3D X-ray diffraction imaging techniques applied to the study of deformation and damage mechanisms in metals

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Résumé

State of the art X-ray diffraction imaging techniques offer unique possibilities for studying deformation and damage mechanisms in metals. Tomographic imaging of the grain microstruture allows to monitor the evolution of the local orientation and strain state of the material as a function of applied strain / fatigue cycles wheras phase imaging techniques enable the detection of damage (cracks, voids). The combined use of these techniques offers (sub)-micrometre resolution characterization of material failure mechanisms at the mesoscopic (grain aggregate) length scale. Numerical simulations on the digital twin and the use of machine learning techniques can reveal new insight into the

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1. Introduction

X-ray diffraction contrast tomography [1] is a near-field X-ray diffraction imaging technique enabling simultaneous characterization of (i) microstructural detail visible in absorption / phase contrast (i.e. second phases, cracks, porosity, etc…), and (ii) the crystallographic grain microstructure, revealed through analysis of the Bragg diffraction signals. With the recent upgrade to a six-dimensional reconstruction framework [2] the method now provides access to spatially resolved crystal orientation maps with an orientation resolution comparable to EBSD and a spatial resolution of order of 1 µm. Moreover, like modern electron microscopes, state of the art X-ray diffraction imaging instruments can nowadays offer complementary imaging modalities like phase contrast tomography, X-ray topography [3] and dark-field microscopy [4], the latter two enabling “zoom-in” observations of individual grains at higher spatial resolution. Repeated, non-destructive characterization of samples subjected to mechanical loading provides rich datasets and allows for direct comparison with numerical simulations carried out on the digital twin of the microstructure [5, 6].

2. Application Example : Study of short fatigue crack driving force

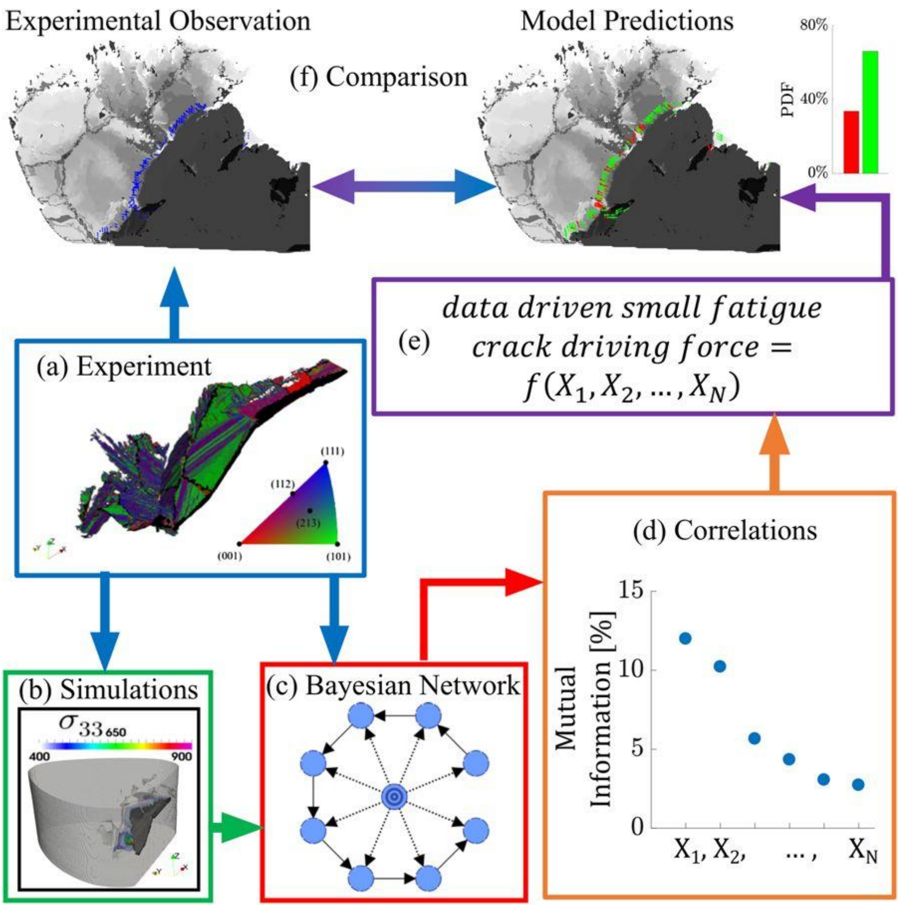

Figure 2. Illustration of probabilistic data analysis approach [5], based on (a) experimental observations of short fatigue crack propagation, (b) numerical simulations on the digital twin of the microstructure. Bayesian networks (c) are used to reveal correlations between micromechanical field variables and observed crack behaviour (d) in order to determine an expression of the short fatigue crack driving force (e), which yields improved crack path prediction capabilities (f).

3. Conclusion

The coupling of 3D experimental observations and numerical simulations can provide new insight into the damage mechanisms in polycrystalline structural materials.

Références

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