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Residual strain change resulting from stress corrosion in Carrara marble

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Residual stresses and strains have been shown to play a fundamental role in determining the elastic behavior of engineering materials, yet the effect of these strains on brittle and elastic behavior of rocks remains unclear. In order to evaluate the impact of stored elastic strains on fracture propagation in rock, we undertook a four-month-long three-point bending test on three large 1100 x 100 x 100 mm Carrara Marble samples. This test induced stable low stress conditions in which strains were concentrated at the tip of a saw cut and pre-cracked notch. A corrosive environment was created at the tip of the notch on two samples (M2 and M4) by dripping calcite saturated water (pH $\sim$ 7.5-8). Sample M5 was loaded in the same way, but kept dry. Samples were unloaded prior to failure, and along with an additional non-loaded reference sample (M0), cored into cylindrical subsamples (ø = 50 mm, h = 100 mm) before being tested for changes in residual elastic strains at the SALSA neutron diffractometer at the Institute Laue-Langevin (ILL), Grenoble, France. Three diffraction peaks corresponding to crystallographic planes hkl (110), (104) and (006) were measured in all three spatial directions relative to the notch. Shifts in the diffraction peak position (d) with respect to a strain free state are indicative of intergranular strain, while changes in the width of the peak (FWHM) reflect changes in intragranular strain.

We observe distinctly different patterns in residual and volumetric strains in hkℓ (104) and (006) for the dry M5 and wet tested samples (M2 and M4) indicating the presence of water changes the deformation mechanism, while (110) is strained in compression around 200 μstrain in all samples. A broadening of the diffraction peaks (006) and (110) in front of the crack tip is observed in M2 and M4, while M5 shows no changes in the peak width throughout the depth of the sample. We suggest water present at the crack tip increased the rate of corrosion, allowing a greater relaxation of extensional strains during the preparatory test, leading to a subsequent increase in compression when the samples were returned to the neutral position prior to our measurement. Thin sections of the notch area help confirm these observations, as a narrow but continuous fracture following grain boundaries is evident in M4 and M2. M5 shows a buildup of extensional strains in the notch tip area due to low loading, though no cracking is evident.

These results provide exceptional insight into the physics of fracture propagation under typical real-world conditions. We observe notably different mechanical inter- and intragranular responses to long-term static low loading under either wet or dry conditions, a result which contributes significantly to our ability to evaluate the potential impact of changes in (for example) rainfall distribution, chemistry, and meltwater production on tensile fracture propagation and alpine rock slope stability.