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► To cite this version:

Nathalie Limodin, Long Wang, Nora Dahdah, Ahmed El Bartali, Jean-Francois Witz, et al.. In situ fatigue tests under X-ray tomography: damage mechanisms in a cast Aluminium Silicon alloy. 9th European Solid Mechanics Conference (ESMC 2015), Jul 2015, Leganes-Madrid, Spain. pp.676. hal-01736327

HAL Id: hal-01736327

<https://hal.science/hal-01736327v1>

Submitted on 16 Aug 2021

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IN SITU FATIGUE TESTS UNDER X-RAY TOMOGRAPHY: DAMAGE MECHANISMS IN A CAST ALUMINIUM SILICON ALLOY

N. Limodin^{1,*}, L. Wang¹, N. Dahdah¹, A. El Bartali¹, J.F. Witz¹, R. Seghir¹, E. Charkaluk¹, J.Y. Buffière²

¹ LML, Ecole Centrale de Lille, Cité Scientifique, 59650 Villeneuve d'Ascq, France
(nathalie.limodin@ec-lille.fr; long.wang@ec-lille.fr; nora.dahdah@ec-lille.fr; ahmed.elbartali@ec-lille.fr; jean-francois.witz@ec-lille.fr; rian.seghir@ec-lille.fr; eric.charkaluk@ec-lille.fr)

² MATEIS, INSA Lyon, Avenue Jean Capelle 69621 Villeurbanne cedex, France (jean-yves.buffiere@insa-lyon.fr)

Key words: Fatigue, Cast aluminium alloy, X-ray tomography, Digital Image Correlation

Defects have a crucial influence on the service life of components and structures. Internal inhomogeneities, e.g. porosities, inclusions or precipitates, are observed to initiate subsurface cracks that can grow undetected until failure. In cast alloys, linking the damage mechanisms with the microstructure is necessary to have a more predictive modelling of fatigue life and to suggest possible ways of improvement in the casting process. The cast Aluminium-Silicon alloy (A319) used for automotive cylinder heads has a multiscale microstructure: porosity with a size that ranges from small gas pores to large microshrinkage cavities, iron intermetallics, eutectic Al₂Cu and eutectic Silicon. To understand its influence on Low Cycle Fatigue, an experimental protocol has been set-up for fatigue tests with in-situ observations.

Room temperature fatigue tests coupled with Questar optical microscope observations were performed to follow initiation and interaction of cracks with the microstructure on large notched specimens. Preliminary X-ray tomography characterization of the specimens was done first to select the area where the pores configuration was likely to initiate a crack and secondly to ease interpretation of the damage mechanisms at the surface. Fatigue tests were also realized under synchrotron X-ray tomography using an in-situ test rig developed at MATEIS laboratory [1] to study crack initiation and growth in bulk at room temperature and at high temperatures that are more representative of the service conditions of cylinder heads, i.e. 150, 200 and 250°C. To have voxel sizes (1.6 to 2.7µm) small enough to distinguish the different features of the microstructure and to detect cracks, small size specimens (cross-section 2×2mm²) were used. The cast material having large and disperse pores, specimens were selected before the tests using laboratory X-ray microtomography to have 3D characterization of the pores and to discard specimens having defects too large as regards the specimen size. Then, pores in 3D images were meshed and Finite Element computation was performed to detect the areas where stress concentration at pores could initiate cracks during the fatigue tests (Figure 1). In-situ 3D observations were thus focussed on these “natural” strain concentrations areas.

2D and 3D in-situ observations during fatigue tests, which were analyzed with digital image or volume correlation, provide complementary information on the influence of pores and hard inclusions on crack initiation and propagation. While 2D observations allow a high spatial

resolution of the field measurement, 3D observations give access to 3D information on the cracks and on the strain field but are limited to larger image resolution.

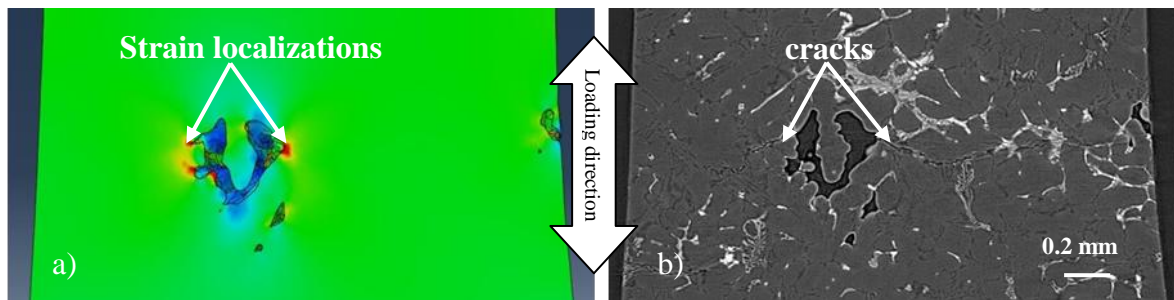


Figure 1: Comparison of FEM simulation results with the cracks observed in the tomography image after 10 500 fatigue cycles.

At room temperature, the predominance of pores on crack initiation is obvious (Figure 2a). Cracks nucleate at hard inclusions in areas where there is enough stress concentration, i.e. at large pores or at a specimen corner (Figure 2b). The crack propagation is highly sensitive to the microstructure as it goes through the hard inclusions rather than through the Al dendrites. Full field measurements either in 2D or 3D have shown strain localizations at hard inclusions (Figure 2c). The locally sharp morphology of these inclusions that form extended networks within the interdendritic space, their higher elastic modulus and brittleness as compared to Aluminium may be part of the explanation. 2D observations have shown that a crack can also be arrested or delayed by inclusions that are perpendicular to the crack growth direction. Although iron intermetallics, eutectic Si and eutectic Al_2Cu have different mechanical properties and morphologies, no difference in their damage behaviour was observed at room temperature or at 150°C . However, above 200°C , crack initiation was always driven by the stress concentration at pores or clusters of pores but fracture damage at eutectic Si, which failed in several areas, either close to or far from the crack front, became predominant.

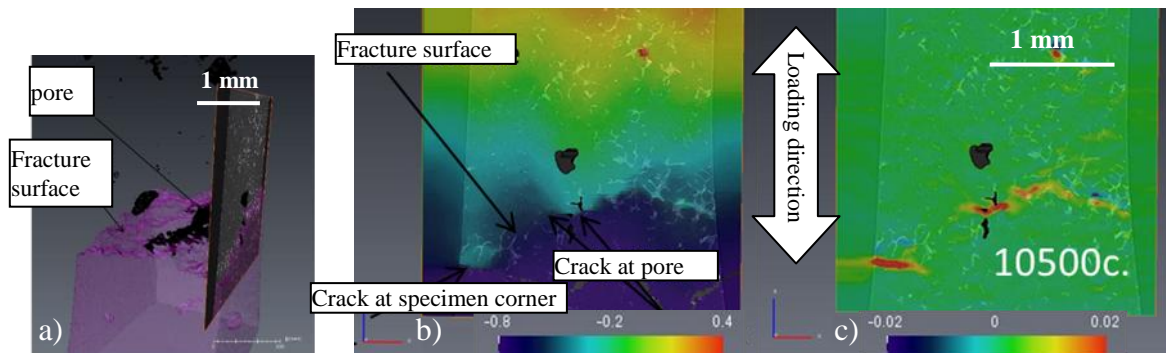


Figure 2: (a) One slice (65 μm below the flat surface) with 3D rendering of pores and fracture surface after 10 500c. and corresponding (b) displacement and (c) deformation fields; Iron intermetallics and eutectic Al_2Cu appear white in the tomography slice shown in behind.

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