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Materials Science and Engineering A 423 (2006) 313–323

MATERIALS SCIENCE & ENGINEERING A

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Acoustic visualization of cold flakes and crack propagation in aluminum alloy die-cast plate

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Received 24 August 2005; received in revised form 23 January 2006; accepted 17 February 2006

Abstract

Acoustic images received at different depths of aluminum alloy (ADC12) die-cast plates containing coarse cold flakes were compared with microstructures at the same depth. The bright and dark regions in the acoustic images coincided with the oxide layer on the initially solidified surface of the cold flake and the body of the cold flake, respectively. These results show the ability of nondestructive detection of cold flakes by the ultrasonic microscopy. The specimens were then fabricated to contain the cold flake at a center, and subjected to three-point bending test. When the coarse cold flake existed apart from the tensile side surface of the specimen, a crack initiated at a small cold flake on the side surface and propagated in the specimen. In this case the bending strength was almost the same as the tensile strength (285 MPa) of the die-cast plate. When the cold flake existed on the tensile side surface or at a position less than 0.5 mm inside the surface, the crack propagated along the oxide layer of the cold flake. In this case, the bending strength decreased from the tensile strength when the cold flake approached the side surface. A relation between the bending strength and the position of the cold flake in the specimen was discussed from the standpoint of the fracture mechanics.

Keywords: Acoustic microscopy; Cold flake; Aluminum alloy; Die-castings; Bending strength; Critical stress intensity factor

1. Introduction

Following increasing application for aluminum alloy die-cast products, many studies have been carried out on their mechanical properties, and it has been reported that the mechanical properties were largely influenced by casting defects, such as irregular structures [1–5], porosities [6], and so on. It has been mentioned that the tensile strength [7] and the fatigue strength [8,9] of die-casts decreased with the increase in the amount of porosities. The irregularities in the structure also affect their mechanical properties, and among irregular structures, cold flakes largely reduce the mechanical properties of the die-castings [10,11]. Cold flakes are included in products during injection process of the cold chamber high-pressure die casting as follows. After the molten metal is poured into the cylinder, it rapidly cools down to the solidification temperature on the cylinder wall and is injected into a die cavity. When the plunger tip runs through the shot sleeve, solidified layers on the inner wall of the sleeve are peeled off and mixed into the flowing liquid. The solid layers are disintegrated and transmitted into the die cavity to form cold flakes in the die-castings. Since the cold flake contains the oxide layer of poor cohesive bonding with the surrounding matrix and these oxide layers are often contaminated by lubricant and stuck by fine porosities [12,13], the cold flakes reduces the mechanical properties of the die-castings.

To assure reliability of die-cast products, it is vital to detect irregular structures, especially the cold flake, for which the nondestructive evaluation plays a very important role. The authors [14] carried out the ultrasonic measurement for aluminum alloy (ADC12) die-cast plates containing cold flakes and showed that the cold flake can be detected nondestructively. Moreover to improve the reliability of die-cast products, it is necessary to specify size and position of the cold flake.

In the present work, the acoustic microscopy was carried out with aluminum alloy die-cast plates (ADC12) containing cold flakes to examine detectability of cold flakes. Furthermore, it was postulated if a position of the cold flake is known, the cold flake can be arranged at a required position with a required orientation

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0921-5093/$ – see front matter
doi:10.1016/j.msea.2006.02.042

in the specimen to examine the influence of the position and the orientation of the cold flake on the mechanical properties of die-cast plates.

Concerning the influence of inclusions on the mechanical properties of materials, researches have been carried out from the standpoint of the fracture mechanics. Murakami et al. [15–17] examined the effect of nonmetallic inclusions on the fatigue strength of the high strength steel, and showed that the area, the position and the shape of the inclusion influenced the threshold stress intensity factor range ΔK_{th} and the fatigue limit in high strength steels. Mayer et al. [9] examined the effect of porosities (voids and shrinkage) on the fatigue property of die-cast magnesium and aluminum alloys and showed if the porosity was equivalent to an initial crack, the fatigue limit was correlated to the critical stress intensity amplitude (ΔK_{cr}). Skallerud et al. [18] examined effects of shrinkage cavities and gas pores on fatigue properties of aluminum alloys, and showed shrinkage cavities significantly reduced the lifetime of the cylindrical aluminum specimen, and if the pore diameter was larger than 0.2 mm, a typical fatigue crack initiated around pores on or near the specimen surface.

We have taken the initiative in showing the importance of cold flake size and position to control the mechanical properties. Therefore, specimens were fabricated to contain the cold flake at different locations, and subjected to a three-point bending test under acoustic microscopy to observe initiation and propagation of a crack in the specimen. Then a relation between the bending strength and the position of the cold flake was discussed from the standpoint of the fracture mechanics.

2. Experimental procedure

2.1. Preparation of materials

In the present study, aluminum alloy (ADC12, a nominal composition of Al–11 mass% Si–2.5 mass% Cu) die-cast plates of two different geometries (plates-A: 6.8 mm thickness, 174 mm length and 50 mm width, and plates-B: 4.0 mm thickness, 300 mm length and 100 mm width) were used. The plate-A was used in the experiment for detection of cold flakes after separating it into three-square plates as shown in Fig. 1. The plate-B

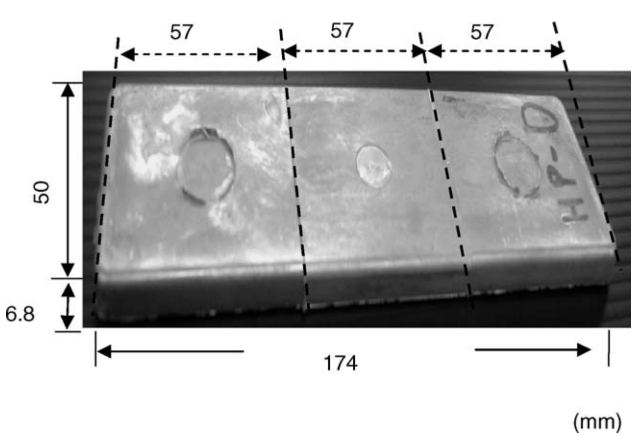

Fig. 1. Die-cast plate of aluminum alloy for detection of cold flake.

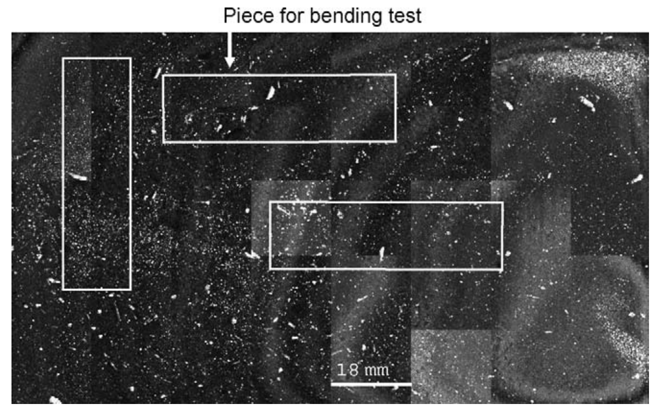

Fig. 2. Preparation of pieces for bending test. Bright regions like nebula are from coarse cold flakes.

was used in the bending test after detection of cold flakes in the required position. The casting procedure was carried out with wider gates after longer shot time lags to contain greater cold flakes of some millimeter in size.

2.2. Acoustic microscopy and ultrasonic measurement

The acoustic microscopy was carried out with the scanning acoustic microscope (SAM, by Hitachi Kenki Co. Ltd) by using a probe generating a longitudinal wave of 50 MHz in frequency and focal distance of 12 mm in water.

For detection of cold flakes, acoustic images were taken at positions 0.5–2 mm below the surface of the plate-A at an interval of 0.1 mm in an area of 9.9 mm × 9.9 mm with a pitch of 16.5 μm. Consecutive images were taken and then combined to obtain an image of 40 mm × 40 mm covering almost the cross-section of the specimen. Before bending test of the plate-B, acoustic images were taken at positions 0.5–2 mm below the surface at an interval of 0.5 mm in an area of 9.9 mm × 9.9 mm with a pitch of 16.5 μm, and combined to obtain an image of 140 mm × 90 mm covering almost the cross-section of the specimen. The acoustic images were also taken from the reverse surface of the plate-B to obtain images at positions 0.5–3.5 mm below the obverse surface.

For comparison, the ultrasonic measurement was also carried out on some specimens with the immersion method. In the mea-

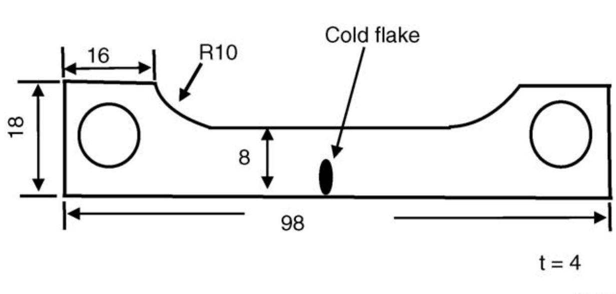

Fig. 3. Shape and dimensions of specimen for bending test having a cold flake at a center.