IN SITU DAMAGE ASSESSMENT IN MICRO-HETEROGENEOUS MATERIALS USING HIGH RESOLUTION X-RAY TOMOGRAPHY

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Metal Matrix Composites (a metal reinforced by ceramic particles or fibers) combine good mechanical properties and a low density. Hence, those materials are very attractive for automotive applications where a gain in weight is highly desirable. However, the poor fracture properties of those materials have greatly restricted, so far, their use in industrial applications. Therefore, in the last years, much attention has been paid to the study of fracture processes of Metal Matrix Composites (MMC). For instance, in situ mechanical tests have been used by several authors and provide very interesting information on the loss of ductility of MMC. However, the relevance of surface examination has to be checked by destructive observations within the material through time consuming techniques like serial sectioning which are not free of artefacts. To overcome this problem, we have used phase contrast tomography, to obtain three dimensional images of damage within materials under stress.

The damage mechanisms of an Aluminium/Silicon Carbide (Al/SiC) composite strained in tension have been studied *in situ* by phase contrast tomography using a specially designed tensile testing device. The phase contrast technique enhances the contrast between the aluminium matrix and the SiC particles with respect to classical attenuation-based tomography. The steady development of cracks in the SiC particles has been monitored on the same sample for increasing values of plastic deformation. The use of phase contrast enables to visualize cracks with an opening lower than 0.5 microns in the SiC reinforcements. For the first time, a quantitative comparison of the damage mechanisms observed at the surface and those observed in the bulk, by a non destructive method, is presented.

EXPERIMENTS

High-resolution x-ray tomography experiments were carried out at the ESRF in Grenoble on the «topography» beamline ID19. Images of damage induced by a tensile test within a MMC (aluminium matrix reinforced by silicon carbide (SiC) particles) have been obtained.

Because of the low difference in the x-ray attenuation of aluminium and SiC, classical transmission tomography, based on attenuation laws, was hardly able to discriminate between matrix and reinforcement. To improve this contrast, the very high lateral coherence of the beamline ID19 was used to produce **phase contrast images** through a very simple experimental set-up [1]. A Fast Read-Out Low Noise CCD detector, developed at the ESRF, was placed at about 1 metre behind the sample to record edge diffraction patterns resulting from discontinuities in the material such as interfaces between reinforcement and matrix or strain-induced cracks. Figure 1 shows a three-dimensional reconstruction obtained from the recorded phase images, where the reinforcing particles are clearly visible.

The studied material was a 6061 aluminium alloy reinforced with 10 % in volume of silicon carbide (SiC) particles with an average size of 120 μm. The material was produced through a rheocasting route and subsequently extruded at high temperature. A special tensile testing device was built in order to record tomographic scans of the sample under load. The frame of the tensile testing device, made out of a PMMA tube, gave negligible absorption on the 2D images along the 180° rotation of the sample during the scan. Small double-shouldered tensile specimens with a cross-section of 1.5 * 1.5 mm^2 and a gage length of 5 mm were used. The sample surfaces were mechanically polished using SiC paper and diamond paste down to 1 μm. The tensile tests were carried out at room temperature using a constant crosshead displacement rate of 150 μm.min^{-1}. Several scans were performed on the same sample at the initial state and after several increments of plastic deformation. During the scan, the position of the crosshead was maintained constant. Before and after the mechanical tests, the sample was observed in a Scanning Electron Microscope (SEM) operated at 20 keV.

RESULTS

Reconstructed 3D volumes show clearly the initiation of damage and its evolution within the material. Internal pores, resulting from the manufacturing process, were observed in the material at the initial state in the vicinity of the SiC particles. At the surface, those pores had been filled by the polishing process and, therefore, only a few of them were detected in the SEM. Thanks to the phase contrast technique, cracks with an opening down to 0.5 μm - i.e. well below the voxel size of 6.5 μm^3 - could be detected in the reinforcing particles.

From a qualitative point of view, the damage mechanisms observed in the bulk did not differ from those observed

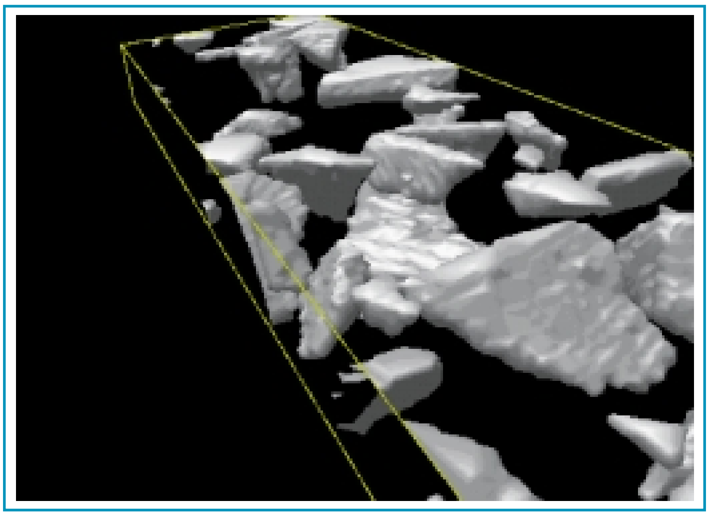

Fig. 1: Three dimensional reconstruction of some reinforcing particles in the interior of an Al/SiC composite. The average size of the particles is 120 µm.

at the surface. Schematically, the evolution of damage as a function of plastic strain can be described as follows:
1 cracking of SiC particles,
2 reinforcement/matrix decohesions,
3 propagation of processing-induced pores.

Representative images of the evolution of damage in the sample during the tensile test are presented in Figure 2.

From a quantitative point of view, however, the present experiment shows that the number of cracked SiC particles as a function of the plastic strain is substantially larger in the bulk than at the surface. Finite element modelling of the deformation process of a two-phase material is now being carried out to try to account for the observed differences between the bulk and the surface.

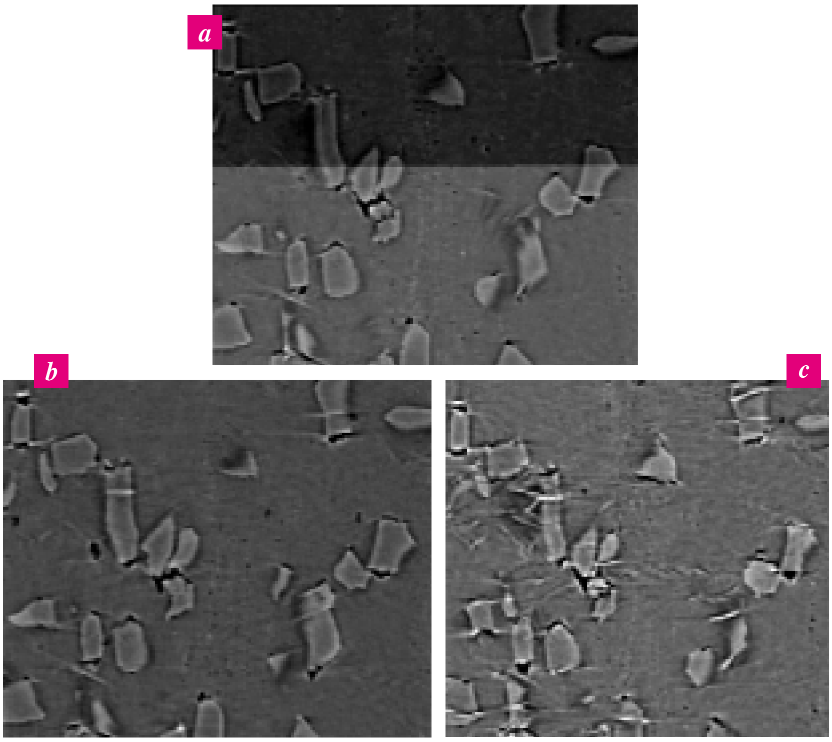

Fig. 2: Reconstructed images of the interior of the sample at the initial state (a) and after two steps of plastic deformation (b and c). A tensile stress was applied along the vertical direction. Some cracks in the particles are indicated by white arrows.

References

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