Microstructural control on compaction localisation in granular materials

Lucille Carbillet[1], Michael J. Heap[1], Fabian B. Wadsworth[2], Patrick Baud[1], Thierry Reuschlé[1]

[1] Ecole et Observatoire des Sciences de la Terre, Strasbourg, FR [2] Department of Earth Sciences, Durham University, Durham, UK

Introduction

Strain localisation has been observed over a large range of scales and under a variety of conditions. In geomaterials, localised deformation may be accompanied by dilatancy and translate into shear bands under nominally brittle conditions or by shear-enhanced compaction and result in compaction bands under ductile conditions. Previous studies suggested that the formation and geometry of compaction bands depends on the microstructure of the rock (Tembe et al. 2008 ; Louis et al., 2009 ; Baud et al., 2012 ; Cheung et al., 2012). We investigated the influence of microstructure on compaction localisation in porous rocks using sintered glass bead samples, which allowed for a tight control on grain size and shape and sample porosity.

Materials: fused soda-lime silica glass beads

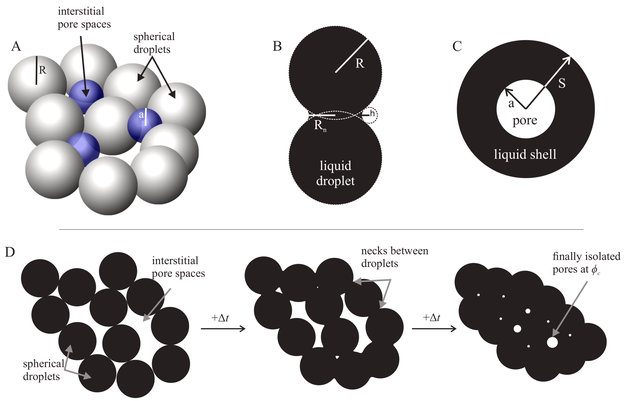

Fig 1. Sintering of an initial system of monodisperse viscous droplets (A). After some time, necks grow between droplets (B). Later, shrinking of pores takes place (C). (Wadsworth et al., 2016)

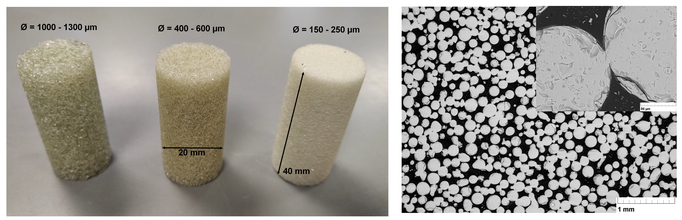

Fig. 2 (right) Sintered glass beads samples (monodisperse) of different mean grain sizes and porosity of 25 % ; (left) Microstructure of an intact sample of 35 % porosity; zoom-in on a contact between two grains (black: porosity ; grey: solid glass)

Methods

Systematic measurements on the synthetic samples: porosity, permeability, P-waves velocity

Triaxial experiments ($\sigma_1 > \sigma_2 = \sigma_3$) conducted at room temperature, on water-saturated samples, with a constant pore pressure P_P of 10 MPa and an effective pressure $P_{EFF} = P_C - P_P$ of 80 and 120 MPa

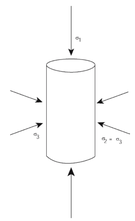

Fig. 4 Schematic representation of the state of stress of a cylindrical sample during tests (Paterson, 1978)

Results so far

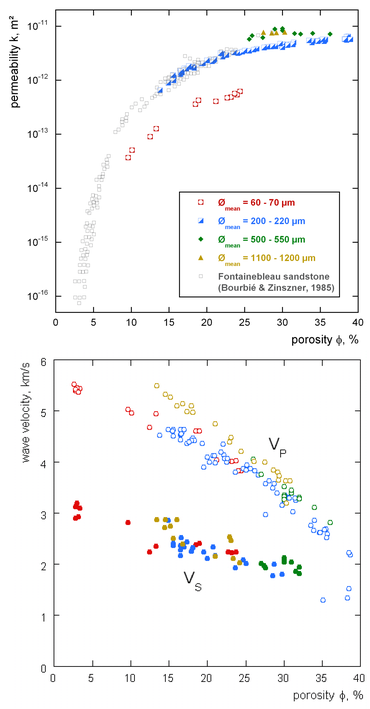

Fig. 5 (left)
(top) Compilation of porosity-permeability data for synthetic samples of four different grain sizes with porosity-permeability data for Fontainebleau sandstone (Bourbie & Zinszner, 1985)
(bottom) Porosity dependance of P and S-waves velocity in synthetic rocks of different grain sizes.

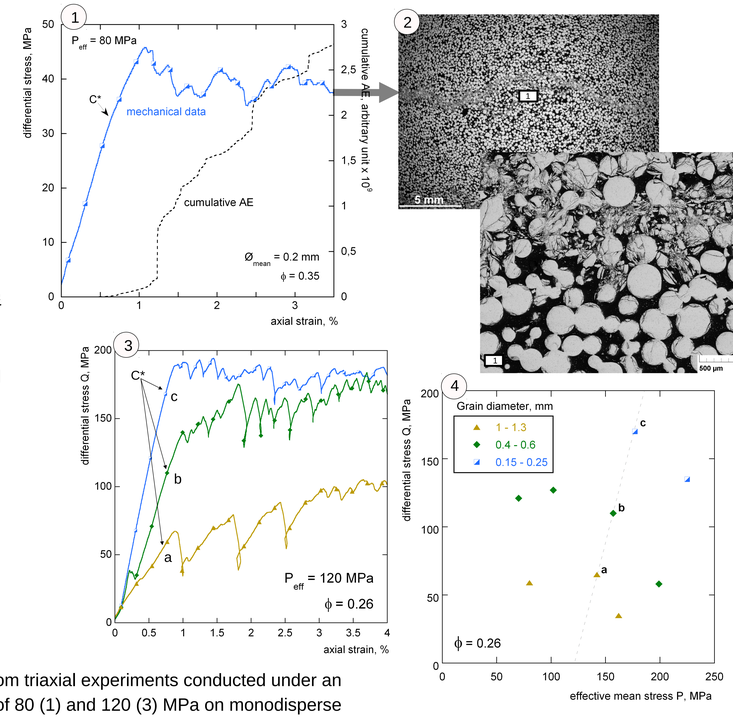

Fig 6. (right)
Mechanical data from triaxial experiments conducted under an effective pressure of 80 (1) and 120 (3) MPa on monodisperse samples of 35 % (1) and 26 % (3) porosity and mean grain diameter of 1.15 mm (yellow), 0.5 mm (green), 0.2 mm (blue). (2) SEM images of the microstructure of the sample of 35 % porosity and 0.15 mm grain size show discrete compaction bands, 2-3 grains wide, oriented perpendicularly to σ_1. Stress drops and concomitant acoustic emissions bursts are observed in the inelastic part of the mechanical data. Such features on the mechanical data are usually associated to the inception of localised deformation in the form of compaction bands. Maximale amplitude of the drops is positively correlated to grain diameter. Critical stresses at the onset of shear-enhanced compaction were identified using mechanical data and acoustic emissions. A compilation of these critical values is presented in (4).

Literature cited

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Conclusions and further work

Sintering glass beads is an effective method to prepare reproducible synthetic rocks which microstructure is analogous to monomineral well-sorted sandstones. Porosity and grain size of the synthetic samples exert a key-control on their bulk properties, such as permeability, P-wave velocity and strength. Mechanical data from triaxial experiments under high confinement on samples of 26 and 35% of porosity demonstrated signature features of compaction localisation. Amplitude of the characteristic stress drops is positively correlated to grain size. To investigate the relationship between grain size, porosity and microstructural attributes of the compaction bands, thin sections of the deformed samples are being prepared and will be studied.