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Understanding three-dimensional damage envelopes

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Microcrack damage leading to failure in rocks evolves in response to differential loading. This loading is often visualized in a two-dimensional stress space through the use of Mohr-Coulomb diagrams. The vast majority of experimental studies investigate damage evolution and rock failure using conventional triaxial stress states ($\sigma 1 > \sigma 2 = \sigma 3$) in which the results can be easily represented in a Mohr-Coulomb plot. However, in nature the stress state is in general truly triaxial ($\sigma 1 > \sigma 2 > \sigma 3$) and as such comprises a 3D stress state potentially leading to more complexity. By monitoring acoustic wave velocities and acoustic emissions we have shown that damage is generated in multiple orientations depending on the loading directions and hence principal stress directions. Furthermore, crack growth is shown to be a function of differential stress regardless of the mean stress. As such, new cracks can form due to a decrease in the minimum principal stress, which reduces mean stress but increases the differential stress. Although the size of individual cracks is not affected by the intermediate principal stress it has been shown that the $\sigma 2$ plays a key role in suppressing the total amount of crack growth and concentrates this damage in a single plane. Hence, the differential stress at which rocks fail (i.e. the rock strength) will be significantly increased under true triaxial stress conditions than under the much more commonly applied condition of conventional triaxial stress. Through a series of cyclic loading tests we investigated the Kaiser effect, we show that while individual stress states are important, the stress path by which this stress state is reached is equally important. Whether or not a stress state has been ‘visited’ before is also vitally important in determining and understanding damage envelopes. Finally, we show that damage evolution can be anisotropic and must be considered as a three-dimensional problem. It is unclear how damage envelopes develop in response to the intermediate principal stress but such understanding is important for understanding three-dimensional crack damage evolution in fault zones.