Progress towards understanding the broadband elastic dispersion in fluid-saturated cracked media from laboratory measurements

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Introduction

The characteristics of mechanical waves propagating through highly porous and permeable porous materials is much studied and appears, for the most part, to be well described by Biot-type models that account for the differential motions of the saturant with the solid frame. This does not necessarily account, however, the behaviour of most real rocks often containing compressible crack-like pores. The greater compliance of these cracks relative to more equant pores they are connected causes local variations in the pore pressure that drives fluid motion. The flux depends on the acting permeability and the fluid viscosity that in turn causes the system's behaviour to depend on the timescale with a number of regimes having been suggested. At the highest frequencies there is insufficient time for fluids to redistribute between adjacent pores; this is the saturated-isolated case. At somewhat lower frequencies fluids can move in what is often referred to as 'squirt flow' in the saturated-isobaric regime. At the lowest frequencies, the fluid can completely drain to an external reservoir. To a large degree, however, this validity of this model remains speculative and in need of experimental validation. Here we review our progress in experimentally studying this problem with the bulk of the material below originating in the theses of Schijns (2014) and Li (2016) with a brief overview in Li et al. (2014).

Methods

The studies to date have focussed on either natural quartzite, sintered composites of glass beads, or a glass rod all cracked by thermal shock. Cylindrical samples were machined from these damaged materials and the elastic moduli measured by ultrasonic pulse transmission at ~ 1 MHz (at the U of Alberta) and by torsion and flexure at low frequencies of 0.01 to 1 Hz (at ANU). We plan to extend these measurements to intermediate frequencies using resonance methods (at LBNL) These methods produced complementary materials with high crack porosities approaching 2.5%. The same samples were used in both sets of experiments. Suites of tests were carried out with the samples completely dry and saturated with either Ar or distilled water and over ranges of effective confining pressures from 5 MPa to nearly 200 MPa. The use of the two fluids allows for the influence of viscosity to be explored.

Results and Discussion

We provide here one illustrative set (Fig. 1) of measurements carried out on the cracked Cape Sorell quartzite under the various saturation conditions and in both apparatus. These cracked materials as expected all displayed a high sensitivity of the moduli and permeabilities to confining pressures. Interestingly, the low frequency (0.1 Hz) and ultrasonic (1 MHz) measurements broadly agree for the dry and Ar saturated conditions, the values are largely insensitive to saturation. The water saturated values, however, lie substantially above those for the dry and lower viscosity Ar saturated. The relative stiffening decreases with confining pressure.

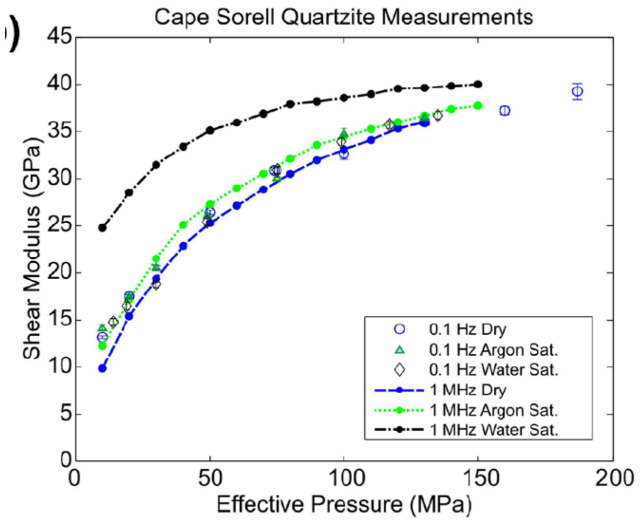

Fig. 1. Observed shear moduli of the cracked Cape Sorell Quartzite as a function of pressure as measured at low (0.1 Hz) and high (1 MHz) frequencies under dry, Ar, and water saturations.

The results are broadly similar for the natural quartzite and sintered glass bead samples, although the pressure dependencies for the glass samples appear to show that the cracks close at lower pressures possibly related to differences in crack dimensions. A second difference is that first glass sample displays significantly greater shear modulus increase at 1 MHz upon Ar saturation in contrast to the observations for the quartzite in Fig. 1.

Conclusions

The deviations in observed moduli between high and low frequencies depends on the fluid saturant and the characteristics of the crack network. The large deviations in the wave speeds serve to reiterate the point that laboratory measurements made at ultrasonic frequencies under fluid saturation need to be interpreted carefully in order to account for potential dispersion.

References

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