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Secondary faulting behavior characterized by nondimensional parameters associated with damage evolution

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We construct a simple, unified model with nondimensional parameters to explain the diversity observed in secondary faulting development in terms of damage (microcrack) generation. Secondary faulting is defined here as the faulting around the main fault plane such as fault rock pulverization and branch development and have smaller scales than the main fault. This behavior is considered to occur as a consequence of damage evolution. They occur separately sometimes, while sometimes they are observed simultaneously. We employ the damage tensor D, which represents the damage state, and the energy release rate tensor Y for formulating mathematical framework to explain this diversity. A parameter Yc is also used in the present framework as the material yielding criterion assumed for Y; if the component of Y excesses Yc, the material is regarded to be yielded. We assume a two-dimensional fault.

There are two important nondimensional parameters consisting of three material parameters with a dimension of stress, eta2, eta4 and Yc, in the present framework; the parameter eta2 represents the effect of damage amount on a constitutive relationship, while the parameter eta4 represents the effect of damage orientation on the constitutive relationship. Therefore, the first nondimensional parameter gamma=eta4/eta2 determines how the microcrack distribution deviates from the isotropic one. It should be noted that eigenvalue for D stands for number density of microcracks whose normal orientation is in the direction of eigenvector for the eigenvalue. The analytical form of the damage tensor shows that the two eigenvalues for D are the same with the condition gamma=0. Microcracks with any orientation appear in this case and only the isotropic fault rock pulverization is expected regardless of the value of $Yc*=Yc/eta2$, the second nondimensional parameter and nondimensional yielding criterion. If gamma is not equal to zero, the two eigenvalues are different and normal orientations of microcracks tend to have similar directions with increasing gamma. In particular, if gamma increases infinity, one of the eigenvalues approaches zero and all the microcracks have the same normal orientation. The tendency for microcrack orientation is related to the branch development angle from the main fault plane. However, in intermediate cases for gamma, it should be noted that both isotropic fault rock pulverization and branch development can appear. If $Yc*$ is selected appropriately, both phenomena are found to occur simultaneously. The parameter $Yc*$ also plays an important role on determining the secondary faulting behavior in these cases.

Nondimensional parameters gamma and $Yc*$ can be concluded to play important roles to determine how the secondary faulting behavior occurs: only isotropic pulverization, only branch development, and both. If the value of gamma is sufficiently small, only pulverization appears. On the other hand, if the value is sufficiently high, branch development occurs. These cases are classified only by gamma and $Yc*$ does not affect the system behavior much. Combination of fault rock pulverization and branch development is characterized by both two nondimensional parameters.

Keywords: damage tensor, nondimensional number, pulverization, branch development