Coalescence of Frictional Fractures in Rock Materials

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ABSTRACT

A unified phenomenological framework is proposed for fracturing phenomena in pre-cracked brittle materials. The framework is developed based on experimental observations from gypsum specimens loaded in uniaxial compression, with either open or closed (frictional) pre-existing discontinuities (flaws). The existing database that included observations from open flaws has been completed with an extensive series of laboratory experiments on gypsum specimens with three closed flaws.

Similar types of cracks and coalescence patterns are observed in specimens with open or closed cracks. Three types of cracks can occur: wing cracks, coplanar, and oblique secondary cracks. Wing cracks are tensile cracks that initiate at or near the tips of the flaws, are stable, and propagate in the direction of maximum compression. Secondary cracks are shear cracks. They are initially stable but may become unstable near coalescence. Coalescence is produced by the linkage of two flaws through wing cracks, secondary cracks, or a combination of wing and secondary cracks. When coalescence occurs through wing cracks only or through a combination of wing and secondary cracks, the process is stable. When coalescence occurs through secondary cracks only, the phenomenon is unstable. Seven types of coalescence have been identified based on the types of cracks that produce linkage of the flaws. The types of coalescence are related to the distribution of the flaws. In left stepping geometries coalescence generally involves wing cracks and/or coplanar shear cracks, while right stepping geometries tend to favor coalescence through wing cracks and/or oblique shear cracks. The laboratory experiments show that coalescence through wing cracks takes precedence. When this type of coalescence is not possible, the mechanism that takes priority is a combination of shear and tensile cracks. The last priority is for coalescence through shear cracks only. Thus coalescence stresses are the smallest when the linkage is through wing cracks and they are the largest when the linkage is through shear cracks only. The principal difference between experimental results from open and closed flaws is that initiation and coalescence stresses are higher for closed flaws than for open flaws. This is due to the friction along the closed flaws, which must be overcome before a crack can initiate and by the capability of closed flaws of transmitting normal stresses.

A new crack initiation criterion has been proposed based on the critical energy release rate. The criterion states that a tensile crack will initiate when the mode I energy release rate reaches the critical energy release rate G_{IC}, which is material dependent, and along the direction where the energy release rate is maximum. An analogous criterion applies for shear cracks, where initiation occurs when the mode II energy release rate reaches the critical value G_{IIC}, also a material property. The criterion has been implemented into the code FROCK. Comparisons between predictions from the code and experiments show that the criterion is able to predict initiation of the wing cracks and of the two types of secondary cracks, as well as the types of coalescence. Initiation stresses and angles are simulated within experimental results. The types of coalescence are predicted well for open flaws with left stepping geometries, while larger differences are observed for closed flaws and in particular for right stepping geometries.