Crack characterization in a Metal Matrix Composite with 3D Phase Congruency and Digital Volume Correlation

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Abstract

Two dimensional Phase Congruency (2DPC) and three dimensional Phase Congruency (3DPC) are powerful new tools for identification of cracks in full field displacement data [1, 2]. Phase Congruency (PC) is a local measure of feature significance, which mathematically imitates the pattern recognition algorithm that the human brain adopts. It is, therefore, suitable for identifying discontinuities in continuum displacement fields, which are caused by cracks. The method is demonstrated in this paper for a 3D dataset of a cracked body. To obtain the volumetric full-field displacements , Digital Volume Correlation (DVC) has been applied to high resolution synchrotron X-ray Computed Tomography (XCT) data [3] acquired at the UK Diamond Light Source. Fracture behaviour of an aluminium based Metal Matrix Composite (MMC) with titanium particles was studied. The multi-phase microstructure of the material and the difference in X-ray attenuation of Aluminium and Titanium produces speckle in the tomograms that can be tracked by DVC. The notched specimen was loaded until cracks were initiated at stress concentrating notches. Tomograms of the specimen were recorded *in situ*, before and after crack initiation, and were analysed using LaVision's DVC software. Using the novel 3DPC analysis, the 3D crack geometry was identified and its opening displacements in the three orthogonal directions were obtained from the surface to the middle of the specimen.

Introduction

Identifying the interaction of cracks with the microstructure of engineering materials is a critical contribution to structural integrity. Now with the aid of imaging techniques that range from digital images acquired by a CCD camera to X-ray tomography images produced by synchrotrons, and full field displacement measurement tools such as Digital Image/Volume Correlation (DIC - DVC), the behaviour of cracks can be characterized in greater detail than ever before. Image correlation methods rely on the comparison at least two 2D or volumetric images: the reference image and a deformed image to obtain a displacement field. In the case of cracked bodies, this displacement information can be used for calculation of fracture parameters such as crack opening displacement (COD) [4], stress intensity factor [5, 6] and strain energy release rate (i.e. J-integral) [7].

Cracks can have a complex geometry within the cracked body and this cannot be captured by surface measurement techniques. Surface measurements are constrained to plane stress conditions where in fact, quite often, the plane strain condition prevails for crack propagation within the material. Therefore, volumetric images provide a better picture of how a crack behaves and interacts with its surrounding microstructure. Being able to detect and visualise cracks within volumetric full field displacement is this a key element of characterising the crack behaviour. However, manual segmentation and crack parameters quantification can be difficult, subjective and time consuming. Phase Congruency (PC) is an image processing technique that has been shown to be an effective and robust tool for detecting cracks using surface displacement fields [2]. It is a dimensionless quantity that is invariant to contrast and scale [8]. Unlike gradient-based feature detectors (e.g. see [9, 10]) the PC method detects the step features in displacement fields which are the signature of cracks. PC also correctly detects features at *all* phase angles and not just those step features that have a phase angle of 0 or 180°.

Methodology

The fracture experiment was conducted using double edge notch tension specimen (Fig 1a) at beamline I12, Diamond Light Source. A 10 kN Shimazdu mechanical testing frame was used to load the sample in-situ, with limited angle tomography (total rotation range 138°). The X-ray beam energy was ~62 keV and the voxel size of the tomographs was 3.25 µm. These were recorded at 50 N and 3500 N load; at higher load cracks with an approximate size of 0.5 mm initiated at the tip of each notch. Digital volume correlation was done with subset size of 16 voxels at 80% overlap (Fig 1b) using the LaVision Davis software (version 8.3.0). 3D phase congruency map (3DPC) was then used to segment the cracks and calculate the 3D crack opening displacement profile. The results for the longer of the cracks are shown in Fig 1c to 1e. The 3DPC was achieved by splitting the volumetric displacement data into 2D slices, which were analysed independently. By stacking the 2D maps, it was possible to segment the crack in 3D and calculate its 3D crack opening profile autonomously (i.e. with no user intervention).

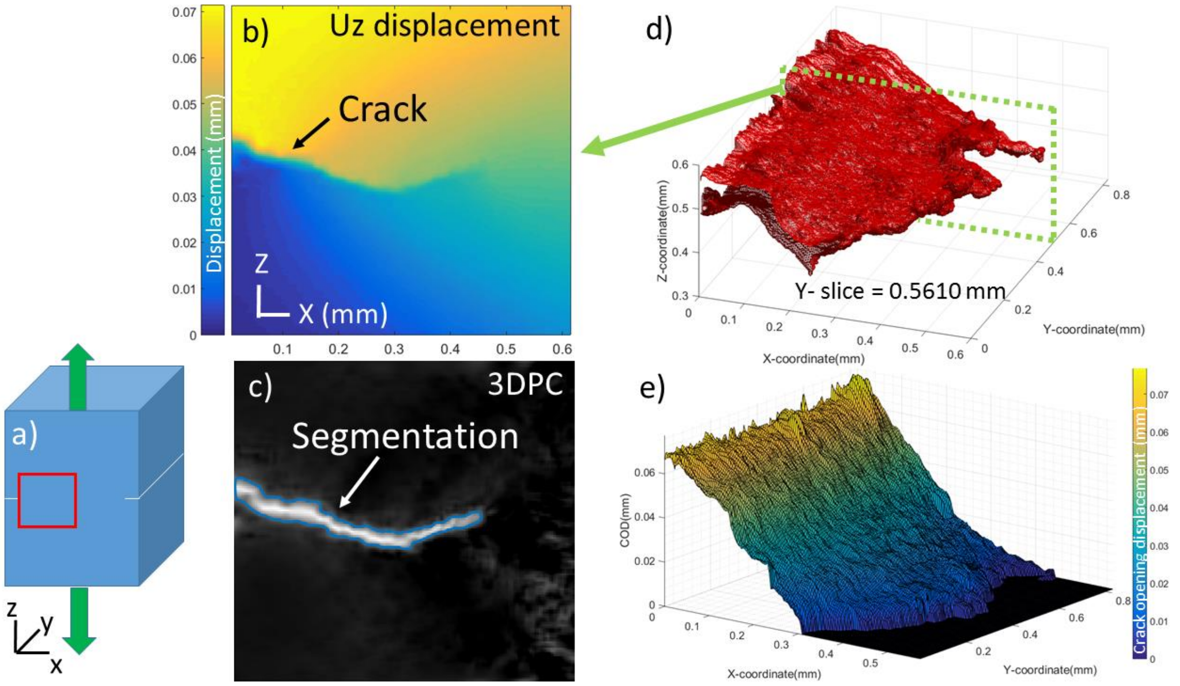

Figure 1 a) Sample region of view b) Uz Displacement slice at y = 0.5610mm c) 3D Phase congruency slice at y=0.5610 mm d) 3D segmentation of Crack e) 3D Crack Opening Displacement (opening mode I).

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