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The development of the skin in HPDC Mg–Al alloys

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ABSTRACT

Cross sectional microhardness mappings were produced for cast-to-shape tensile specimens of seven high pressure die cast binary Mg–Al alloys, with Al content ranging from 0.47 to 11.6 mass%. A softer, well differentiated core region, became apparent as a result of the presence of large externally solidified grains (ESGs) only for concentrations above about 4 mass% Al. For these alloys the skin layer was increasingly patchy and uneven in both hardness and depth as the Al concentration increased. SEM observations showed that the ESGs are stochastically distributed near the surface in the more concentrated alloys, unlike for the leaner ones in which they are segregated preferentially to the core region. The lack of ESGs on the skin layer of the leaner alloys stems from their less permeable mushy zone during solidification.

1. Introduction

Due to partial solidification of the melt in the shot sleeve of cold chamber high pressure die cast (HPDC) process of Mg alloys [1,2], the liquid is inserted into the die cavity with up to 20% solid fraction of externally solidified grains (ESGs). The ESGs are relatively large grains which migrate to the center of the die cavity [3] driven by shear flow effects, especially when the geometry of the cross section is simple [2,4–6]. The segregation of ESGs towards the center also ensures that the volume fraction of eutectic is greater near the surface [7]. The overall result is two well differentiated regions on the casting cross section [8–13]: a surface layer with a fine grain microstructure and higher integrity and hardness, normally referred to as the skin, and a coarser grain microstructure region, weaker and with lower integrity, or core. The coexistence of two regions of different strength on the casting cross section entails a strong mutual interaction during plastic yielding, with the harder skin imposing an elastic constraint on the softer core which delays the onset of full plasticity on the latter [14,15].

A recent study of alloys with similar eutectic fractions but widely different solidification behaviors showed that the grain microstructures of the skin and core are largely determined by the solidification dynamics of the particular alloy system [6]. When the solidification entails a wide, more permeable mushy zone separating liquid and solid, the differentiation between skin and core is less marked, and the skin is less uniform, than when the mushy zone is narrow and less permeable. It can be anticipated that in an alloy system such as the Mg–Al in which the solute is very soluble, many of these effects should appear.

The present study is thus aimed at describing the grain microstructure of the skin and core regions of a range of binary HPDC Mg–Al alloys. Microhardness mappings covering the entire cross section of cast-to-shape tensile specimens, similar to those used in earlier work by the present authors [6,14–17] were used to characterize the local strength of the skin and core. Calculations based on the Scheil–Gulliver equation [18] were used to relate the details of the grain microstructures of the skin and core to the solidification dynamics of each alloy. For simplicity, the present work is based on cylindrical specimens, whereas a companion paper [19] discussing the yielding behavior of the same alloys is based on rectangular specimens. The conclusions of both studies are valid for either geometry.

2. Materials and experimental details

Seven binary alloys, with Al contents given in Table 1, were cast using a 250 T cold chamber HPDC press. More details about the casting parameters can be found in ref. [13].

The study was carried out using cast-to-shape cylindrical cross section, dog-bone shaped tensile specimens of gauge length dimensions diameter 5.75 mm and length 30 mm.

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Table 1
Mg–Al alloys composition as measured by atomic emission spectroscopy (ICP-AES).

Alloy	1	2	3	4	5	6	7
Al (mass%)	0.47	0.93	1.82	4.37	5.51	8.77	11.6

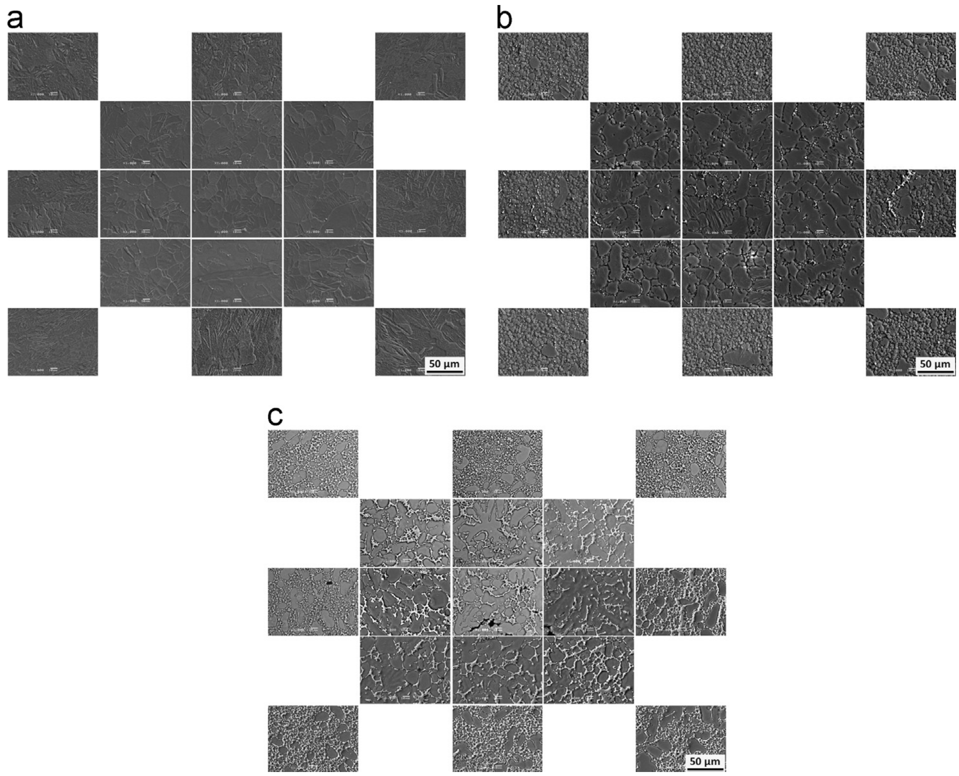

Fig. 1. Solidification microstructures at different locations of the cross section for (a) Mg-–0.47 mass% Al alloy, (b) Mg-4.37 mass% and (c) Mg–11.6 mass% Al alloy.

Cross sectional samples were cut from the gauge length of undeformed specimens and polished down to 0.05 μm colloidal silica for hardness measurements. Samples for SEM observation were also etched with glycol for 15 s.

The microhardness was mapped using an automated Vickers microhardness tester, with a load of 50 gmf and a dwell time of 12 s. According to the ASTM E384-07 standard, at least 2.5 times the indentation diagonal (predetermined to be around 40 μm) must separate adjacent indentations or away from the casting surface, therefore a minimum distance of 100 μm was set near the casting surface. At the core (~1050 μm away from the surface) the spacing was increased to 150 μm. Microhardness maps were then created using a commercial software package (Surfer).

The microstructural analysis was made on the same specimens used for microhardness mapping; care was taken to ensure that the surface used for microscopy was adjacent to the one used for mapping. The gauge length of one of the most concentrated alloy specimens was sectioned in three separate locations and each section microhardness-mapped to assess the consistency of the results. Only minor differences were observed.

3. Results

3.1. Microstructure

Fig. 1 illustrates the effect of changing the Al content on the grain and eutectic microstructure. A uniform microstructure over the entire cross section consisting of primary α (Mg) grains was observed in the dilute alloys (Fig. 1a, Mg–0.47 mass% Al), whereas for the concentrated ones (Fig. 1b and c, Mg-4.37 and Mg–11.6 mass% Al) near the surface a fine in-die solidified primary α (Mg) grain microstructure prevailed, although with the scattered presence of ESGs. At the core the ESGs predominated. The grain microstructures for rectangular cross section specimens of the same alloys have been published elsewhere [14,15,19]. The solute effects on the microstructure of the skin and core were generally similar for both geometries (flat or cylindrical), although due to the radial symmetry of the solidification process the skin appeared better defined in the round specimens.

The number of ESGs scattered near the casting surface is manifestly larger in the 11.6 mass% Al alloy (Fig. 1c) than in the 4.37 mass% Al alloy (Fig. 1b). A comparison of the grain microstructures of all of the alloys using sets of images like those of Fig. 1 showed a monotonic increase in the number of ESGs at the skin region for solute concentrations above 4 mass%. Save for minor details related to the symmetry, the same was observed in the rectangular specimens (see ref. [15]).

3.2. Microhardness mapping

Fig. 2a–g shows microhardness maps of specimens of the alloys studied. For Al contents of less than 2 mass% (Fig. 2a–c), the hardness map was relatively smooth over the entire cross section, save for a few points of relatively low hardness values associated with localized microporosity. The relative differentiation between