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MONITORING FATIGUE DAMAGE IN HYPOEUTECTIC AL-SI CASTINGS WITH VARYING MICROSTRUCTURE CHARACTERISTICS

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Abstract

Due to their low density, good recyclability and producibility of complex net shapes, cast aluminium alloys are promising candidates for many demanding applications in mobility, power generation and machinery. The inherent microstructure inhomogeneity is the most striking challenge in placing cast Al alloys in cyclically loaded components. Therefore, obtaining a quantitative understanding of the correlation between casting process, microstructure parameters and fatigue properties (fatigue limit, fracture mechanical data) is the aim of the present study.

1. Introduction

Cast aluminum alloys are increasingly used for structural lightweight applications in automotive engineering. Here, hypo-eutectic (7-9 wt% Si) cast Al alloys show a good compromise between strength and ductility (strain at fracture > 5%). By optimized casting processes and precipitation-strengthening (0.3-0,5wt% Mg), these alloys can be applied for high-loaded components, such as transverse control arms of the chassis unit in automotive engineering. However, associated with geometry-related variations in the solidification conditions, cast microstructures are characterized by a pronounced inhomogeneity. Parameters, like the (secondary) dendrite arm spacing ((S)DAS), size and shape of (i) the eutectic silicon, (ii) the gas porosity, and (iii) the shrinkage porosity, are strongly dependent on the local solidification conditions (in the mold) and quenching conditions (after heat treatment). Accordingly, the material's strength data can be provided within a certain range only, depending on the most relevant microstructure parameters.

Although, often the porosity seems to be most relevant for fatigue crack initiation, it has been shown that for pore sizes below approx. 100µm the microstructure parameters DAS (depending on the cooling rate) and eutectic silicon (depending on the refining by Sr/Na) are predominant in determining the fatigue behavior. In high cycle (HCF), and very high cycle fatigue (VHCF), cracks tend to propagate along the {111} slip planes of the single-phase dendritic fcc Al. They are deflected or loose energy by interacting with the interdendritic Si + fcc Al eutectic.

Today, the correlation between these microstructure features and the local occurrence of cyclic plasticity, crack initiation and fatigue crack propagation is only understood in a qualitative way. Therefore, it is the aim of the present work to derive quantitative data by (i) generating Wöhler-type fatigue life data (SN curves), (ii) measurement of the threshold value of the stress intensity range ΔKth from fatigue crack measurements, and (iii) to track in-situ fatigue initiation and propagation to obtain a microstructure-based understanding of the fatigue damage process.

2. Results

Various casting systems were used, that allowed to adjust DAS and porosity in a systematic manner. Step-wedge castings of AlSi8Cu3 and AlSi7Mg0.3, were used to vary DAS between 20 and 80µm. By ultrasonic fatigue testing, it was shown that the decrease in DAS is associated with a drop in the 10^9 cycles fatigue limit by up to 25% ($\Delta\sigma_{FL}$=-25 MPa). Contrary to that result, the threshold stress intensity range of fatigue crack initiation ΔK_{th} increases with increasing DAS from approximately 8 to 12 $MPa{\cdot}m^{0.5}$ (Figure 1c). Interactions between propagating fatigue cracks and the inhomogeneous microstructure were monitored by a light optical microscope and a high-resolution thermocamera mounted at the high frequency resonance/ultrasonic testing systems to identify microstructural barriers to fatigue crack propagation. After obtaining the scatterd da/dN data, the respective microstructure section was examined by means of scanning electron microscopy (SEM) in combination with EBSD to identify the operating slip systems. An example os such a measurements is shown in Figure 1b.

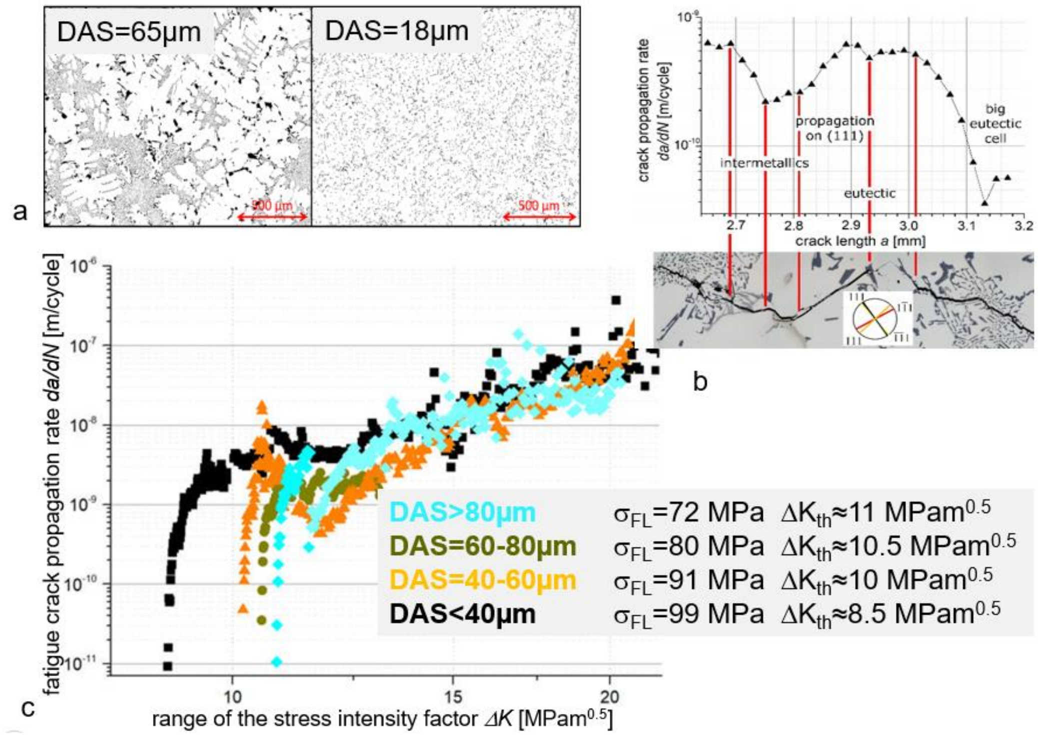

Fig.1 – Interactions between microstructure und fatigue crack propagation in Al-8Si-3Cu cast aluminum alloy: (a) cooling-rate dependent variation of the DAS (taken form a commercial engine block), (b) *da/dN* vs ΔK associated with varying DAS, and (c) direct correlation of microstructure features with local *da/dN*.

Since often large shrinkage pores (>>100µm) were found to be crack-initiating, a hydrogen treatment strategy has been developed to avoid the occurrence shrinkage porosity by obtaining a homogeneous setting of hydrogen porosity. First results revealed that microporosities act as crack barriers and lead to a decrease in both ΔK_{th} and the slope m of the Paris curve ($da/dN=C\cdot\Delta K^m$), respectively.

3. Conclusions

Fatigue damage evolution and fatigue life of cast Al alloys are governed by the porosity, dendrite arm spacing, eutectic silicon, intermetallic precipitates and strength of the dendritic aluminum. Adjustment of these microstructure parameters by tailored casting systems and fatigue testing revealed that the fatigue limit σ_{FL} increases and the threshold of the stress intensity range ΔK_{th} decreases with decreasing DAS (microstructure refinement). Microscopic in-situ-tracking of fatigue damage yields a detailed understanding of the fatigue mechanisms that will be the basis of a numerical short crack modeling approach in the future.

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