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Time-dependent brittle creep in Sandstone

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The characterization of time-dependent brittle deformation is fundamental to understanding the long-term evolution and dynamics of the Earth's upper crust. The chemical influence of water promotes time-dependent deformation through such mechanisms as stress corrosion cracking that allows rocks to deform at stresses far below their short-term failure strength and at very low strain rates. Stress corrosion crack growth is highly non-linear and accelerates towards dynamic failure over extended periods of time, even at constant applied stress (brittle creep). Recent theoretical models, based on mean-field damage mechanics, suggest that the growth and interaction of cracks during brittle creep leads to acceleration to failure once a critical damage threshold has been reached.

Here we report results from a study of time-dependent brittle creep in water-saturated samples of porous sandstones under triaxial stress at a confining pressure of 50 MPa and a pore fluid pressure of 20 MPa. The sandstones studied were: Bentheim sandstone with an initial porosity of 23%, and Darley Dale sandstone with an initial porosity of 13%. Since the processes involved are highly non-linear, it has been necessary to run experiments over several orders of magnitude in time (from tens of minutes to tens of days), resulting in creep strain rates in the range 10^{-6} to 10^{-9} s^{-1}. Crack damage evolution has been monitored throughout each experiment by measuring the damage proxies of strain, volume change and output of acoustic emission energy. We have also quantified the level of damage independently using quantitative microstructural analysis of the spatial distribution of cracks in post-test samples using optical and scanning electron microscopy. We find that the level of crack damage required to initiate the acceleration to failure, as measured by all our damage proxies, is approximately the same regardless of the applied creep stress and the resulting creep strain rate. These results therefore support the idea of a critical damage threshold for the transition form stable (secondary) creep to unstable (tertiary) creep.

Recent pilot experiments also suggest that the creep strain rate increases with increasing pore fluid pressure even when the differential stress is maintained at constant value. This further supports our interpretation that brittle creep is due to stress corrosion, with the chemical activity of water enhanced at higher pressures. This contrasts with the purely mechanical effect of a pressurized pore fluid predicted by the effective stress law.