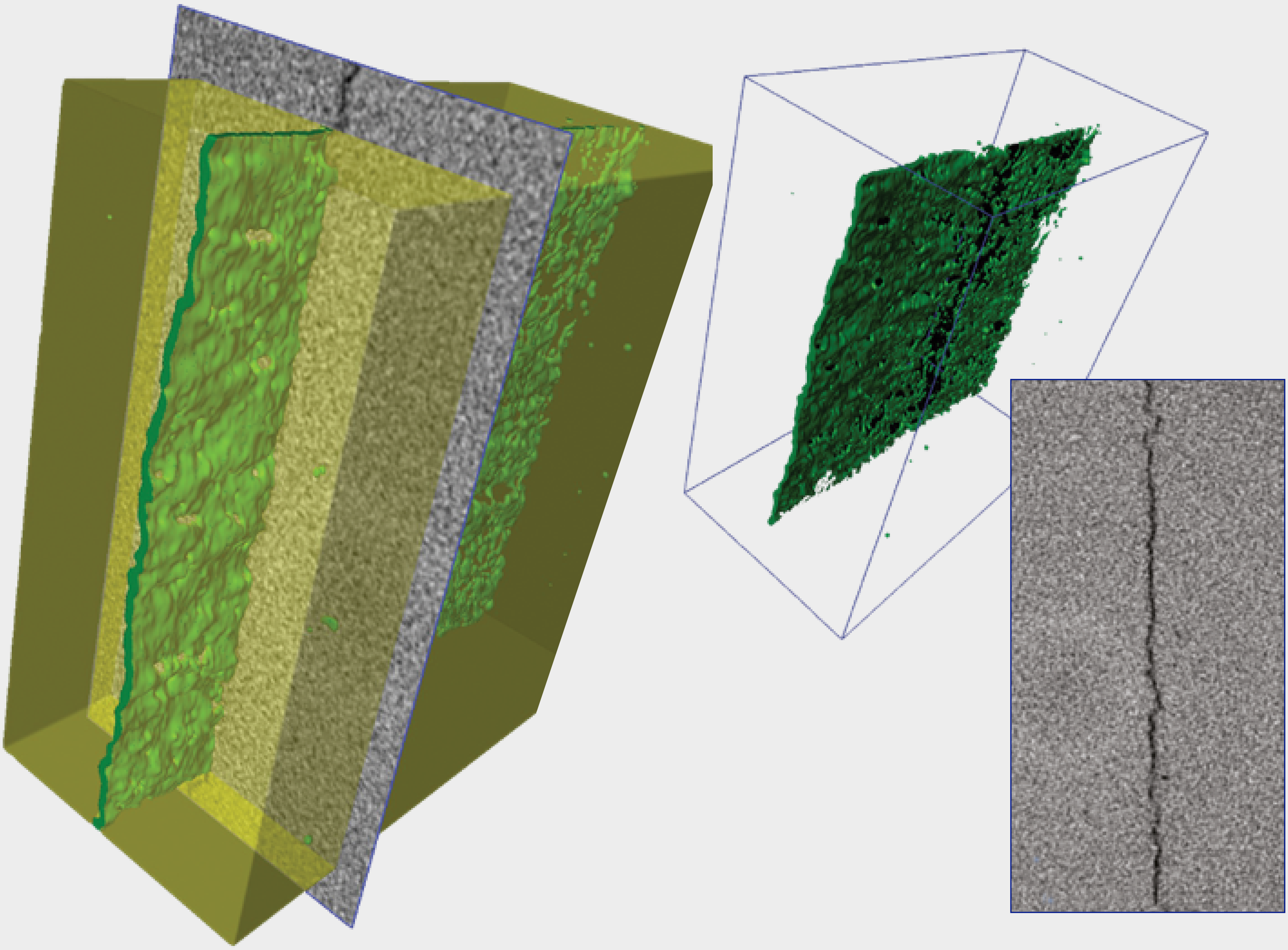
Application Note



Observing Fracture Mechanics

ZEISS X-ray Microscopes

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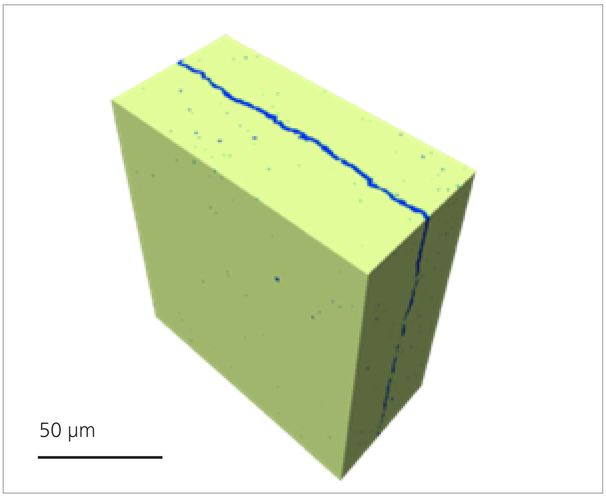
Fracture is a prevalent material failure mechanism that, while occurring at the microscopic scale, can have catastrophic macroscopic consequences. Structural failures due to fracture have led to immense financial damages as well as countless losses of human life.[1] As new materials are deployed into environments requiring increased performance, reliability and operational lifetimes,[1] interests in understanding and eliminating fracture from building materials now span the industrial, academic, and political sectors.

Introduction

Fracture mechanics involve two vital stages: crack initiation and propagation.[2] Both the initiation and propagation stages are exceedingly sensitive not only to load, but also to the microstructure and environment. Initiation is strongly dependent on pre-existing conditions, such as voids, crystallographic defects, inclusions, and damage locations that play a large role in the beginning stages of crack formation. Propagation, in a related manner, is sensitive to all of the same parameters as crack initiation with the addition of the grain structure, boundary conditions, orientation of crystal planes, and microscopic heterogeneities, such as local hardness and compositional variations.[3]

Using X-ray microscopy, researchers are now able to observe and measure the true nature of crack initiation and propagation without disrupting the sample.Traditional fracture models involve multiple simplifying assumptions about microstructure and 3D crack geometry. As such, it is often problematic to correlate the results of such models to the actual fracture mechanics of real-world specimens. *In situ* 3D visualization of the fracture process, including observation of local defects and heterogeneities prior to crack initiation, the volumetric mapping of the crack initiation, as well as the growth and the resulting fracture itself, open up new opportunities to understand and model the mechanics of fracture.



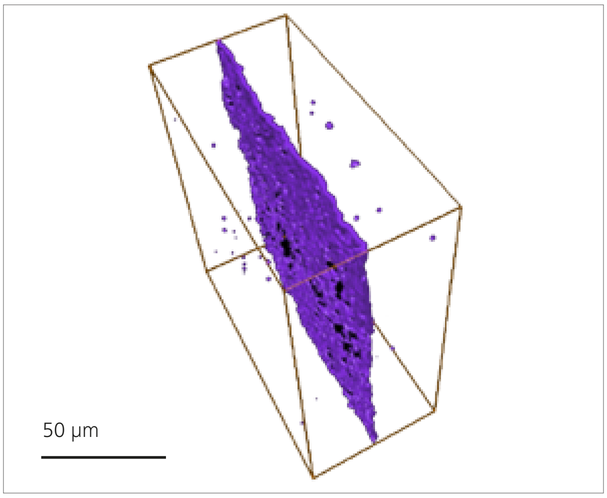


Figure 1 *(Left) 3D segmented volume of internal micro-cracks of a 3 mm Fe rod subject to a fatigue test. The crack size ranges from a few micrometers in the propagation region down to sub-micron length scales at the tip. (Right) the isolated crack of the same structure virtually extracted.*

Observing 3D microcracks with traditional techniques such as scanning-electron and optical microscopy is challenging since they are limited to 2D cross-sectional studies of the propagated crack as an exposed surface. The crack structure revealed by these techniques may be misleading because crack microstructure is altered due to either releasing the load applied to the specimen or the cross-sectioning process in sample preparation. Overcoming the inaccuracies in characterization using traditional approaches relies on statistical studies of the material, adding new experimental variables and increasing the complexity of data analysis.

Xradia Versa deliver 3D sub-surface measurements about the actual crack propagation within the natural material microstructure. The non-destructive nature of the *in situ* observation of the fracture mechanics makes it uniquely able to accurately map fracture mechanics as a function of applied load (e.g., in a tensile loading device, 3- and 4-point bend cells, or dual-cantilever beam setups). ZEISS X-ray microscopes (XRM) thus enable direct characterization of the crack geometry and microstructure, while simultaneously observing the crack growth in the same sample as a function of load.

In Figure 1, ZEISS Xradia Versa was used to analyze the fracture *in situ* of a 3 mm iron (Fe) rod under load. The specimen was placed in a tensile loading device and subjected to a maximum stress of 14 MPa applied for 50,000 cycles at a frequency of 20 Hz. Imaging with a voxel size of 0.62 µm revealed the crack tip down to submicron features (Figure 2), which was subsequently analyzed with imaging and analysis software for an accurate visualization of the precise propagation geometry (Figure 1, right).

Conclusion

3D X-ray microscopy is a powerful tool for increased accuracy in experimental fracture mechanics investigations. Combining the ZEISS Xradia Versa imaging platform with fracture testing devicesenables *in situ* observation of crack propagation without disturbing its natural microstructure. The experiment may be extended to studies using ZEISS Xradia Ultra for precise crack tip analyses, down to 50 nm resolution for increased measurement precision.

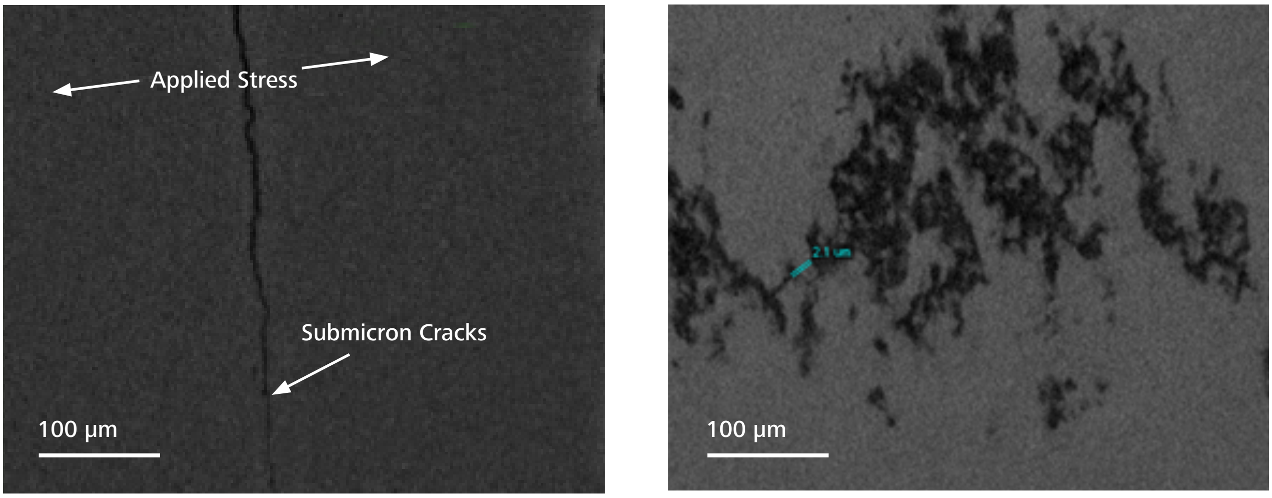


Figure 2 *(Left) This 2D virtual slice shows a crack close to the sub-micron propagation tip. (Right) Virtually slicing through the specimen in the crack plane reveals the local microstructure contributing to the fracture.*

References

[1] Roylance, 2001, MIT Course Notes. Available: http://ocw.mit.edu/courses/materials-science-and-engineering/3-11-mechanics-of-materials-fall-1999/modules/frac.pdf

[2] V. Lamacq and M. –C. Dubourg, "Modelling of initial fatigue crack growth and crack branching under fretting conditions," Fatigue Fract. Engng. Mater. Struct. 22, (1999), pp. 535-542.

[3] R.O. Ritchie, "Mechanisms of fatigue-crack propagation in ductile and brittle solids," International Journal of Fracture, 100: 55–83, 1999.

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