Combined X-ray Tomography and Diffraction Analysis of Damage Evolution in Aluminum

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Introduction

Accurate assessment of the remaining safe life of structural materials necessitates a detailed prognosis of the extent of damage. If the evolution of damage can be tracked *in situ* at the microscale, this information can be integrated with mechanics models to obtain a reliable health assessment of the material. By combining X-ray microtomography with microdiffraction on the same specimen, one can conduct a detailed investigation of damage evolution. Whereas microtomography provides high resolution three-dimensional images of damage, microdiffraction yields local stress/strain data of the same region.

This technique was employed in a preliminary study of an Al alloy (A356) with casting-induced voids as initial, internal damage. Under applied tensile stress, the specimen was imaged via microtomography while microdiffraction measurements were taken around the vicinity of the initial damage area to quantify local lattice strains. The specimen eventually failed around the void. The results reveal stress/strain variations both within the damage area and as a function of applied stress.

Methods and Materials

A tensile sample of A356 was prepared by, first, employing tomography at the Center for Nondestructive Evaluation, ISU to locate a void in large castings and then center it within a gauge section of 3 mm diameter. One projection of the void had approximate dimensions of 100x25 μm^2 and was located near the sample edge (Fig. 1).

The combined diffraction-tomography experiments were conducted at beamline 2-BM of the Advanced Photon Source using a 21 keV X-ray beam. The spot size was ~25 µm for microdiffraction. Two seperate CCD detectors collected the tomography and diffraction data in transmission, the latter centered around the Al 214 reflection. A custom-built load cell exerted uniaxial tensile stress onto the sample quisistatically while data were collected. Applied stress values ranged from 0 to 160 MPa at which point the sample failed. Local strain data were collected at sixteen different locations around the void (Fig. 1). These locations were identified and tracked at each load via imaging. Point 16 was located away from the void and was used as a reference to represent the damage-free response of the material.

Results and Discussion

The combined diffraction-tomography technique allowed a detailed study of damage evolution around the void. For instance, a comparison of radiographs with increasing load showed the changing shape of the void, as well as the formation of cracks near its edge as highlighted in Fig. 1. The microdiffraction data yielded information about local strains and their evolution as a function of stress. Fig. 2 exhibits strain data from some locations around the void. The strains were estimated with respect to the Al 214 *d* spacing at 0 MPa stress at each location. They are compared to applied (elastic) strains obtained by dividing applied stress with the Al Young's modulus (=70 GPa).

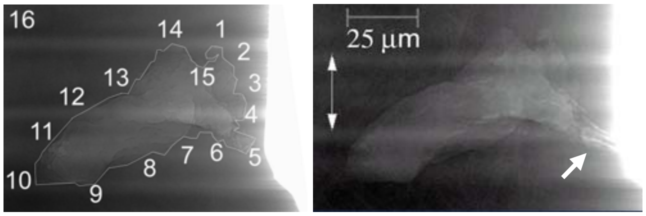

Fig. 1. Strain measurement locations around the void (left). Radiograph of the void under load (in the direction of the vertical arrow) just before failure (right). The second arrow on the right points to cracks that formed near the sample edge.

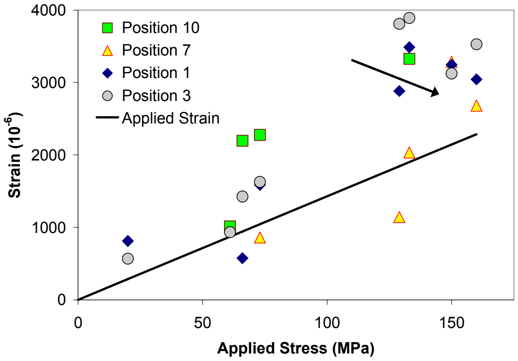

Fig. 2. Lattice strain evolution at several locations around the void (marked on Fig. 1) as a function of applied stress. Strains were estimated with respect to 0 MPa stress and thus indicate relative strain changes during loading. The applied strain plot was obtained from the stress/Young's modulus ratio.

The local strain data exhibited large variations, both among different locations and as a function of stress. Some of these variations were likely due to experimental artifacts such as sample displacement between load changes. The local strain data were also influenced by intergranular strains due to the small sampling volume of the microdiffraction experiments. Nevertheless, there was a clear overall trend towards compression at high stresses (indicated by an arrow in Fig. 2) in contrast with the macrosopic applied strain suggesting evolving plastic deformation. Similarly, plastic deformaion was indicated by the texture evolution of the Debye rings (not shown). Here, as the stress increased, the initial graininess significantly decreased leading to a more uniform distribution of intensity along the Debye ring. This resulted from the increased mosaicity in the microstructre due to plastic deformation.

In conclusion, the combined X-ray microdiffraction-microtomography technique was shown to be a powerful tool to study damage evolution at the microscale.

Acknowledgments

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