A visco-elastic damage rheology and rate- and state-dependent friction

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We present relations between a visco-elastic damage rheology model and rate- and state-dependent (RS) friction. Both frameworks describe brittle deformation, although the former implies a deforming zone while the latter may be associated with sliding surfaces. At present, the most detailed description of rock friction is provided by the RS friction. This framework accounts for the evolution of frictional strength as a function of slip, slip-velocity and state variables that characterize properties of the sliding surfaces. The RS friction provides a conceptual framework incorporating the main stages of an earthquake cycle. However, this formulation does not provide a mechanism for possible evolution of the geometry and elastic properties of the deforming rocks. Such processes are accounted for in damage rheology models that generalize Hookean elasticity to inelastic brittle deformation by relating an intensive damage state variable to evolving elastic properties. Analyses of stress-strain and acoustic emission laboratory data during deformation leading to brittle failure indicate [Hamiel et al., 2004] that the fit between model predictions and observations improves if we also incorporate gradual accumulation of a non-reversible deformation with a rate proportional to the rate of damage increase. Shear strain larger than a threshold value induces material degradation, while post-failure behavior under lower strain produces healing. This allows for an overall cyclic stick-slip motion along a narrow zone with localized damage. Each deformation cycle (limit cycle) can be divided into healing and weakening periods associated with decreasing and increasing damage, respectively. Analytical and numerical results demonstrate the connection between kinetic parameters of the damage rheology model and the frictional parameters (conventionally referred to as \(a\) and \(b\)). The direct effect and the magnitude of the frictional parameter \(a\) are related to the material strengthening with increasing rate of loading. The strength and residence time of asperities (elements) in a weakening stage depends on the rates of damage and irreversible strain accumulation. The transient stage and overall change in friction parameters \((a-b)\) are controlled by the duration of the healing stage and asperity (element) strengthening during this stage. For a model with spatially variable properties, the damage rheology reproduces the logarithmic dependency of steady-state friction on both the sliding velocity and the normal stress. The transition from a velocity strengthening regime to a velocity weakening can be obtained by varying the rate of inelastic strain accumulation and keeping the other damage rheology parameters fixed.