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Effects of twin-roll casting process parameters on the microstructure and sheet metal forming behavior of 7050 aluminum alloy

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ABSTRACT

In the present study, strips of 7050 aluminum alloys were cast using twin roll casting technology (TRC) where roll casting speed, roll gap, cooling water flow rate and initial cooling water temperature were varied. The optimized process parameters and their effects on TRC of 7050 aluminum alloys strips were investigated. The optimized process parameters and properties were obtained to be roll gap of 1.8 mm, roll casting speed of 11.4 m/min (12 r/min), cooling water flow rate of 11.1 m^3/h and initial cooling water temperature of 20.8 °C. The macro morphology, microstructure, hardness and yield stress of the strips were investigated using optical microscopy, scanning electron microscopy (SEM), energy dispersion spectroscopy (EDS) and Vickers hardness. The homogeneous microstructures and improved mechanical properties were obtained by increasing the roll casting speed and roll gap thickness.

1. Introduction

Twin-roll casting (TRC) is an important technology for producing metal and alloy sheets, which was first devised by Bessemer as a new steel making process in 1956. The TRC technology has several advantages over the conventional casting methods, such as low consumption of power and time. It combines casting and hot rolling together into a single operation, thus ensuring an efficient process. In a typical TRC process, the molten metal is fed into the gap between two internally water-cooled running rolls. Park et al. (2007a) demonstrated that the cooling rate of the molten metal can reach up to 10^2 °C/s during TRC processing. Haga et al. (2003) devised a twin roll caster for aluminum alloys using high thermal conductivity roll and no lubricant, to investigate the effects of these on the casting speed and mechanical properties. In their study, heat transfer between melt and roll was improved using hydrostatic pressure of the melt and the lubricant was not used to increase the casting speed. After solidification, the metal undergoes a hot deformation to produce the final sheet, as reported by Ju and Hu (2006).

The process parameters of TRC significantly influence the quality of the sheets, as reported by Mino et al. (2006), particularly for the ultra-thin fast cast (Xiao and Cai, 1999). It was found that finer microstructures decreased elemental segregation (Watari et al., 2007), and higher solid super saturation rate of strips were obtained with TRC (Park et al., 2007b). Fine grain (5 μm) sheets of AZ31 magnesium alloy strip were obtained by Zhao et al. (2012) using an asymmetric twin-roll cast. Moreover, the quality of the sheet is sensitive to the process parameters, such as the roll casting speed. Haga and Suzuki (2001) proposed a melted drag twin-roll caster with a speed of 30 m/min for producing sheets from AA3003, Al-6Si, and Al-12Si alloys. Haga et al. (2007) later demonstrated a high speed twin-roll caster with speed of 60m/min for Al-Fe alloys. Recently, Wang and Zhou (2014) examined the effects of surface conditions and microstructure of AA1050 alloy strips on the surface quality of the produced sheets. However, rarely research reports the TRC processing of 7050 aluminum alloy.

As one of the super high-strength aluminum alloys, 7050 aluminum alloy satisfies the requirements of aerospace applications, which was reported by Heinz et al. (2000). Later, Clark and Johnson (2003) used 7050 aluminum alloy sheet as the parts in several aircrafts such as the airliner of Boeing-777, military jet fighter F/A-18Hornet, and F-22 Raptor.

However, to date, there are no reports on the optimization of process parameters during TRC preparation of aluminum alloys sheets, especially for high-strength 7050 aluminum alloy. Thus, the aim of this study was to investigate the effects of TRC

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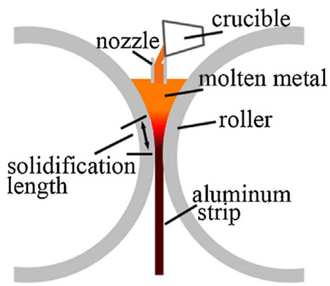

Fig. 1. Schematic of the twin-roll caster.

process parameters on the microstructure and sheet metal forming behavior of the 7050 aluminum alloy. Moreover, the TRC process parameters were optimized for producing high quality aluminum sheets.

2. Experimental procedure

A vertical type twin-roll caster was used in this study. A schematic diagram of the TRC setup is shown in Fig. 1. Copper rollers with a diameter of 300 mm and equipped with an internal water-cooling system were employed. The width of the roll gap can be controlled by a hydraulic system. Immediately prior to rolling, the 7050 aluminum alloy was superheated at a temperature of approximately 20 ~ 30 K which is above its melting point. The molten aluminum alloy was then poured onto the cold surfaces of rollers through the nozzle. Because of the wider solidification rage of high alloy content aluminum alloy, the detailed experimental parameters are shown in Table 1 which according a series of experiments results.

In order to optimize casting parameters and to prepare sheets with high quality surfaces, different casting speeds and casting roll gaps were evaluated in this study. The roller speeds of 7.5 m/min (8 r/min) and 11.4 m/min (12 r/min), and the roll gap widths of 1 mm and 1.8 mm were selected as the process parameters to investigate their influences on the sheet quality. The experimental process parameters used in the study are shown in Table 2. Processes A and B were termed as group 1 experiment with the gap of 1 mm, while processes C and D were termed as group 2 experiment with the roll gap of 1.8 mm. At the beginning of each group experiment, the roll speed was 7.5 m/min (Process A and Process C) for 100–120s, and then accelerated to 11.4 m/min (Process B and Process D), which was then maintained until the end of the experiments. The thickness of the roll-casting sheet was recorded during the entire experimental process.

3. Results and discussion

3.1. Optimization of TRC process parameters

Results of two group experiments are shown in Fig. 2(a) and (b). The speed of TRC was 7.5m/min at the beginning of the experiment and then was accelerated to 11.4m/min after steady casting for 100–120s in both experiments. In this study, casting speed was changed to compare the thickness variations in roll-casting sheets under the same conditions. The sheet thickness was found to be approximately 3–5 mm with TRC speed of 7.5m/min (Fig. 2(a)), while it was 2–4 mm at the TRC speed of 11.4m/min. It is evident that the thickness of the TRC sheet varies with roll-casting speed. As shown in Fig. 2(b), the thickness of the TRC sheet did not fluctuate much. At the TRC speed of 7.5 m/min and 11.4 m/min, the sheet thickness was 3.5–4.5 and 2–3.5 mm, respectively, indicating a reasonably uniform thickness.

Table 1
Experimental conditions for the twin roll casting process.

Roller parameters	Copper, D = 300 mm, W = 100 mm,
Heating temperature	20 ~ 30 K, above the melting point of Al alloy
Roll-casting speed	7.5 and 11.4 m/min (8 and 12 r/min)
Roll gap	1 and 1.8 mm
Aluminum alloy	Al-5.89 Zn-2.16 Mg-2.1 Cu (wt.%)

As shown in Fig. 2, the sheet thickness decreased as the roll-casting speed increased. If the product/multiplication of roll-casting speed and thickness of the sheet remains constant, the following relationship is obtained:

$$K = v \times h_1 \quad (1)$$

K——productivity constant;
v——roll-casting speed, mm/min;
h_1——sheet thickness, mm.

However, the product of the casting speed and sheet thickness was found to be within a certain range in the present study. The sheet thickness will be smaller at higher thermal conductivity of the roller shell material and roll casting speed. The same conclusion was given by Hou et al. (2010), who commented that for producing a higher thickness of the roll casting sheet, a lower speed would be more suitable.

3.2. Observations of macro morphology

As shown in Fig. 3(a), the aluminum sheets had broken into pieces, and surface of the sheets was not smooth following first group experiment. On the other hand, it can be seen in Fig. 3(b) that the sheet from second group experiment remains in a good shape without breaking and its surface quality was significantly better than the one after first group experiment.

From the point of view of the process parameters, these experimental observations can be explained using several key factors described below:

3.2.1. Roll gap

The roll gap thickness controls the amount of melted aluminum accommodation between the rollers. For the same volume of melted aluminum, a wider roll gap results in less depth of the melted cavity. According to Xiao and Cai (1999), the factors that cause increased the depth of melt alloy lead to a tendency to crack. This is because the greater the melt alloy depth, the larger the contact area will be between melt alloy and roller. A large melt alloy depth also leads to a greater rolling deformation on the sheet surface. Relative shear motion easily occurs between the interior and surface of the sheet with changing in the shear pressure. The cracks begin to form on the surface of sheet when relatively large shear motion occurs. The macro morphology of the sheet indicated that sheets with good quality surfaces were obtained with wider rolls gaps in the second group experiment.

3.2.2. Cooling water flow

In order to ensure faster cooling, the cooling water flow underneath the roller shell was increased leading to lower surface temperature of the roller. When the cooling water flow rate was 11.1 m^3/h, more heat was radiated from rolling region. Thus, it is anticipated that the amount of heat transferred with the flow rate of 11.1 m^3/h was much greater than that of 8.95 m^3/h water flow causes the temperature drop of the molten aluminum more quickly. Sheets with smaller grain sizes were obtained with faster cooling/solidification speed.