Materials and Design 32 (2011) 4216–4224

Contents lists available at ScienceDirect

Materials and Design

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

A new method of semi-continuous casting of AZ80 Mg alloy billets by a combination of electromagnetic and ultrasonic fields

Zhiwen Shao, Qichi Le *, Zhiqiang Zhang, Jianzhong Cui

Key Laboratory of Electromagnetic Processing of Materials, Ministry of Education, Northeastern University, Shenyang 110004, PR China

ARTICLE INFO

Article history:
Received 30 November 2010
Accepted 18 April 2011
Available online 27 April 2011

Keywords:
A. Non-ferrous metals and alloys
C. Casting
E. Mechanical

ABSTRACT

The influence of low frequency electromagnetic field and power ultrasonic field on the microstructure of AZ80 Mg alloy billets was studied. The magnetic flux density and time average electromagnetic volume force density were obtained by numerical simulation. The acoustic pressure distribution was also numerically calculated in order to characterize the ultrasonic field propagation. After comparison of the different effects of grain refinement by low frequency electromagnetic casting (LFEC) and ultrasonic casting (UC), a new method (LFEC + UC) was developed by simultaneously applying ultrasonic vibration to the melt during low frequency electromagnetic semi-continuous casting of AZ80 Mg alloy billets. With the application of the compound field under the optimum conditions, the as-cast macrostructure and microstructure were refined and homogeneously distributed. An obvious improvement of mechanical properties was finally obtained. The mechanisms of grain refinement and interaction of low frequency electromagnetic field and power ultrasonic field with the melt were discussed.

1. Introduction

Magnesium alloys have comprehensive properties which include low density, high specific strength and stiffness, excellent machinability, superior damping and magnetic shielding capacities. Therefore, they are particularly attractive in various fields, such as aviation and spaceflight, automobile and computer manufacturing, communication, optic instruments and so forth [1,2]. However, low strength and poor ductility have greatly limited the application of magnesium alloys.

Nowadays, the grain refinement of magnesium alloys has become an important research field because mechanical properties can be significantly enhanced by grain refinement. Usually, two different approaches which include chemical stimulation and physical induction [3–6] are used to obtain grain refinement during the solidification process. Chemical refinement is a standard practice for many commercial magnesium alloys. Chemical elements, such as Zr, C and Ca are added as grain refiners into Mg alloys and the addition of these grain refiners can effectively refine grain size, but it also results in many problems associated with formation of foreign particles, hot tearing and drosses [7–9]. In addition, many alloy systems such as Mg–Al alloys do not have an established chemical refiner and alternative approaches to grain refinement need to be established. Vives [10] studied the effects of electromagnetic vibrations induced by the interaction of alternating electric and stationary magnetic fields during the solidification of aluminum alloys and obtained the refinement of microstructure and improvement of surface quality of ingots. Guo et al. [11] has demonstrated that the grain of the Mg alloy billets could be greatly refined by low frequency electromagnetic casting (LFEC). Also, previous studies [12,13] have shown that the grain refinement induced by electromagnetic field was closely related to the electromagnetic forces and the skin effect could result in the sharp reduction of electromagnetic forces, which in turn led to poor effect of grain refinement in the central part of the billets and largely restricted the casting diameter. On the other hand, ultrasonic treatment has been approved to be a simple and effective physical method for solidification control and grain refinement [14,15]. Many studies on ultrasonic treatment of low-melting alloys, aluminum alloys and magnesium alloys have been reported [16–19]. Atamanenko et al. [20] studied the effects of ultrasonic grain refinement of some Zr and Ti containing aluminum alloys and formulated some criteria for efficient grain refinement of aluminum alloys by ultrasonic treatment. They also showed that the grain size would increase with the increase of the ultrasonic treated volume. Eskin [21] investigated the continuous ultrasonic casting (UC) of aluminum alloys and magnesium alloys and indicated that the continuous casting of light alloys with ultrasonic treatment of the melt in molds improved not only the structure of molten metal, but also the surface quality of large ingots. However, as reported by Ma et al. [22], the significant grain refinement induced by ultrasonic treatment occurred exclusively below the radiating face of the sonotrode and the grain size would increase with increased propagation distance of ultrasound. It indicated that the individual application of ultrasonic field would result in different effect of

* Corresponding author. Tel.: +86 24 83683312; fax: +86 24 83681758.
E-mail addresses: rorywen@gmail.com, qichil@mail.neu.edu.com (Q. Le).

0261-3069/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2011.04.035