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Fatigue behavior and life prediction of cast magnesium alloys

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ABSTRACT

Fatigue behavior of magnesium castings has been investigated with NZK (Mg–Nd–Zn–Zr) alloys and other magnesium alloys including AZ91D, GW103, and AM-SC. Multi-scale fatigue (MSF) life models have been adapted to estimate fatigue lives of the magnesium castings studied. Results indicate that fatigue failure of magnesium alloys with few casting defects is dominated by crack initiation first within a grain close to the free surface and then propagation in trans-granular mode through either twin grain boundaries in the T4 heat treatment condition or from persistent slip bands in the T6/T7-treated condition. The fatigue life of cast magnesium alloys can be well predicted using multi-scale fatigue (MSF) models together with characteristic microstructure constituent – grain sizes.

1. Introduction

Magnesium alloy castings are increasingly used in cyclically-loaded structural applications for light weighting and better performance [1–10]. The increasing use of cast magnesium components under cyclic loading has drawn considerable interest in their fatigue performance. Fatigue properties of cast magnesium components strongly depend on the population of casting defects and the characteristics of microstructural constituents [11–17]. This has been clearly demonstrated in as-cast Mg–Zn–Y–Zr [16] and AZ91-T4 [17] Mg alloys. During cyclic loading, casting defects serve as stress concentration sites for fatigue crack initiation. Like aluminum castings, fatigue life of cast magnesium alloys is determined by the maximum defect size [12,15–17]. In the absence of casting defects or when the casting defect is smaller than a critical size [13,14], the fatigue properties of cast magnesium alloys strongly depend on the characteristic microstructure constituents including grain size, second-phase particles, and nano-scale precipitates, which are determined by their composition, casting and heat treatment conditions [18–23]. It has been reported that magnesium casting alloys like NZK (Mg–Nd–Zn–Zr) alloys show a clearly linear H–P relationship between rotating bending fatigue strength and grain size [22]. The NZ30K (Mg–3Nd–0.2Zn–1Zr) alloy also shows a significant fatigue response to heat treatment, particularly age hardening. Compared with the as-cast alloy, the peak-aged (T6-PA: 14 h at 200 °C) alloy shows about 17–25% increase in fatigue strength [21,22]. In NZK alloys, neodymium (Nd) is an effective element to improve the fatigue properties [23].

Because of the complexity of microstructural constituents in cast magnesium alloys, it has long been a challenge to estimate the fatigue life of defect-free magnesium castings, particularly when the variation in microstructural constituent size and distribution is considered. This paper is aimed to first review the fatigue behavior of magnesium alloys with few casting defects and then to adapt multi-scale fatigue (MSF) models originally developed for cast aluminum alloys [24] to predict the fatigue lives of various magnesium alloys.

2. Fatigue failure in defect-free magnesium alloys

2.1. Crack initiation

Generally, fatigue cracks always initiate at the locations of the maximum local stress and the minimum local strength [24]. Local yielding in sample surfaces is inevitable because the sample surfaces experience the maximum alternate tensile and compressive stress during rotating bending fatigue [22]. In addition, surface grains are the weakest and they deform plastically at the lowest stress leading to the formation microcracks within a grain. Therefore, in the absence of casting defects or when the casting defect is smaller than a critical size, fatigue cracks of magnesium

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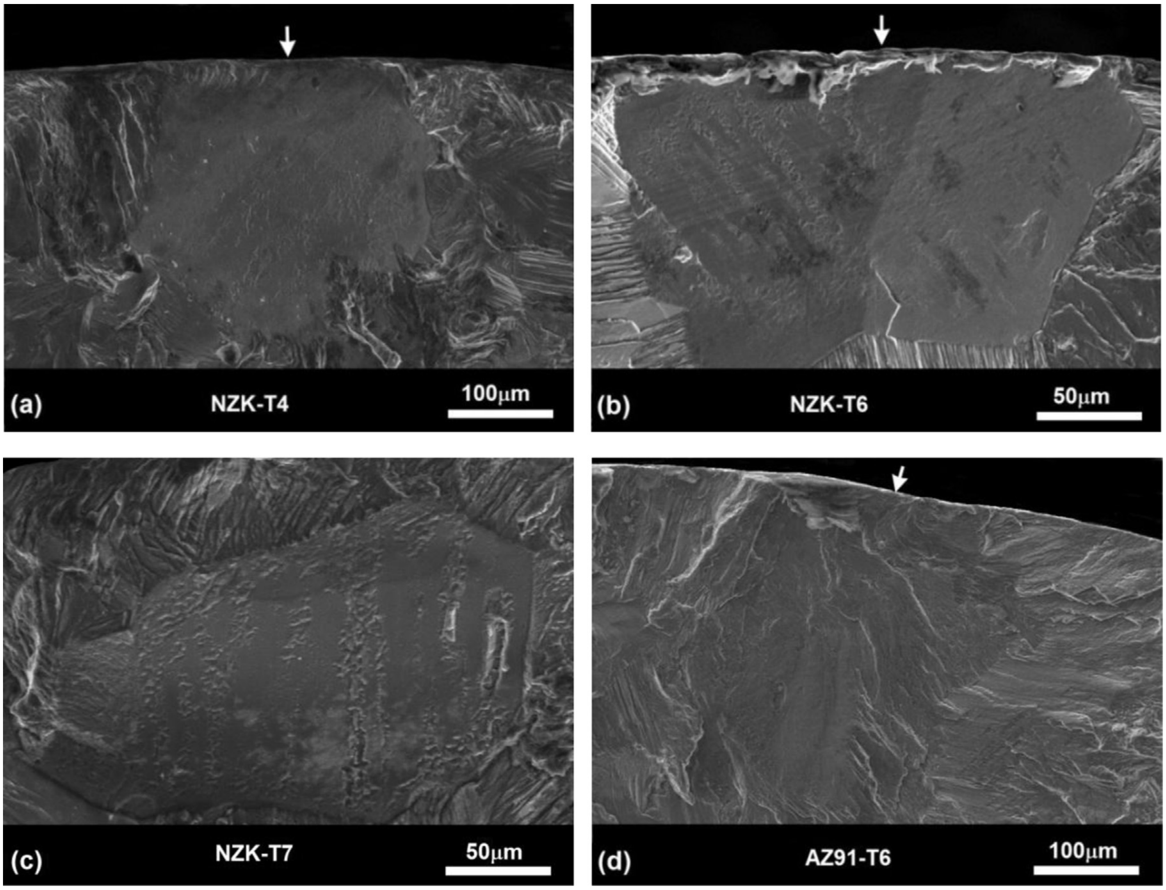

Fig. 1. Fatigue crack was initiated from twin grain boundaries in (a) cast NZK-T4 alloy and persistent slip bands in (b) NZK-T6 alloy, (c) NZK-T7 alloy and (d) AZ91-T6 alloy. The fatigue test is the rotating bending test (RB). Image was taken using secondary electron imaging [SEI].

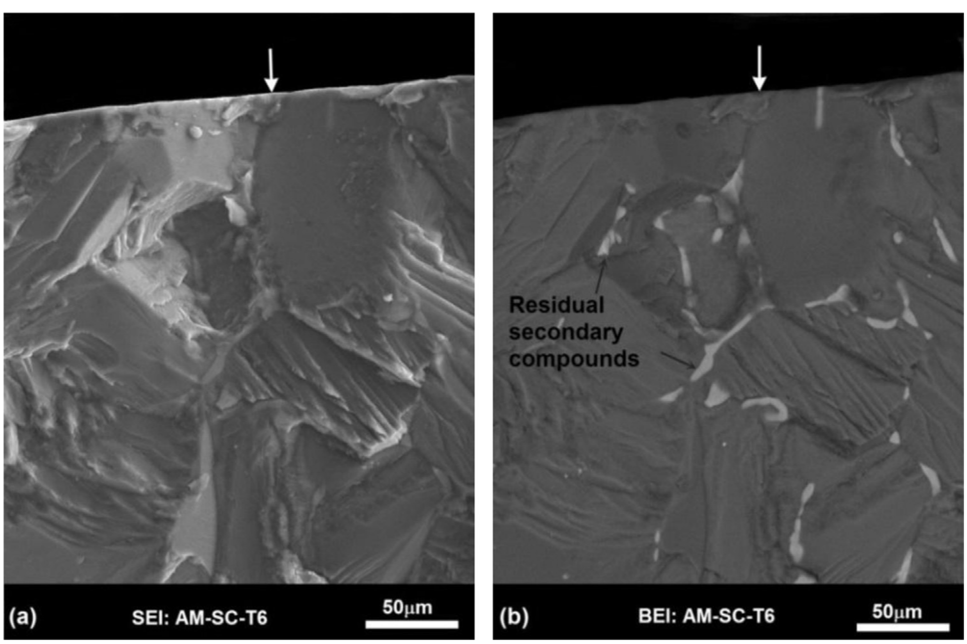

Fig. 2. Fatigue crack was initiated from persistent slip bands in AM-SC-T6 alloy [19]. The fatigue test is the rotating bending test (RB). Images were taken using (a) SEI and (b) backscattered electron imaging [BEI].

alloys mainly originate from the sample free surface or subsurface (as show in Figs. 1 and 2). The crack nucleation sites for the alloys show that the fatigue crack initiates at the isolated facet of the cleavage plane. The large facet that initiates fatigue crack is on the order of the grain size in T4- (540 °C × 10 h) and T6/T7-treated (540 °C × 10 h + 200 °C × 14 h / 250 °C × 10 h) NZK alloys, indicating that fatigue failure originates mainly from local shearing near the specimen-free surfaces. For cast magnesium alloys, it is commonly accepted that both {0001} < 11–20 > basal slip and < 10–12 > twinning are two main deformation systems at room