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A broadband laboratory study of the seismic properties of cracked and fluid-saturated synthetic glass media

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In order to better understand the frequency dependence or dispersion of seismic-wave speeds and associated strain-energy dissipation in cracked and fluid-saturated crustal rocks, we have conducted a broadband laboratory study of synthetic glass media. The glass materials were prepared either from dense soda-lime-silica glass rod or by sintering glass beads of similar chemical composition. Along with sub-equant pores contributing either 2 or 5% porosity for the sintered-bead specimens, quantifiable densities of cracks, generally of very low aspect ratio, were introduced by controlled thermal cracking. Permeability was measured under selected conditions of confining and pore pressure either by transient decay with argon pore fluid or with the steady-flow method and water pore fluid. The water permeability of the cracked glass-rod specimen decreased strongly with increasing differential pressure Pd to $\sim$ 10-18 m2 near 10 MPa. Further increase of differential pressure towards 100 MPa resulted in modest reductions of permeability to specimen-specific values in the range (0.5 – 2) $\times$ 10-19 m2. The characteristic frequencies for the draining of cylindrical specimens of such low permeability are estimated to be < 10 mHz, so that undrained conditions can be expected even at the 10-300 mHz frequencies of the forced-oscillation tests. The same or similarly prepared glass specimens were mechanically tested with sub-Hz forced-oscillation methods, a kHz-frequency resonant bar technique, and MHz-frequency ultrasonic wave propagation, before and after thermal cracking. The cracked specimens were successively measured under dry, argon- (or nitrogen-) saturated and water-saturated conditions. The shear and Young's moduli measured on the cracked materials typically increase strongly with increasing differential pressure below a threshold of $\sim$30 MPa beyond which the pressure sensitivity becomes substantially milder. This behaviour is quantitatively interpreted in terms of pressure-induced crack closure, inferred also from in situ X-ray tomography, through differential effective medium theory. In this approach, the pressure-dependent bulk and shear modulus deficits for the dry cracked media, are used to infer the crack density, whose pressure sensitivity in turn yields the zero-pressure distribution of crack aspect ratios. The aspect-ratio distributions inferred in this way for each of the cracked glass media are dominated by narrow cracks of aspect ratio < 4 $\times$ 10-4. Comparison of the moduli measured dry, argon- (or nitrogen) saturated, and water saturated, reveals systematic increases of the effective shear and Young's moduli on fluid saturation of each material at MHz frequency, which at least for water saturation, persist to the lower kHz and sub-Hz frequencies. Such stiffening on fluid saturation is characteristic of the saturated-isolated regime in which stress-induced gradients in pore pressure remain unrelaxed. In marked contrast, the elastic moduli measured at sub-Hz frequencies on the cracked sintered glass-bead specimen of 5% porosity, are unaffected by fluid saturation – diagnostic of the saturated-isobaric regime. Such observations of frequency-dependent effective elastic moduli for cracked and fluid-saturated media underscore the need for care in the application of conventional laboratory ultrasonic data at the much lower frequencies of field seismology.