X-Ray Imaging for Compaction Band Characterisation in Porous Sandstones*

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Abstract

Compaction bands in porous sandstones are planar zones of finite thickness that form almost normal to the direction of maximum compression. Grain-scale mechanisms indicate porosity reduction by grain crushing and movement of fragments into pores, along with grain movements. Such bands can have important impacts on fluid flow in sandstone reservoirs. We investigate by experiments the grain-scale processes occurring during compaction band formation in two porous (~22%) sandstones with similar grain-sizes (~300μm). Vosges sandstone is 93% quartz, 5% microcline, 1% kaolinite and 1% micas; it is moderately sorted with sub-angular to rounded shapes, and cement occurs mostly as quartz overgrowths. The texture of Vosges is more heterogeneous than the Bentheim, which has rounded grains, and is composed of 95% quartz, 3% feldspar and 2% kaolinite. Cylindrical samples of 40mm/80mm (diameter/length) for Vosges, and 50mm/100 mm for Bentheim, were loaded under triaxial compression with confining pressure of 130–190 MPa. All specimens had a circumferential notch at their mid-length to force localization. X-ray CT was obtained before and after the experiments, defining the changes caused by deformation. The standard deviation of the grey-scale values in Vosges is smaller than that in Bentheim (undeformed), which implies a more homogeneous density for the former due to cementation. Compaction bands created in both sandstones are identified as zones of low standard deviation values, due to compacted material and associated local porosity reduction. In the Bentheim raw X-ray images, compaction bands are also visible as higher-density regions. In both sandstones, compaction bands have curved or irregular shapes rather than the planar ones expected, and have orientations as low as 66° to the shortening. Acoustic emission data shows that the deformation mechanisms involve shear motions as well as volume loss. Local strains calculated with Digital Image Correlation confirm the AE interpretations, revealing both volumetric and shear strains that vary within and near the bands. Pore networks extracted from the 5μm resolution X-ray images of the localized zones allow us to calculate the flow properties of compaction bands and matrix in both sandstones. Permeability reduction is significant (~3 orders), and calculated relative permeability provides insights into the multi-phase flow effects of such bands.
Background & Perspectives

Compaction bands in porous sandstones

- Non-symmetric triaxial compression experiments performed under confining pressures ranging from 130 MPa to 190 MPa. Compaction bands developed in all samples.
- Multi-scale techniques, full-field methods, non-destructive and destructive to different sensitivity and resolution. Measurements took place before, during, and after laboratory deformation.

Study material

Voges sandstone

- 22% porosity
- 93% quartz, 5% feldspar, 1% kaolinite, 1% mica + some oxidises
- 300 μm mean grain size
- Sub-angular to round grains

Bentheim sandstone

- 22% porosity
- 95% quartz, 5% feldspar, 2% kaolinite
- 300 μm mean grain size
- Round grains

Vegetation bands

- Concentration bands in porous sandstones
- Competnet bands contain quartz and feldspar
- Vein-fed crushing and brittle shear in quartz and feldspar
- Are observed in regions where compaction band developed.

Visualisation of compaction bands

- Circumferential notch
- Non-planar, curved, multiple compaction bands
- Fracture in dark colours, low density and denser regions in light colours

Porosity and permeability calculations

- Volume including mainly the compaction band (Fig. 6c)
- Volume from an undeformed sample (Fig. 5c)

Conclusions

- The compaction bands in this study (experimentally created in porous sandstones) may produce large changes to rock texture, hence properties, with permeability reduction of ~10^-6 compared to that of the matrix (undeformed rock). These non-planar, curved bands are characterised by grain fracturing and crushing, compacting and shear strains as well as porosity decrease.

References