Materials Science and Engineering A 527 (2010) 3975–3983

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

Evaluating high-temperature mechanical behavior of cast Mg–4Zn–*x*Sb magnesium alloys by shear punch testing

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ARTICLE INFO

Article history:
Received 10 February 2010
Received in revised form 25 February 2010
Accepted 1 March 2010

Keywords:
Cast Mg–Zn–Sb alloy
High-temperature shear punch test
Grain refinement

ABSTRACT

High-temperature shear punch test (SPT) was employed to investigate the effects of 0.15, 0.4 and 0.7 wt.% Sb additions on the microstructure and mechanical properties of an as-cast Mg–4%Zn alloy. The shear behavior of the alloys was investigated in temperature range of 25–250 °C. The results showed good reproducibility of the data obtained by the SPT for these cast alloys. The dendritic structure of the base alloy was refined after Sb additions, the effect being more pronounced in Mg–4%Zn–0.4%Sb. This alloy had the highest shear strength among all materials tested, mainly due to the formation of the thermally stable Mg_3Sb_2 second-phase particles. These particles are believed to increase the material's resistance to the applied shear stresses in the deformation zone during deformation SPT of the investigated system. However, when antimony content was increased to 0.7 wt.%, a slight decrease in strength of the alloy was observed, which was attributed to the formation of coarse Mg_3Sb_2 particles.

1. Introduction

Low density, good castability, high specific strength and stiffness, and reasonable cost make magnesium alloys attractive for aerospace and automotive applications. Despite these advantages, poor mechanical properties and lack of a stable microstructure at elevated temperatures are the most important barriers on the way of expansion of these alloys. Mg–Al alloys, such as AZ91, AZ61, and AM60 are the most common types of magnesium alloys which are widely used for their moderate strength at room temperature [1–3]. On the other hand, their mechanical properties at temperatures above 150 °C are poor because of the presence of non-stable $Mg_{17}Al_{12}$ phase [3–5]. Accordingly, attempts have been made to develop new Mg base alloys having structural stability at the high temperatures.

Among many possible choices, alloys based on Mg–Zn system are of particular interest for further improvement as new Mg base alloys, because of their pronounced age hardening response. In order to increase the strength of Mg–Zn alloys, effects of adding several alloying elements have also been investigated. Buha [6–8] has studied the effects of adding trace amounts of different alloying elements on age hardening behavior and precipitation of Mg–Zn-based alloys and observed improved age hardening response by accelerating the kinetics of precipitation and increasing number density of precipitates. However, due to the appreciable costs usually associated with long solutionizing and aging treatments, it is quite desirable to enhance the high-temperature mechanical properties of cast Mg alloys without heat treatment. This can be facilitated by using alloying elements such as Sb, which can produce thermally stable second-phase constituents in the as-cast condition.

According to the Mg–Sb binary phase diagram [9], the solubility of Sb in solid Mg is negligible, and thus the Mg_3Sb_2 intermetallic compound can be readily formed. This is a highly stable phase with a melting point of about 1245 °C, which is expected to enhance mechanical properties at elevated temperatures. It has been reported that [10] adding small amounts of Sb to AZ91 alloy resulted in significant increase in yield strength and creep resistance at elevated temperatures up to 200 °C. This was attributed to the formation of rod-shaped Mg_3Sb_2 particles which strengthen both matrix and grain boundaries effectively. In another study, addition of up to 1 wt.% Sb to ZA84, besides forming Mg_3Sb_2 particles, refined the ternary $Mg_{32}(Al,Zn)_{49}$ compound [11]. Recently, Nayyeri and Mahmudi [12,13] studied the effects of Sb additions on the creep resistance of a cast Mg–5Sn binary alloy. They reported that Sb refined the dendritic structure of the base alloy and decreased the creep rate by forming thermally stable Mg_3Sb_2 second-phase particles.

Shear punch test (SPT) is a minature testing technique, which is based on blanking operation [14] for evaluating mechanical properties. A sheet sample is clamped between two die halves and a flat cylindrical punch is driven through the sample, punching a circular disc from it. By plotting shear stress against normalized displacement, SPT curves are obtained which are similar to those

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0921-5093/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2010.03.007

obtained in uniaxial tension tests. Mechanical properties such as the shear yield stress (SYS), ultimate shear strength (USS), and elongation values can be obtained from the SPT data. There are many reports in the literature indicating that the SPT is an efficient method being capable of producing strength data which are well correlated with those found by the conventional tensile tests [15,16]. Although this method has been primarily employed for testing thin wrought materials, it has also been used for evaluating the strength of a cast AM60 magnesium alloy at room temperature [17]. To the best of authors' knowledge, SPT has not been previously used for evaluating high-temperature mechanical properties of any cast magnesium alloy. It is therefore, the aim of the present work to study the effects of Sb additions on the mechanical properties of a cast Mg–Zn alloy by SPT at both room temperature and elevated temperatures.

2. Experimental

2.1. Materials and processing

The base composition of the studied alloys was Mg–4 wt.%Zn. To investigate the effects of antimony additions on the microstruc-

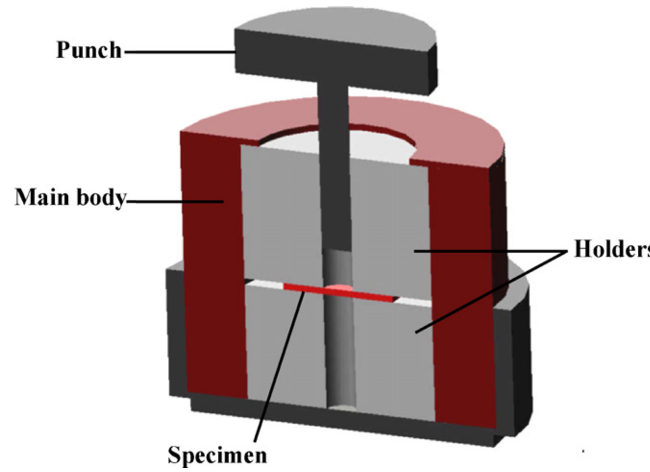

Fig. 1. Schematic representation of shear punch-die assembly.

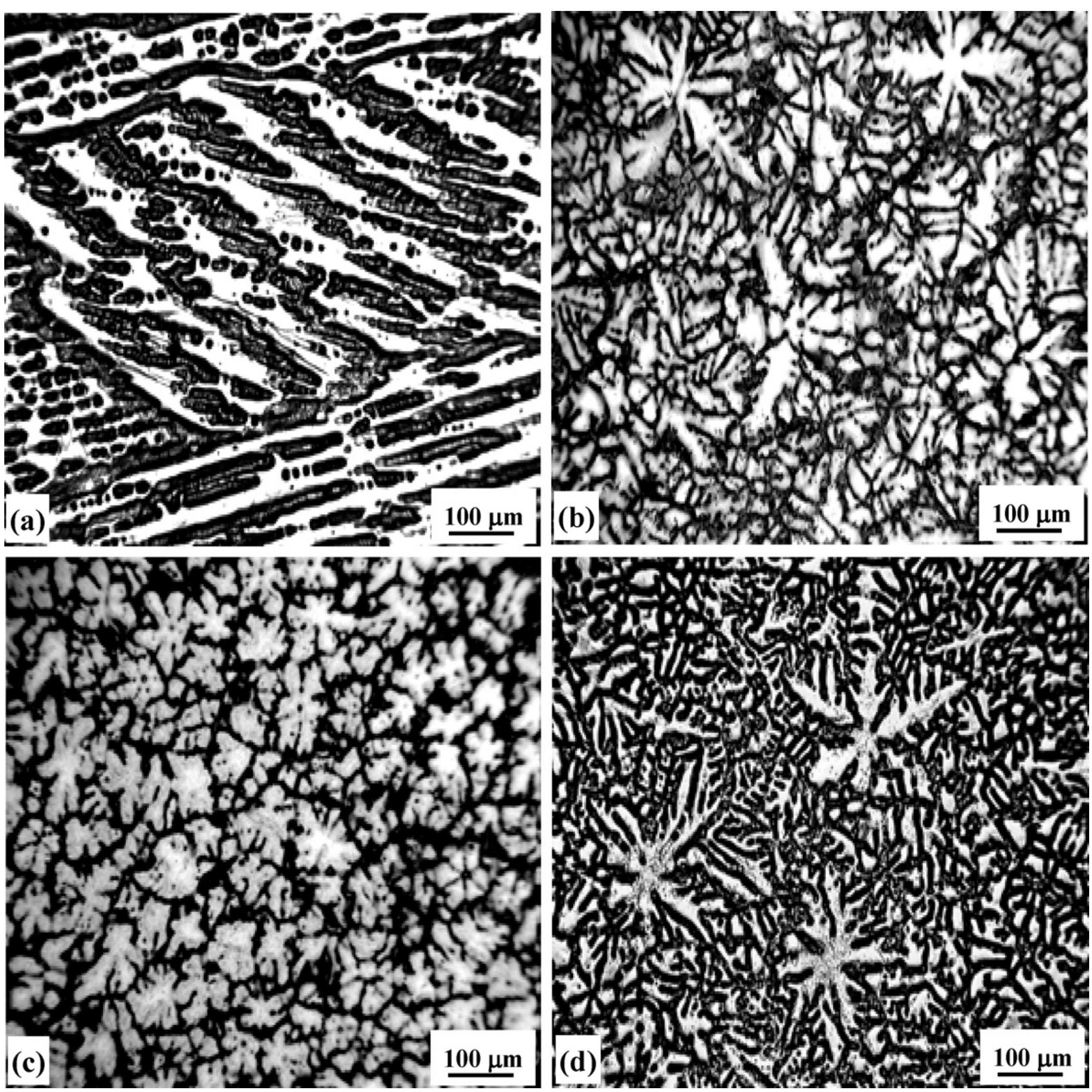

Fig. 2. Optical micrographs of the as-cast alloys: (a) Mg–4Zn, (b) Mg–4Zn–0.15Sb, (c) Mg–4Zn–0.4Sb, and (d) Mg–4Zn–0.7Sb.