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A directional Kaiser damage-memory effect under true-triaxial loading

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Microcrack damage leading to failure in rocks evolves in response to differential loading. The vast majority of experimental studies investigate damage evolution, the ‘Kaiser damage-memory’ effect and rock failure using conventional triaxial stress states ($\sigma 1 > \sigma 2 = \sigma 3$). Such stress states develop a crack population that displays cylindrical transverse isotropy. However, in nature the stress state is in general truly triaxial ($\sigma 1 > \sigma 2 > \sigma 3$) and experiments that utilise such loading conditions can generate crack populations that display planar transverse isotropy which in turn effects properties such as permeability and strength. We investigate the evolution of crack damage under both conventional and true triaxial stress conditions using results from measurements made on cubic samples of sandstone deformed in three orthogonal directions with independently controlled stress paths. We have measured, simultaneously with stress and strain, the changes in ultrasonic compressional and shear wave velocities in the three principal directions, together with the bulk acoustic emission (AE) output. Changes in acoustic wave velocities are associated with both elastic closure and opening of pre-existing cracks, and the inelastic formation of new cracks. By contrast, AE is associated only with the inelastic growth of new crack damage and so we use the onset of AE to determine the onset of new crack damage. By mapping these damage onsets under both conventional triaxial and true traixial sequential cyclic loading we have shown that ‘damage envelopes’ evolve dynamically and can be pushed closer to the failure envelope. Whether a stress state has been ‘visited’ before is key to determining and understanding damage states. Crack damage populations can be generated with multiple orientations depending on the arrangement of loading directions and hence principal stress directions. The sequential cyclic loading tests show that further damage in any one population commences only when the previous maximum differential stress ‘seen’ by that population is exceeded. Understanding anisotropic damage is important for applying the results of true-triaxial tests and hence better replicating natural fractured systems.