Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 22(2012) s450−s456
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Microstructure evolution and mechanical properties of AZ80 alloy reheated from as-cast and deformed states

ZHAO Gao-zhan [1], YANG Lin [2], DUAN Xun-xing[2], REN Xiao-hua[2], ZHU Li-min[2], YANG Ting-jun[2], GUO Xiang-yong[2], HAO Shao-nan[2]

1. No.59 Institute of China Ordnance Industry, Chongqing 400039, China;
2. Chongqing Institute of Coal Science Research Institute, Chongqing 400037, China

Received 28 August 2012; accepted 25 October 2012

Abstract: Microstructure evolution and mechanical properties of AZ80 alloy reheated from the as-cast and deformed states were investigated. A new method, cyclic closed-die forging (CCDF), was employed to deformation of AZ80 as a recrystallization and partial melting (RAP) process. During partial remelting, finer, rounder and more homogeneous grains can be obtained from CCDF-formed alloys than from as-cast alloys. Prolonging isothermal holding time from 0 to 40 min, the mean grain size of solid particles in as-cast state decreased initially and then increased, however, that of CCDF-formed alloys increased continuously. The degree of spheroidization was improved in as-cast alloys with prolonging holding time. In contrast, in CCDF-formed alloys, the value of shape factor increased initially and then decreased. Microstructure evolution during remelting is dominated by many factors, for example distortion energy providing recrystallization driving force, Ostwald ripening mechanism, grain coalescence. Compared with the as-cast alloys, the CCDF-formed AZ80 alloy got a significant improvement in tensile properties. YS, UTS and elongation increased by 89%, 45% and 242% respectively. This can be mainly attributed to the grain refinement and elimination of defects.

Key words: AZ80 alloy; recrystallization; partial melting; cyclic closed-die forging; spheroidization; aggregation

1 Introduction

Semi-solid processing was established as a high-volume, near-net shape manufacturing process for components in the trade of mechanism producing, electronic part and aviation [1−3]. Compared with the traditional cast materials, billets formed by semi-solid processing have less segregation and porosity, and therefore have better mechanical properties. Because a globular microstructure of solid is needed and will exert a significant influence on the mechanical properties of products formed by semi-solid processing, the production of semi-solid billets is very important [4−6].

The required globular microstructure can be obtained by a number of routes. Solid-state routes include the strain-induced melt activation (SIMA) process and the recrystallization and partial melting (RAP) process [7]. The SIMA process involves severe hot working producing directional grain structure in the alloy. A critical level of strain must be introduced into the alloy either as an integral part of the hot working, or by cold working as a separate step subsequent to the hot working, prior to heating to above the solidus temperature [8,9]. The RAP route involve working, e.g. extrusion, below the recrystallization temperature followed by reheating to the semi-solid state [10]. LIN et al reported the effect of pre-deformation on the globular grains in AZ91D alloy as a result of the SIMA process. They found that the pre-deformation refined the α-Mg grains in the semi-solid microstructure due to the recrystallization mechanism, and further improved the tensile properties due to the refinement strengthening mechanism [11]. JI et al [12,13] reported the formation process of AZ31B semi-solid microstructures through the SIMA method. They found that increasing the heating temperature could accelerate the spheroidizing process, resulting in semi-solid microstructures containing small spheroidal particles; with a longer holding time in the vicinity of 883−893 K, the solid content slightly changed and the solid particles became irregular in shape.

In this work, a new method called cyclic closed-die forging (CCDF) was employed to deformation of AZ80 magnesium alloy in the RAP route. The microstructure

Corresponding author: ZHAO Gao-zhan; Tel: +86-23-68792232; E-mail: chfzgz@126.com
DOI: 10.1016/S1003-6326(12)61745-2

evolution and mechanical properties of the material reheated for different holding time were investigated, both in the as-cast and deformed states. In addition, the coarsening kinetics under the two states in the semi-solid state was also studied.

2 Experimental

Before experiment, as-cast AZ80 alloy ingots were prepared from outsourcing, with the measured composition (mass fraction) of 8.9% Al, 0.53% Zn and 0.25% Mn. Firstly, CCDF was employed to predeform a portion of as-cast AZ80 ingots, and the principle of the CCDF process is represented schematically in Fig. 1. A billet was first compressed in the vertical direction and then in the horizontal direction. The equivalent strain per operation is given by

$$\varepsilon_e = 2n\frac{\ln(H/W)}{\sqrt{3}} \quad (1)$$

where ε_e is the equivalent strain imposed by the CCDF die configuration, n is the number of CCDF passes, W and H are the width and height of the specimen, respectively [14,15]. Before CCDF, the as-cast AZ80 ingots were machined into a billet with a dimension of 80 mm×80 mm×160 mm. This as-cast billet was held at 380 °C for 40 min and then was processed through the closed die preheated to 380 °C, with a speed of 2 mm/s. Molybdenum disulphide (MoS_2) was used as a lubricant during CCDF. Before each pass, the as-cast billet was heated at 380 °C for 6 min. The billet was processed for 4 passes, and then air cooled to room temperature.

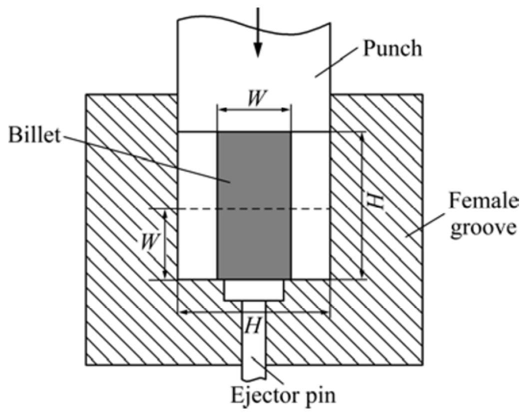

Fig. 1 Schematic of cyclic closed-die forging (CCDF)

The microstructure evolution during partial remelting in the semi-solid state was investigated on as-cast and four-pass CCDF-formed AZ80 cylindrical samples of d8 mm×12 mm, respectively. These samples were heated to semi-solid temperature of 570 °C in a furnace under a protective gas flow (Ar atmosphere), isothermally held and quenched in cold water. The furnace temperature was controlled by a thermocouple placed next to the sample being isothermally held. Samples were heat treated isothermally at 570 °C for 0−40 min.

For the thixoforming, slugs with size of d80 mm× 120 mm were cut from as-cast and CCDF-formed billets. The slugs were rapidly induction heated in the semi-solid region and then thixoformed into a die. The heating of the slug was monitored by using two K-type thermocouples embedded in the slug. The die was preheated to 400 °C and the billets were preheated at 570 °C for 10 min. During thixoforming, the punch speed was about 10 cm/s. The pressure exerted by the punch on the slug was gradually increased to a pre-determined level of 200 MPa and kept for 60 s.

Samples after partial remelting were hot mounted in conductive phenolic resin and prepared for optical microscopy using standard metallographic techniques. The remelted samples from as-cast were etched with 4% HNO_3 aqueous solution and those from CCDF were etched with a solution of 100 mL ethanol, 6 g picric acid, 5 mL acetic acid and 10 mL water. The microstructure of samples was studied and analyzed using optical microscopy. Grain size was measured from the resulting microstructures using an image analysis system [16,17]. Samples for tensile testing were machined from the thixoformed components and were tested using an Instron 5569 testing machine at a crosshead speed of 0.5 mm/min. The tensile samples had a gauge length of 15 mm and a thickness of 2 mm. Each tensile value was the average of at least three measurements.

3 Results and discussion

3.1 Microstructures of as-cast and CCDF-formed AZ80 alloys

Figure 2 shows the microstructures of as-cast and CCDF-formed AZ80 alloys. As shown in Fig. 2(a), the microstructure of as-cast AZ80 alloy consisted of the matrix (α-Mg) and the intermetallic phase (β-$Mg_{17}Al_{12}$). The intermetallic phase was thick, semi-continuous or continuous net-like and mainly distributed at grain boundaries. However, an obvious directional band grains appear in Fig. 2(b) along the deformation direction after being CCDF-formed. The grain boundaries were not clear and the net-like β-$Mg_{17}Al_{12}$ was broken into small particles distributed in the matrix. Obviously, the CCDF-formed grains were unrecrystallized and the materials can therefore be classified as being consistent with the RAP process.

3.2 Microstructures of as-cast and CCDF-formed AZ80 alloys during remelting

Figures 3 and 4 show the microstructures of as-cast