the 0.75 m/min sheet casted without the compound field. The near surface part also consists of well-developed dendrites with an average arm size of 8–13 μm and many worm shaped segregation zones 5–10 μm wide and 50–70 μm long. The sizes of the dendrite arms and segregation zones are much smaller than in the 1.5 m/min sheet. The macro-segregation belt disappears in the center part and the microstructure is much the same as near surface part. In the 0.75 m/min sheet casted with the compound field shown in Fig. 2(d) and (f), the dendrites are further refined compared with the non-field condition and with a smaller and more uniform size of 5–8 μm. What's more, the number of the worm shaped segregation apparently decreases and the size of the rest diminishes to some extent. The average dendrite arm size in the as-cast 7075 sheet under different casting conditions is shown in Fig. 3 to make the effect of casting speed and the field shown more apparently. The arm size decreases markedly under lower casting speed and the compound field.

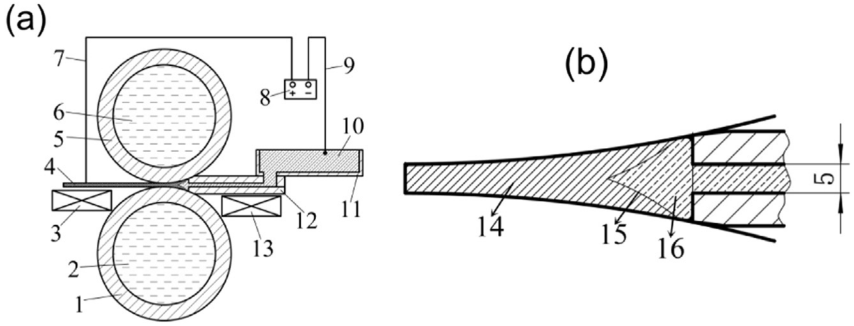

Fig. 1. (a) Schematic diagram of electromagnetic TRC and (b) the roll-casting zone: 1-lower roller; 2 and 6-cooling water; 3 and 13-coil; 4-7075 sheet; 5-upper roller; 7 and 9-PEF wire; 8-pulsed power supply; 10 and 16-7075 melt; 11-sluice; 12-nozzle; 14-solidified alloy; 15-solidification interface.