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Shape matters: pore geometry and orientation influences the strength and stiffness of porous rocks

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The geometry of voids in porous rock fall between two end-members: very low aspect ratio (the ratio of the minor to the major semi-axis) microcracks and perfectly spherical pores with an aspect ratio of unity. Although the effect of these end-member geometries on the mechanical behaviour of porous rock has received considerable attention, our understanding of the influence of voids with an intermediate aspect ratio is much less robust. Here we perform two-dimensional numerical simulations (Rock Failure Process Analysis, RFPA2D) to better understand the influence of pore aspect ratio (from 0.2 to 1.0) and the angle between the pore major axis and the applied stress (from 0 to 90°) on the mechanical behaviour of porous rock. Our numerical simulations show that, for a fixed aspect ratio (0.5) the uniaxial compressive strength and Young's modulus of porous rock can be reduced by a factor of ∼2.4 and ∼1.3, respectively, as the angle between the major axis of the elliptical pores and the applied stress is rotated from 0 to 90°. This weakening effect is accentuated at higher porosities. The influence of pore aspect ratio (which we vary from 0.2 to 1.0) on strength and Young's modulus depends on the pore angle. At low angles (∼0-10°) an increase in aspect ratio reduces the strength and Young's modulus. At higher angles (∼40-90°), however, strength and Young's modulus increase as aspect ratio is increased. At intermediate angles (∼20-30°), strength and Young's modulus first increase and then decrease as pore aspect ratio approaches unity. We find that the analytical solutions for the stress and Young's modulus at the boundary of a single elliptical pore are in excellent agreement with our numerical simulations. The results of our numerical modelling are also in agreement with recent experimental data for porous basalt, but fail to capture the strength anisotropy observed in experiments on sandstone. The alignment of grains or platy minerals such as clays may play an important role in controlling strength anisotropy in porous sandstones. The modelling presented herein shows that porous rocks containing elliptical pores can display a strength and stiffness anisotropy, with implications for the preservation and destruction of porosity and permeability, as well as the distribution of stress and strain within the Earth's crust.