3rd International Conference on Tomography of Materials and Structures
Lund, Sweden, 26-30 June 2017, ICTMS2017-45

HOW MICROFRACTURE ROUGHNESS CAN BE USED TO DISTINGUISH BETWEEN EXHUMED CRACKS AND IN-SITU FLOW PATHS IN SHALES

Pluymakers, Anne[*1], Kobchenko, Maya[1] & Renard, François[1,2]

[1] PGP, Departments of Physics and Geosciences, University of Oslo, postboks 1048, Blindern, 0316 Oslo, Norway
[2] University Grenoble Alpes, ISTerre, 38000 Grenoble, France

Keywords: X-ray micro-tomography; 3D image processing; Geomaterials and Geoengineering; Hurst exponent

Summary: We use X-ray micro-tomography to extract the roughness of cracks and veins. Mode I cracks in shale have a low Hurst exponent of 0.3, veins have 0.5. These values are related to microstructure and linear elastic fracture mechanics. H = 0.4-0.5 is representative for (geo-engineered) fractures in Pomeranian shale.

1. INTRODUCTION

The roughness of natural fault surfaces does not only control many aspects of earthquake mechanics (*1*), but is equally of importance for fluid flow through natural and induced fractures (*2–4*). Shales in particular are studied for their importance as caprock to hydrocarbon reservoirs and CO2 plus nuclear waste storage sites, for which the lack of effective transport pathways is paramount. In contrast, it is the efficiency of transport through existing and induced fractures and faults that controls the primary migration of hydrocarbons and the recovery of shale gas. Fracture roughness is an important control on transmissivity, especially in small aperture cracks (e.g. , *4*). Data on roughness of representative fault surfaces in shale rocks is lacking, mainly because of their fragile nature. In this study we investigate the roughness of low to no displacement fractures and veins found in a shale drill-core using X-ray microtomography and white light interferometry. Using the fractures in the Pomeranian shale from Poland we have verified if X-ray micro-tomography can be used to extract quantitative information on the surface roughness of cracks. By comparing the data from veins and cracks, we find that the Hurst roughness exponent can be used as a microstructural criterion to distinguish between exhumation and in-situ fractures. This provides a step forward towards the characterization of potential flow paths at realistic depth in shales.

2. EXPERIMENTAL METHOD

The Pomeranian shale is a typical dark-grey to black clay-rich shale. We had access to cohesive drill-core material obtained from ~4 km depth in Poland (courtesy of Polish Oil & Gas Company). We obtained four 8 mm diameter core samples for 3D X-ray microtomography scans (XCT, 10-40 mm long), and five cm-sized open fracture or vein samples for 2D white light interferometry measurements (WLI). In these cylindrical samples there are several calcite veins and open cracks present. We have scanned the core samples using a laboratory tomograph (Nikon XT H 225 ST), at voxel sizes of 11 to 26 µm. For one sample we also scanned a subvolume at 7 µm voxel size, and a subvolume of the same sample has been scanned as well at the beamline ID19 at the European Synchrotron Radiation Facility (ESRF), at two different voxel sizes (1.7 and 0.16 µm. The decrease in voxel size of the ESRF scans helps distinguish the cracks and veins with better resolution.

The 3D images were segmented using the software package AvizoFire© (edition 9). We isolated crack and vein data to enable subsequent quantitative analysis of their topography. In order to isolate objects, we traced the matrix-air interface for the cracks, and the vein-matrix interface for the veins. The topography of the fractures exposed on the surface of the slabs was measured directly using a white light interferometer (Wyko NT1100) plus Veeco software with vertical nanometer resolution. For these slabs we measure the vein-air interface, and we interpret them to be similar to the matrix/air interface of the open cracks extracted in 3-D with XCT.

Once the 2D (white light interferometry) and the individual fractures and veins from the 3D (XCT) data were acquired, we analyzed the topography of the fractures and of the vein-matrix interface. The variation of the height of a surface is called the roughness, and we quantify how the roughness amplitude varies with the measurement

* e-mail: pluymakers@gmail.com

scale with the Hurst exponent H, in order to characterize the spatial correlations in the samples. To determine the Hurst exponent H, we have followed the standard steps as outlined in detail by Candela and co-authors (*5*, *6*).

3. RESULTS

A summary of all results in provided in Figure 1. At the lowest resolution of 20-30 µm/voxel, the 3D data do not exhibit significant difference between top, bottom and differential surfaces (i.e. fracture aperture or vein thickness), nor any difference in slope for the x- or the y-direction. The cracks exhibit a Hurst exponent H ~0.29±0.1 on the low resolution 3D data (20-30 µm/voxel). At 5x magnification, the WLI data indicate an average Hurst exponent is 0.28 to 0.30. Roughness values obtained with both methods are thus consistent at comparable magnifications, which indicates that the 3-D data obtained from microtomography scans can indeed be used to extract quantitative properties on the roughness of the vein/rock and fracture/matrix interface.

Using the XCT data we can compare the veins and cracks, where the veins formed at depth, and the open cracks are exhumation cracks. The vein-rock interface exhibits a Hurst exponent of ~0.53±0.11, and the cracks exhibit H ~0.29±0.1 This difference in roughness exponent is attributed either to the difference in opening mode and/or to the difference in in-situ stress. This implies that the Hurst roughness exponent can be a microstructural criterion to determine between exhumation and in-situ fractures. To be fully confident this could be extrapolated to other shales more research is required, though there seem to be no a priori reasons why the aforementioned principles/mechanisms would not apply to other drill core shales.

Using the XCT data, we have extracted the open crack with the highest aperture at all resolutions. The roughness curves for the different resolutions overlap, leading to a clear trend over four orders of magnitude of spatial scales. At the resolutions above 0.16 µm/voxel the curves exhibit average Hurst exponents of approximately 0.3±0.1. In contrast, at the highest resolution of 0.16 µm/voxel, the Hurst exponent becomes more uniform, with on average H = 0.51. For fine-grained heterogeneous rock such as shale the Hurst roughness exponent changes with scale of observation, which is related to the microstructure. Imaging and roughness determination should be performed done at a resolution that is appropriate for the feature of interest, i.e. keeping the microstructure in mind.

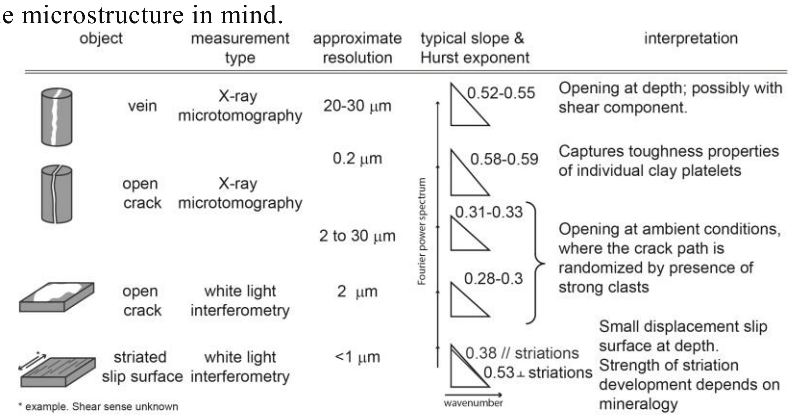

Figure 1. Summary of observations and interpretations. The Hurst values indicated in the table represent the range of average values for each object type (*7*).

References

1. C. H. Scholz, *The mechanics of earthquakes and faulting* (Cambridge University Press, Cambridge, 2002).
2. S. R. Brown, Fluid flow through rock joints: the effect of surface roughness. *J. Geophyiscal Res. - Solid Earth*. **92** (1987), doi:10.1029/JB092iB02p01337.
3. C. Noiriel, B. Madé, P. Gouze, Impact of coating development on the hydraulic and transport properties in argillaceous limestone fracture. *Water Resour. Res.* **43**, W09406 (2007).
4. J. P. Fitts, C. A. Peters, Caprock Fracture Dissolution and CO2 Leakage. *Rev. Mineral. Geochemistry*. **77**, 459–479 (2013).
5. T. Candela *et al.*, Characterization of Fault Roughness at Various Scales: Implications of Three-Dimensional High Resolution Topography Measurements. *Pure Appl. Geophys.* **166**, 1817–1851 (2009).
6. T. Candela, E. E. Brodsky, The minimum scale of grooving on faults. *Geology*. **44**, 603–606 (2016).
7. A. Pluymakers, M. Kobchenko, F. Renard, How microfracture roughness can be used to distinguish between exhumed cracks and in-situ flow paths in shales. *J. Struct. Geol.* **94**, 87–97 (2017).