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Materials Science and Engineering A 402 (2005) 258–268
MATERIALS SCIENCE & ENGINEERING A
www.elsevier.com/locate/msea

Microhardness mapping and the hardness-yield strength relationship in high-pressure diecast magnesium alloy AZ91

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Received in revised form 7 April 2005; accepted 7 April 2005

Abstract

Microhardness maps of cross-sections of high-pressure diecast test bars of AZ91 have been determined. Specimens with rectangular cross-sections, 1, 2 and 3 mm thick, or with a circular cross-section 6.4 mm in diameter, have been studied. The hardness is generally higher near the edges in all specimens, and more so near the corners of the rectangular specimens. The hardness at the center of the castings is generally lower, due to a coarser solidification microstructure and the concentration of porosity. The evidence confirms that the surface of the castings is harder than the core, but it does not support the concept of a skin with a sharp and definable boundary. This harder layer is irregular in hardness and depth and is not equally hard on opposite sides of the casting. The mean hardness obtained by integrating the microhardness maps over the entire cross-section increased with decreasing thickness of the bars, and was found to be in good correlation with each bar's yield strength.

Keywords: Alloy AZ91; Magnesium diecasting alloys; Microhardness; Yield strength; Skin effect

1. Introduction

1.1. Casting thickness and yield strength

The yield strength[1] [1–4] of high-pressure diecast (hpdc) test bars of magnesium alloy AZ91 decreases monotonically with increasing cross-sectional thickness, as Fig. 1 shows. The casting thickness is a geometrical rather than a physical parameter, but its use as a reference for the strength, as well as for other mechanical properties such as ductility [1–6], of hpdc material, is justified, as the thickness is the single most important factor determining the casting and solidification conditions. As hpdc products of AZ91 alloys are primarily used for thin-walled castings, such as in automobile components and mobile electronics, there is a practical interest in understanding the relationship between casting thickness and strength, which, as shown in the companion paper [7], is not well established. Surprisingly, however, systematic studies of the effect of casting thickness on the strength of hpdc alloy AZ91, or similar alloys, are few.

1.2. The microstructure of high-pressure diecastings

The high solidification rate inherent to the hpdc process gives rise to a unique non-homogenous microstructure in alloy AZ91. Of particular interest is the region adjacent to the casting surface, commonly referred to as the skin [2,3,8–10]. Mechanically removing the outer layer in thin (1 mm) castings produces a marked decrease of the yield strength [3], while similar experiments on thick (10 mm) castings [5] have little effect, and it has been suggested that the presence of the skin accounts for the higher yield strength in the thinner sections [3,6,7]. Weiler et al. [10] reported that the tensile behavior of AM60 alloy diecastings tends to match that of the skin.

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[1] Yield strength and 0.2% proof stress are used as synonyms throughout this paper.

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doi:10.1016/j.msea.2005.04.042

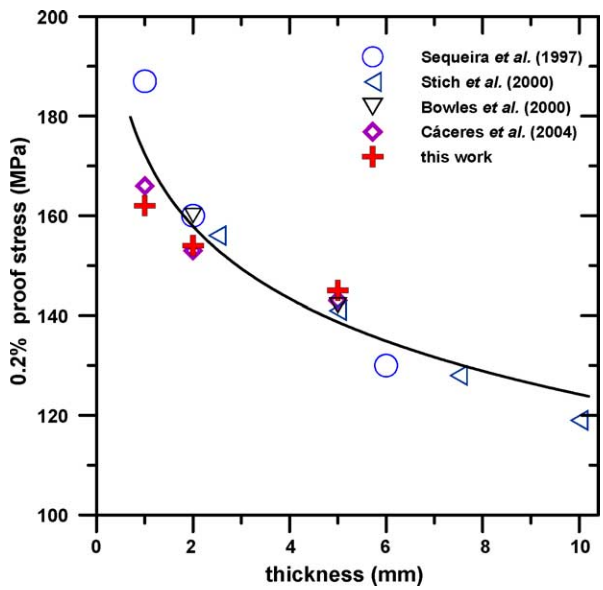

Fig. 1. The yield strength of test specimens as a function of their thickness in high-pressure diecast magnesium alloy AZ91. Data points from Refs. [2,3,7,8].

The central region of the cross-section, or core, is characterised by larger grains of α-Mg phase [4,11] and tends to be softer than the skin. It is generally thought that partial solidification occurs within the shot sleeve [12], and the liquid is inserted into the die cavity with up to 20% solid fraction. These solid particles often segregate to the center of the die cavity [13], especially in simple shapes, although this is not always the case [12]. Hence, the formation of these larger grains is independent of the cooling rates in the die cavity.

Regions of concentrated porosity are also characteristic of hpdc material. These vary in size and location, depending on the casting conditions and on the shape of the casting. They often exist close to the surface in thin castings, and deeper in the center of thicker ones. They may appear as bands or closed loops, or they can be densely scattered without much pattern [7,14].

1.3. Methods for identification of the skin

A skin seems to be a common microstructural characteristic of hpdc material, although a universally agreed definition is lacking. Existing definitions used in a number of previous studies are mostly based on microhardness measurements, but they tend to be mutually inconsistent. For instance, Sequeira et al. [3] have defined it for AZ91 as the depth at which the hardness value across the thickness is above 82 Hv. Hence, they found that the skin relative depth decreases with increasing casting thickness. In other instances, the skin has been defined as the region outside the porosity band [4], which results in an opposite conclusion, with skin depth increasing in thicker samples. While this definition is attractive, being based on an obvious microstructural feature, in practice, it can be ambiguous since castings of equal thickness can have varying porosity patterns or none at all. Thus, the very idea of a discrete skin with a definable boundary may be misleading [4].

On closer examination, it is evident that only limited attempts have been made to map the hardness values across the cross-section of bars of different thickness. In fact, the hardness profiles that have been reported to date have been limited to several line transverses through the middle of the specimen's cross-sections, while it seems obvious that as the thickness of the casting decreases, the regions closer to the corners become increasingly important. These need to be explored in detail if an accurate description of the skin is to be produced.

The objective of this study was to determine the hardness profiles of the entire cross-section of specimens of hpdc alloy AZ91 of different thickness and shape. It was hoped that by mapping the hardness across the full cross-section, a spatially accurate definition of the skin would be produced. This, in turn, would provide some more insight into the relationships between yield strength, hardness, microstructure and casting thickness discussed in the companion paper [7].

2. Experimental methods

2.1. Materials

Commercial AZ91D alloy was used for the experiments. The alloy was cast to shape as tensile specimens using a 250 t Toshiba cold chamber diecasting machine. The rectangular cross-section specimens had a 50 mm gauge length, 10 mm width, and 1, 2, or 5 mm thickness. Cylindrical samples were also cast with a diameter of 6.4 mm. All materials were tested in the as-cast condition.

2.2. Tensile testing

Uniaxial tensile tests were carried out on a hard-beam testing machine fitted with hydraulic grips, at a crosshead speed of 2 mm/min, with a 50 mm knife-edge extensometer attached. Digital files were stored for each test for later analysis.

2.3. Hardness testing

Vickers macrohardness tests at 10 kgf load were performed at five evenly spaced locations along the gauge length of six undeformed specimens for each thickness. Four of these specimens were then tensile tested, while the remaining two were sectioned into 10 mm long bars using a low-speed diamond disk saw. The cross-sections of these bars were polished to 1 μm for microhardness testing and metallographic examination.