Research Programs

Porosity and Fatigue Performance Interactions in Aluminum Cast Alloys

Research Team:

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Cast aluminum alloys are seeing increasing uses in the automotive industry due to their excellent castability, corrosion resistance, and especially their high strength to weight ratio. The increasing use of high integrity shaped cast aluminum components under repeated cyclic loading, has focused considerable interest on the fatigue properties of cast Al-Si alloys.

Fatigue properties of cast aluminum components strongly depend on casting defects and microstructural characteristics. However, there are differing opinions as to which are the critical microstructural characteristics. For example, some experimental data support the view that fatigue resistance, as with tensile ductility, is improved by refining the dendrite arm spacing and the size of the eutectic silicon particles. However, the deleterious effect of casting defects has also been recognized. Liquid aluminum is prone to hydrogen adsorption and to oxidation; gas porosity and oxide inclusions are inevitably found in aluminum castings. In addition, if the casting is not properly fed, shrinkage porosity results, which is also quite deleterious to fatigue properties. Gas pores are, typically, spherical, whereas shrinkage pores have an irregular three-dimensional shape. Both of these types of pores can also be associated with aluminum oxide films.

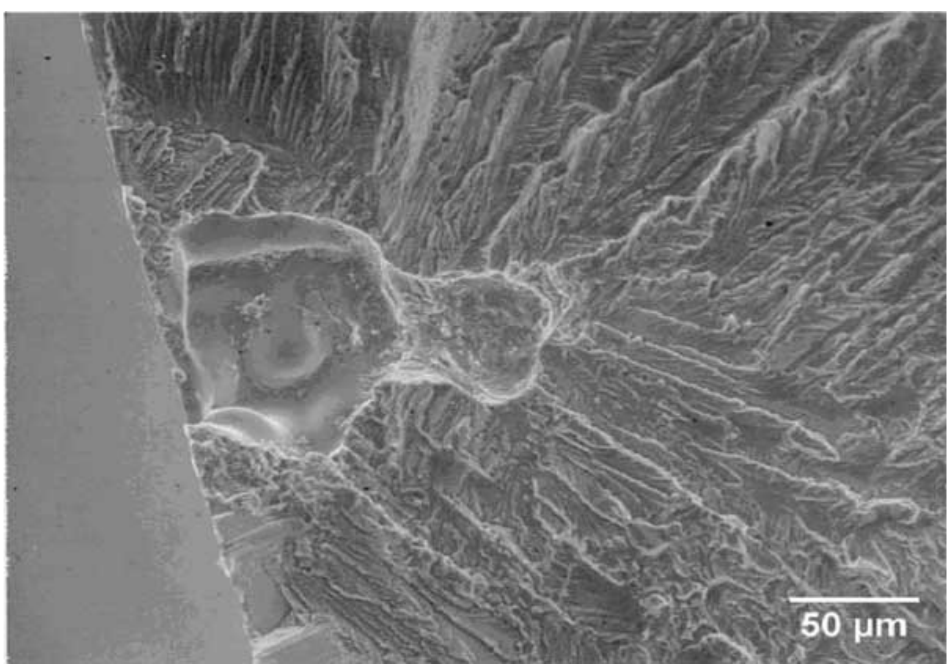
A quantitative method for predicting the relation between fatigue life and defect size has only recently been developed; however, it is still not possible to fully account for the effects of pore shape and defect type on fatigue life. A comprehensive understanding based on experimental data does not exist. In practice, a certain amount of porosity can be tolerated in castings; however, this varies with the application. It is important to identify the specific contributory roles of defects and other microstructural parameters on fatigue life. Furthermore, a quantitative understanding of the role of defects is crucial to establishing defect acceptance standards for both design specifications as well as for quality control purposes.

In order to achieve these objectives, an experimental investigation was carried out with one of the most commonly used aluminum casting alloys, A356. The study examined the influence of casting defects (porosity and oxide films) and secondary dendrite arm spacing (SDAS), on the resultant fatigue performance under different stress conditions. The cast alloy was chemically modified with strontium to isolate the effects of eutectic particle size and morphology. To examine the existence of critical defect (pore/oxide) size for fatigue crack initiation, test castings with various degrees of porosity and oxide films were prepared by controlling the hydrogen level in the melt and mold fill. The fatigue lives of castings with different size pores and oxide films were then compared with HIP-ed samples, in which the pores were eliminated.

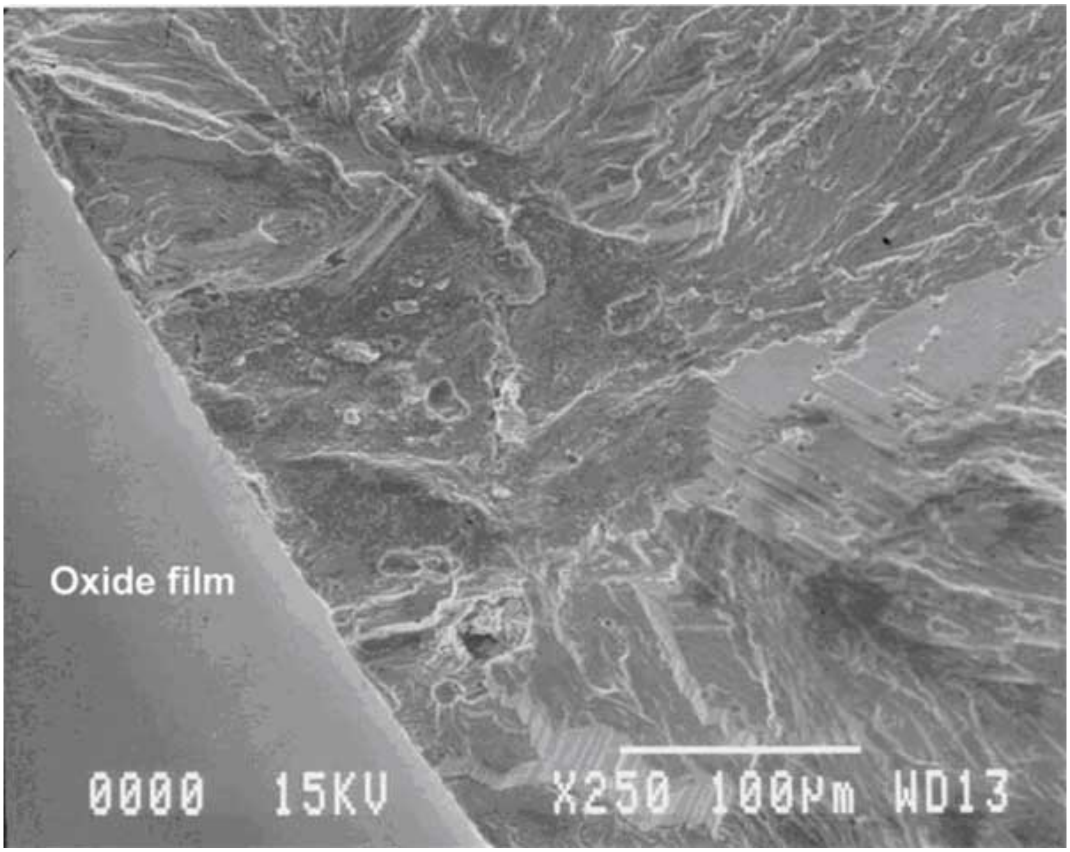
In addition, test castings were made from clean and well-degassed melts, and HIP-ed before machining to ensure porosity-free specimens. A permanent wedge mold and an end-chill sand mold were employed to get a range of solidification rates and thus a variety of SDAS values. To study the influence of aluminum dendrites on fatigue, the alloy was Sr modified to obtain a constant eutectic particle size and morphology over a range of SDAS values.

Based on the experimental results, the following conclusions can be drawn.

1. Casting defects have a detrimental effect on fatigue life by shortening not only fatigue crack propagation but also the initiation period. The decrease in fatigue life is directly correlated to the increase of defect size.
2. Castings with defects show at least an order of magnitude lower fatigue life compared to defect-free materials. Porosity is more detrimental to fatigue life than oxide films.
3. There exists a critical defect size for fatigue crack initiation, below which fatigue crack initiates from other competing initiators such as eutectic particles and slip bands. In Sr modified cast A356 alloy, the critical defect size is in the range of 25 to 50 m.
4. A two-parameter Weibull model describes well fatigue life data and performance of A356 alloys with or without casting defects.
5. A simple long crack LEFM model can give satisfactory predictions of fatigue life of castings containing defects.
6. In the absence of casting defects, the fatigue life of A356/357 castings is a function of microstructural fineness (SDAS), composition, eutectic modification, and heat treatment.
7. In unmodified alloys, fatigue life decreases with increasing SDAS in both finer (SDAS<40μm) and coarser (SDAS>60μm) structures; while in microstructures with intermediate SDAS values (SDAS: 40~60μm), the fatigue life seems constant with SDAS.
8. In Sr-modified material having fine microstructures (SDAS<60μm), fatigue life decreases with increasing SDAS values, while in coarser microstructures (SDAS>60μm), fatigue life increases with increasing SDAS values.
9. Sr-modified alloys show longer fatigue lives compared to unmodified alloys.
10. Increasing Mg content from 0.4% to 0.7% significantly decreases fatigue life in both unmodified and Sr-modified alloys.
11. Increasing Fe content decreases fatigue life particularly for alloys with large SDAS values.
12. Alloys having low yield strength values present short fatigue lives. An adequate solution treatment time, such as 12 hrs (for a T6), is beneficial due to the dissolution and segmentation of the large Fe-particles.



(a)



(b)

Figure 1. SEM micrographs showing different defects originating fatigue cracks in the Sr-modified A356 castings (a) pores (b) oxide films.

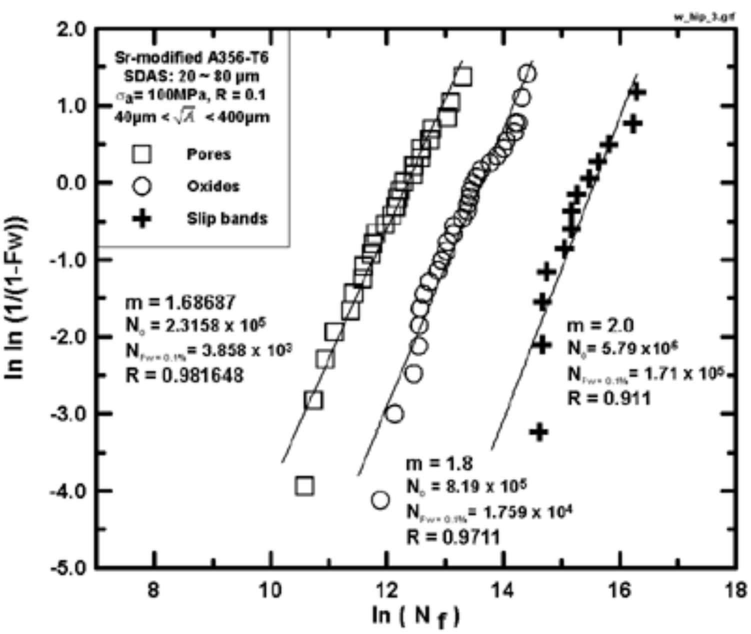
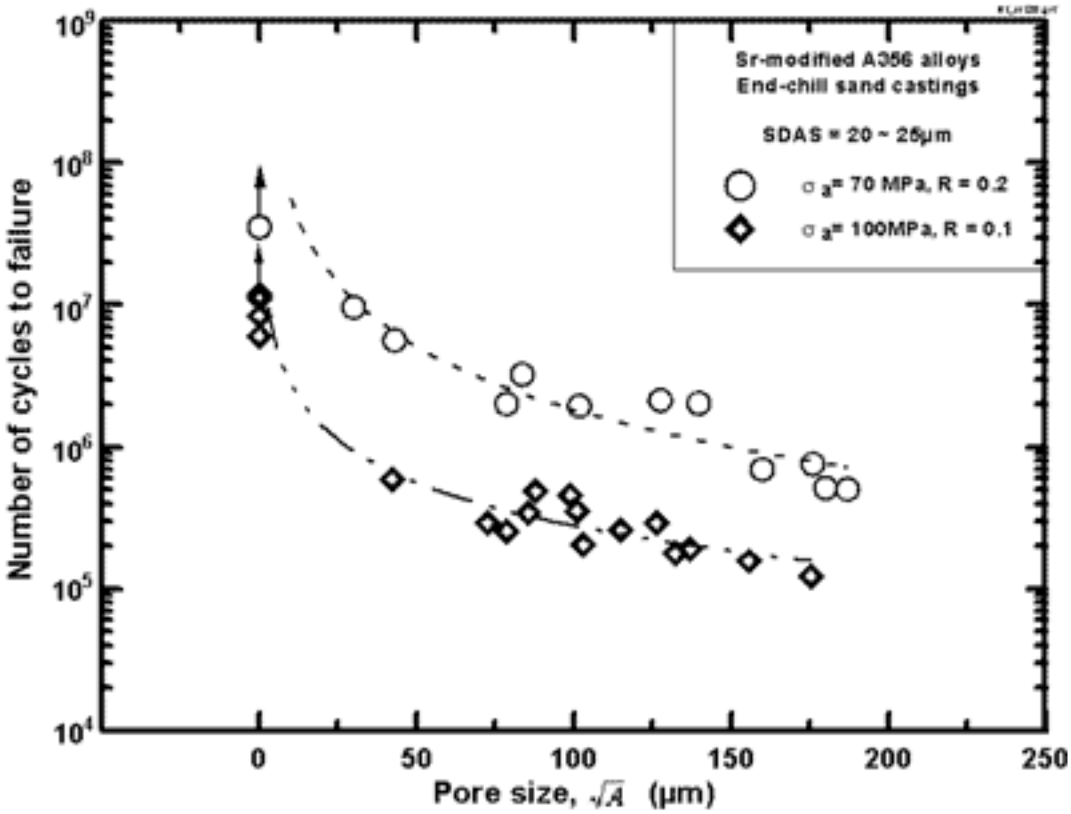
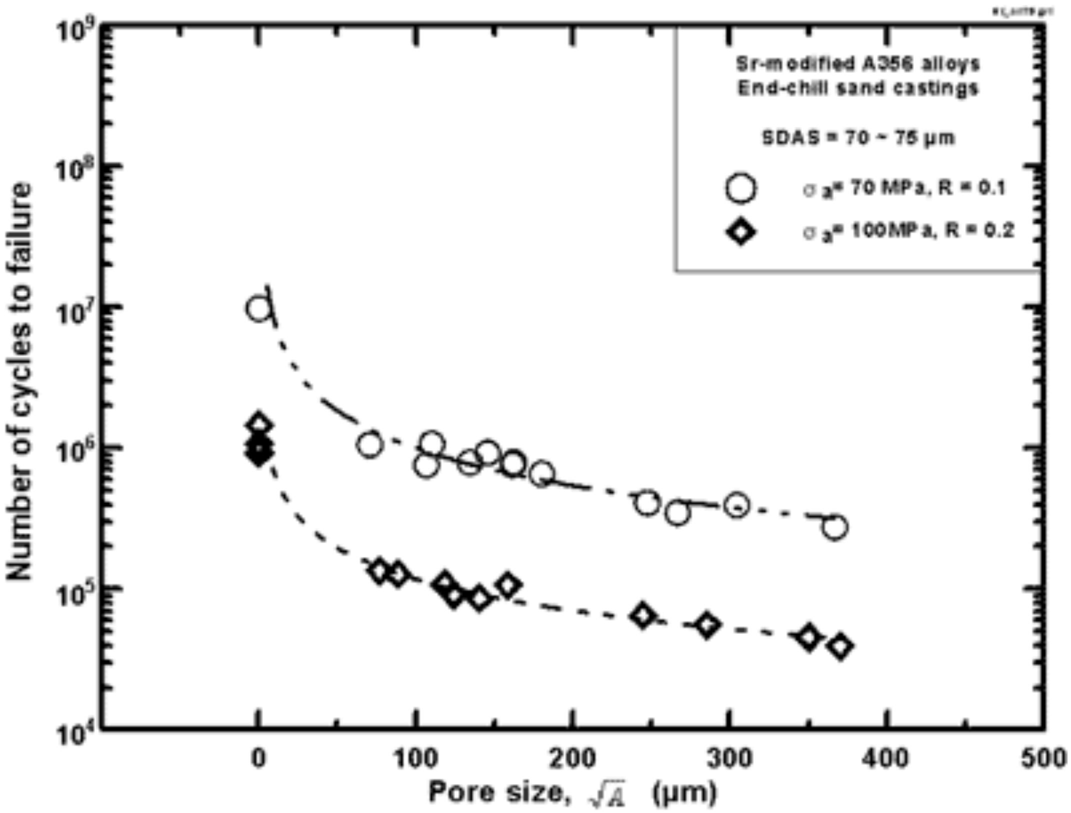


Figure 2. Two-parameter Weibull plot for fatigue life data of the Sr-modified A356 casting alloy containing a variety of defects.



(a)



(b)

Figure 3. Fatigue life of a Sr-modified A356-T6 alloy as a function of pore size; (a) SDAS: 20~25 μm, (b) SDAS: 70~75 μm.

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- Q. G. Wang, D. Apelian, D. A. Lados, "Fatigue Behavior of A356-T6 Aluminum Cast Alloys: Effect of Casting Defects - Part I", J. of Light Metals, Vol. 1, No. 1, pp. 73-84 (2001).
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