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ARTICLE

Mechanical Properties and Formability of Ultrasonic Treated Twin Roll Casting Magnesium Alloy Sheet

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Abstract: The effects of ultrasonic treatment on the microstructure and properties of twin roll casting Mg-2.45%Al-0.92%Zn-0.69%Ce-0.21%Mn alloy strip were studied. The results show that the ultrasonic treatment improves strength, elongation and limiting drawing ratio of the alloy strip. The highest limiting drawing ratio of the sheet is 2.16 at 250 °C. The improvement of properties is attributed to the refinement of α-Mg grains and the modification of $Mg_{17}(Al, Zn)_{12}$ and AlCeMn phases by ultrasonic treatment during the twin roll casting process. The grain size of the twin roll casting strip is refined from 150 μm to less than 30 μm with the ultrasonic treatment power of 800 W, and the needle-like shape of the AlCeMn phase is modified to a globular shape; therefore, the mechanical properties and formability of the magnesium alloy sheet are improved.

Key words: magnesium alloy; grain refining; twin roll casting; ultrasonic vibration

Magnesium alloys have been used in the automotive and electronic industries because of their light mass and high specific strength [1]. In particular, the demand for light mass automobile construction has increased for petrol conservation [2]. Magnesium alloys are one of the suitable candidates to replace steel and aluminum for automotive sheet applications. However, the major barrier for the widespread application of magnesium alloy sheets in cars is their high manufacturing cost [3]. Because magnesium has a hexagonal close-packed crystal structure with limited workability and deformability at ambient temperature, the magnesium alloy slabs need to be reheated frequently for hot rolling. As a result, the magnesium alloy sheets from direct chill (DC) cast ingots are more expensive than steel and aluminum alloys[4,5]. It is known that twin roll casting (TRC) can produce magnesium alloy strips less than 6 mm in thickness compared to the conventional ingot casting magnesium slabs that have thicknesses of 100~300 mm[6,7]. The TRC process can save several production steps in the manufacturing of sheets compared to DC technology. However, the problems of TRC magnesium alloys include coarse columnar grains, large amounts of defects, such as edge cracks or surface voids, and the restriction to dilute alloys with a narrow freezing range [8]. Magnesium is generally alloyed with the addition of 3%Al and 1%Zn to obtain a wrought magnesium alloy with a narrow freezing range from 605 to 630 °C, which is suitable for TRC[9]. A small amount of manganese can improve the corrosion resistance of Mg-Al-Zn system alloy[10]. The addition of cerium in the Mg-Al-Zn alloy increases oxidation resistance of molten magnesium liquid during the TRC process and refines the casting grains[11]. Therefore, in the present paper, the Mg-3%Al-1%Zn-0.8%Ce-0.3%(wt%) Mn alloy was designed to produce sheets by TRC technology. There are few reports about the technology applied in the TRC process to fabricate magnesium alloy strips. Thus, ultrasonic treatment (UST) of the molten alloy was performed to improve the quality of the experimental magnesium alloy during the TRC process[12]. The comparison of the microstructure and mechanical properties of TRC Mg-Al-Zn-Ce-Mn alloy with or without UST in different conditions

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was provided to study the effects of UST and to develop new technology to fabricate high quality TRC magnesium alloy strips.

1 Experiment

A lab-scale version of a twin roll caster machine with a pair of steel rollers of 400 mm in diameter and 500 mm in width was used in the experiment. The rotation speed and gap of the rollers could be adjusted according to the experimental conditions. The nominal composition of the experimental alloy was Mg-2.45%Al-0.92%Zn-0.69%Ce- 0.21%Mn (wt%). The alloy was melted at 660~680 °C and transferred into a preheated header box with a size of 260 mm×200 mm×80 mm, where the liquid flowed into the roll casting zone. The setting width of the TRC experimental alloy was 260 mm, and the thickness was 4.0 mm. The contact length between the rollers and molten metal was 45~46 mm. The roll casting speeds were varied from 2.5 to 2.8 m/min. The molten alloy was shielded by the CO_2+0.5vol%SF_6 mixture gas during the TRC procedure.

In the experiment, ultrasound was performed on the molten experimental alloy in the header box during the whole twin roll casting process. The ultrasonic oscillation device used in the TRC consisted of an acoustic generator and a transducer with a stainless steel horn. The horn was immersed about 10~15 mm deep in the molten alloy. The fixed frequency of ultrasound was 20 kHz±200 Hz. The ultrasonic powers of 400 W and 800 W were introduced through the ultrasonic generator in the molten alloy liquid with a temperature of 660~680 °C to evaluate the effects of UST.

The tensile test was performed to evaluate mechanical properties of the TRC experimental alloy in as-cast, hot rolling and annealing conditions. All experimental specimens were machined from the TRC strips with or without ultrasonic treatment. The TRC alloy strip without the UST was prepared as a control specimen. Three types of tensile samples were machined from the TRC strips parallel to the casting direction (CD) and the transverse direction (TD) and at an intermediate (45º) orientation (as shown in Fig. 1). Three measurements per sample were performed, and the average values were used to describe the tensile properties. The tensile test was performed on an Instron 8032 mechanical testing machine at ambient temperature in accordance with ASTM standard B557M-94.

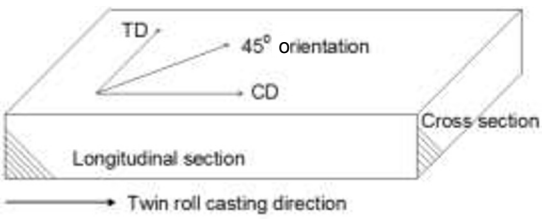

Fig.1 Schematic diagram of specimens machined from the twin roll casting strip

The TRC experimental alloy strips were homogenized at 450 °C for 12 h and then hot rolled at 400~450 °C from approximately 3.6~4 mm to 1.2~1.3 mm with three rolling passes. Each rolling reduction was about 25%, 33% and 35%. After hot rolling, the rolled alloy sheet was annealed at 400 °C for 1 h and cooled in the furnace. The deep drawing ability test was performed on a HILLE universal sheet metal testing machine to examine the forming characteristics of the magnesium alloy sheets produced by the TRC strip.

The microstructures of the experimental alloy in different conditions were examined by a Polyvar-MET optical microscope (OM) with a digital software to calculate the average grain size, a JSM-5600Lv scanning electron microscope (SEM) with energy-dispersive X-ray spectroscopy (EDX) and a Tecnai G^2 20 transmission electron microscope (TEM). The samples for optical observation were polished by emery paper and etched in a 0.5 vol% nitric acid-ethanol solution. Samples examined by TEM were electro-polished by a twin-jet electro-polishing facility in a mixture of 3% HNO_3 and 97% ethanol at a temperature of –15~–25 °C.

2 Results and Discussion

2.1 Microstructures and properties of TRC Mg-Al-Zn-Ce-Mn alloy strip in the as-cast state

Fig.2 shows the microstructures of TRC experimental magnesium alloy strip without UST and with different applied UST power levels. The microstructure of TRC alloy without UST exhibits a typical dendrite of primary α-Mg phase on the cross section of the strip. Although the TRC magnesium alloy generally obtains refined as-cast grains compared with the conventional DC ingots, the columnar dendritic structure is predominant over the equiaxed grain structure. As shown in Fig.2a, the dendrites of α-Mg in the TRC alloy strip are coarse, and the grain size is over 150 μm. Normally, the cast strip is reduced by about 10% during the TRC process. The microstructure of the TRC strip on the longitudinal section along the casting direction shows that the dendrites deform and the grain sizes are heterogeneous after the continuous roll casting process (Fig.2b). The UST has a significant effect on the refinement of the α-Mg phase dendrites. As shown in Fig.2c, with an ultrasonic power of 400 W, about half of the amount of dendritic primary α-Mg phases change to the spherical shape. The size of the dendrite grain drops to less than 100 μm. The grains on the longitudinal section also show heterogeneous morphology (Fig.2d). Increasing the UST power would result in less dendritic branches and shorter arms. With a high UST power of 800 W, the dendritic grains change to uniform spherical grains with a size less than 30 μm (Fig.2e). In particular, the grain deformation parallel to the roll casting direction is homogeneous on the longitudinal section (Fig.2f).