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Coupling of experimental measurements to study the influence of microscopic defects on the fatigue damage in A319 Al-Si alloy

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Abstract. An experimental protocol based on the coupling of kinematic field measurements on the surface and in volume at the microstructure scale has been set up in order to study the influence of the casting microstructure upon the initiation and propagation of cracks in low cycle fatigue. Preliminary applications of this protocol on tensile tests were successful as it allowed tracking the development and localization of plastic deformation and identifying the initiation sites of microcracks during tests in relation with the observed surface and volume microstructures. Application of the proposed protocol to low cycle fatigue is an on-going work.

In the automotive industry, the Lost Foam Casting (LFC) process is gradually replacing the traditional die casting (DC) process in order to optimize geometry, reduce cost and control consumption. However, aluminum alloy automotive parts produced by the LFC process have coarser microstructure and porosity defects than parts produced with conventional casting processes at faster cooling rates. This coarse microstructure has a major influence on the fatigue properties and crack initiation [1]. In order to study its influence upon the initiation and propagation of cracks in Low Cycle Fatigue (LCF), a detailed experimental protocol has been set up based on the coupling of kinematic field measurements on the surface and in volume at the microstructure scale. The present work focuses on the use and validation of this protocol under tensile loading.

For both 2D and 3D in-situ tests, a preliminary 3D characterization of the specimens by X-ray microtomography [2] is performed (i) in order to thoroughly characterize the population of defects, (ii) to screen the most suitable specimens for tensile and fatigue tests, (iii) and to select samples where a crack is more likely to initiate in the observation area where field measurements will be performed.

During 2D tensile tests, in situ observations of the sample surface are done with Questar long distance microscopy. A colour etching [3] is used to provide the specimen surface with a natural texture that is necessary to realize Digital Image Correlation (DIC), to an acceptable spatial resolution without masking the microstructure. The DIC is performed using Elastix software [4]. Moreover post-mortem analysis with Scanning Electron Microscopy (SEM) allows characterizing the microcracks

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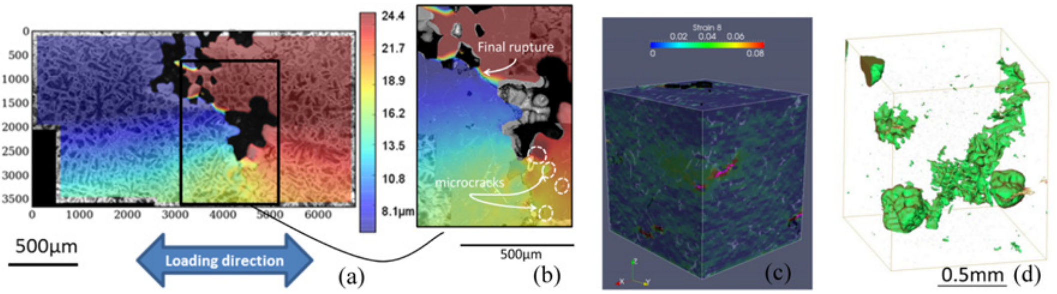

Figure 1. 2D tensile test with (a) displacement field along the loading direction ($\varepsilon \sim 0.5\%$) and (b) a close-up view of the final rupture area; images obtained with post-mortem SEM are shown in transparency. 3D tensile test with (c) ε_{zz} strain field with pores shown in grey color and cracks in purple and (d) 3D rendering of the cracks in yellow color and pores in green.

at the specimen surface at a finer scale in order to compare their locations with the measured displacement fields.

Figure 1a shows an example of a displacement field measured with DIC on the specimen gauge length. A close-up view of the area where the final rupture occurred is presented in Fig. 1b. A good correlation is indeed observed between discontinuities in the displacement field and microcracks formed at eutectic and intermetallic hard inclusions.

During 3D tensile tests, in situ observations of the sample volume are performed with X-ray microtomography (MATEIS, France). An in-situ test rig [5], installed in the tomography chamber, allows to load the specimen. The numerous and finely dispersed microstructural features inside the material, i.e. iron intermetallics and Al_2Cu phase, are used as natural markers for Digital Volume Correlation (DVC), which is performed with the Mechanical Image Correlation (MIC3D) algorithm developed by J. Réthoré (LaMCoS, France).

A 3D longitudinal strain field computed from DVC along the loading direction at the last step before failure is shown in Fig. 1c. A good correlation is observed between strain localization and the observed cracks. The correlation residual error is found to be maximal at the cracks locations in Fig. 1d, thus it provides a less arbitrary way to extract the cracks than direct greyscale thresholding from the tomography image.

Under tensile loading, the cracks are observed to initiate at large pores and microshrinkage cavities and then to propagate along the hard inclusions towards the free surface when cracks originate from a subsurface pore.

The application of the proposed protocol on tensile tests gave encouraging results. The validated protocol has already been applied to the study of in-situ 2D/3D LCF tests using a newly developed 2D/3D image correlation platform based on C++ and designed to process large data volumes in a limited amount of time.

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