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Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

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	Experiment title: In situ characterization of the influence of casting defects in fatigue damage of aluminium alloys with high resolution tomography and Digital Volume Correlation	**Experiment number**: MA-2037
Beamline: ID19	**Date of experiment**: from: 2014/04/01 to: 2014/04/05	**Date of report**: 2014/07/17
Shifts: 12	**Local contact(s)**: Elodie Boller, Vincent Fernandez	*Received at ESRF/*

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Report:

In-situ fatigue tests at (moderately) high temperatures and characterised by high resolution tomography were performed on ID19. The main objective of the experiment was to obtain in situ 3D images of the initiation and growth of damage during cyclic mechanical loading of an Aluminium Silicon automotive cast alloy (AlSi7U3) at temperatures relevant for service conditions (T~200°C).

A radiation furnace equipped with four halogen lamps has been designed and used successfully with a fatigue machine used previously by some of the proposers. The X-ray beam goes through the static furnace via two holes in the water cooled furnace walls. During the tomography scans (180° rotation) the in situ fatigue machine rotates freely within the furnace while keeping the samples gage length at the focal center of the four lamps. A quartz tube (2 mm thick) is used to transmit the load from the top to the bottom of the machine. The quartz material induces an acceptable and quasi constant attenuation of the beam during the rotation. The furnace design provides a relatively large (20 mm height) and homogeneous hot zone ($dT/dz < 0.3$ °C/mm), with very little temporal fluctuations (< 1 °C/hr). Images were obtained in pink beam mode (E=35 keV) on a CMOS PCO Dimax detector (2048 pixels^2). The scan duration was 45 s (2000 Images) with a 2.75 µm voxel size. Thanks to the large spatial coherence of the beam on ID19 eutectic Si particles could easily distinguished from the surrounding Al matrix and small (~ few microns long) cracks could easily be detected. The scan time was short enough to avoid creep/relaxation effects at the temperatures investigated (T< 250°C). Seven fatigue specimens with a 2×2 mm² cross section were tested: 2 at 150°C, 2 at 200°C and 3 at 250°C. Unixial tensile fatigue tests at constant stress amplitude were performed with a load ratio of 0.1 and a maximum stress of the order of 150% of the yield stress at the corresponding temperature (low cycle fatigue). Because of this high stress level, a significant amount of plastic strain was obtained in the samples during loading so that the load had to be constantly re-adjusted manually along the fatigue life. In practice, therefore, the amount of strain imposed during the test could not be accurately controlled. A situation that should be improved in the future. Nevertheless, to the best of the authors' knowledge, **this is the first time that 3D propagation of fatigue cracks is observed in situ in 3D above room temperature, in a metallic material.**

The results obtained at the two lower temperatures, (150°C and 200°C), showed that cracks initiate first at large subsurface pores and then propagate along the hard inclusions towards the free surface (Figure 1 a).

At 250°C, an additional damage mechanism is also observed: cracks are also detected in Silicon particles (see arrow on Figure 1 b) around the main pore that drives to failure but also in other areas of the specimen gage length (Figure 1 c).

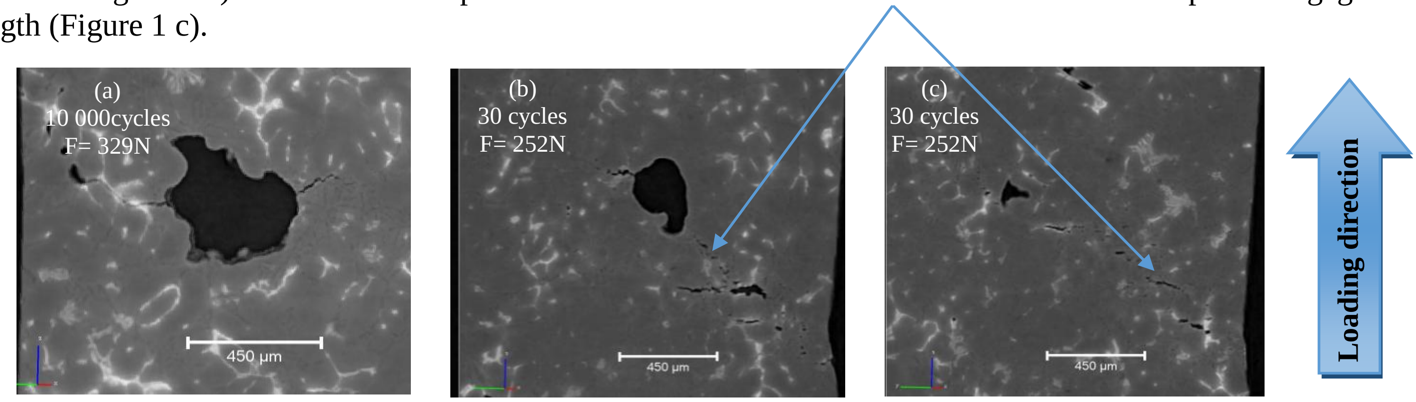

Figure 1: Microcracks observations at (a) 150°C, (b) 250°C at the main pore and (c) at 250°C far away from the main pore

3D images obtained by laboratory tomography were used to generate microstructurally realistic meshes of the microstructure within the present samples (pores + matrix, no intermetallic second phase); those meshes were used to perform Finite Element (FE) simulation of the strain/stress distribution during loading (elasto plastic calculation). An example of these simulations is shown in figure 2: a large strain concentration can be seen; close to the pore cluster where crack initiation was indeed observed. Figure 2 also shows the strain field calculated by Digital Volume Correlation (DVC) along the loading direction at the first cycle between the minimum and maximum load; the image of the microstructure was superposed to this field to allow comparison of the crack path with local deformation. The DVC results are in good agreement with the FE simulation regarding the strain concentration around the pores, however a large strain accumulation close to hard second phase particles associated with a small pore is also detected by DVC but not by the FE simulation which is based on an oversimplified mesh (see arrow).

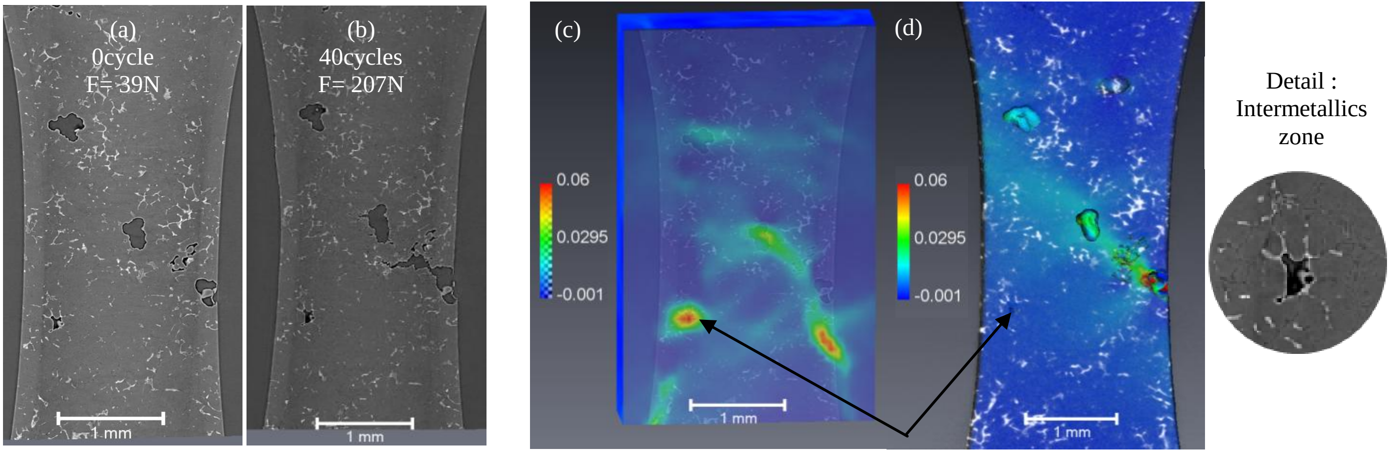

Figure 2: 3D rendering (a) & (b) of fatigue cracks in AlSi7Cu3 specimen initiated from a subsurface pore after 40 cycles at 250°C with (c) the corresponding strain field measured with DVC and (d) the strain field computed by Finite Element Modeling. The crack initiation location is in good agreement with the FE calculation which does not predict, however, a large plastic strain accumulation (arrows & detail) detected by DVC and induced by a smaller pore surrounded by intermetallic phases.

The DVC analysis of the 3D images recorded in situ helps to understand the relations between initiation sites and crack path and the local microstructural features: crack initiation is porosity driven while propagation is correlated with the presence of hard intermetallic phases. It also gives some very interesting information on the degree of complexity which has to be taken into account in so-called “realistic” microstructures to reproduce actual strain development within the samples.

Finally, it should be noted that the small cross section of the samples (2×2 mm^2), which was selected to match a small voxel size, gave only limited information on the propagation of the cracks: once initiation had occurred the load on the unbroken ligament led very rapidly to failure.