Competition of different fatigue crack initiation mechanisms under torsional load of cast AlSi7Mg03 alloy: An investigation using synchrotron 3D observations

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Abstract

This paper focuses on the effect of the microstructure, including porosities, eutectic zones and alpha grains, on the mechanisms of fatigue crack initiation and crack propagation under torsional loads for the cast AlSi7Mg03 aluminium alloy. The objective of this work is to understand the effect of grain crystallographic orientation, the grain size and the presence of porosity on the crack initiation and propagation mechanisms in torsion, not only on the surface but also in the volume. In order to achieve this objective, in-situ fatigue tests have been conducted in a synchrotron beamline at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. These experiments made it possible, on one hand, to obtain high resolution and high contrast 3D tomography images of the microstructure (with the voxel size of 1.3 μm) in which we can observe clearly micro-cracks (with an opening distance smaller than the voxel size). On the other hand, thanks to the Diffraction Contrast Tomography (DCT) technique, the 3D images have been rendered which include information about the grains size, the grain morphology and the grain orientation. The superposition of the 3D tomography and DCT images make it possible to know all of the necessary information related to the microstructure. These data were captured throughout the fatigue life of the specimen in the in-situ torsional tests.

Unlike tension loading mode, which only reveals tension cracks from pores, torsion enables the simultaneous observation of crack initiation mechanisms from both Persistence Slip Bands (PSBs) and pores. This point is very important because it make possible to analyse the different mechanisms (and the effect of surrounding microstructure) of cracks in the same specimen, i.e., under exactly identical loading conditions. It was observed that for the cracks initiated from PSBs, crack initiation occurs in a shear mode and is greatly influenced by the grain orientation. All observed cracks occur on the slip system plans presenting the highest resolved shear stress. The presence of a pore increases the shear stress amplitude at the

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local point, making it easier to activate crack initiation from PSBs. The crack propagation from one grain to adjacent grains is governed by two factors: the resolved shear stress of the latter and the twist and tilt angles between these grains. The grain boundaries are the main microstructural barrier arresting crack growth.

For the crack initiations from pores, these cracks occur in the opening mode on the plans presenting the highest macroscopic normal stress. No link to the grain orientation was found. The pore size is the key factor governing this crack initiation mechanism. Regarding the propagation mechanism, no clear microstructural barrier slowing crack growth down was observed. The growth rate of cracks in this mode is relatively steady but generally much lower than the cracks formed from PSBs.
Finally, a statistical analysis of the competition of the two mechanisms to form the final crack (that leads to the failure of specimens) showed that, depending on the density of initiated cracks and the crack growth kinetic, the cracks initiated from PSBs govern at high applied stress levels (tau_amp> 90MPa) while at lower stress levels (tau_amp< 80MPa) the cracks initiated from pores win.