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DERIVATION OF COHESIVE-ZONE MODELS ACCOUNTING FOR FRICTION AND DILATANCY

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Cohesive-zone models (CZMs) are widely used to simulate initiation and propagation of cracks along structural interfaces. They represent an effective alternative approach to fracture-mechanics-based methods for a wide variety of problems at very different scales, such as crack growth in dams, mortar-joint failure in brick masonry, bond-slip response of reinforcing bars in concrete, debonding of adhesive joints, delamination or fibre-matrix debonding in composites, among many others. Many of such problems entail combination of mode II and compressive mode I, whereby a significant amount of energy is dissipated in the process due to friction, which is often accompanied by dilatancy. Therefore, in order to formulate models that properly account for the underlying physics of the problem it is essential to capture the distinct types of dissipation due to fracture and friction, the role played by the geometry of the asperities along the interface and the associated interlocking effect.

Several interface models accounting for damage-friction coupling have been proposed in literature, see e.g. Del Piero and Raous [1] and references therein. Some of them are based on nonassociative softening plasticity, as for the multidissipative interface model proposed by Cocchetti et al. [2] and the contributions given by Bolzon and Cocchetti [3] and by Červenka et al. [4] in the field of concrete dams analysis, and by Giambanco et al. [5].

A different strategy was followed by Alfano and Sacco [6], Alfano et al. [7] and, more recently, Sacco and Toti [8], where interface damage and friction have been combined in a cohesive zone model based on a simplified micromechanical formulation. The main idea was to consider a representative area at a micromechanical scale, which is assumed to be additively decomposed into an undamaged and a fully damaged part; moreover, it is supposed that friction occurs only on the latter. The evolution of damage is assumed to depend on the elastic energy in the undamaged part while the frictional behaviour is governed by a Coulomb law. To simulate dilatancy and interlocking this approach was adopted by Serpieri and Alfano [9], within a multi-scale framework in which, at a small scale, the asperities of the interface are represented in the form of a periodic arrangement of distinct inclined planes, denominated Representative Interface Element (RIE); the interaction within each of these surfaces is governed by the formulation proposed in Alfano and Sacco (2006).

The above formulation by Serpieri and Alfano was recently revisited by Sacco et al. [10], where it was shown that use of a single damage variable, combined with the choice of having a threshold damage function only depending on the damage variable itself and an equivalent displacement norm, requires coincidence of fracture energies in modes I and II to preserve thermodynamic consistency. Furthermore, it was shown that by enhancing the model to account for friction and interlocking, the latter associated with the interface roughness, based on the simplified, yet physically well justified, micro-mechanical assumptions made by Serpieri and Alfano [9], results in retrieving the experimental evidence that the measured fracture energy in mode II is typically quite higher than in mode I, with good agreement with experimental results reported in the literature.

In this contribution, after a review of the above formulations [6-10] within the framework of thermodynamics with internal variables, the attention is focused on some of the current open issues: in particular, the methods presented in Refs. [9, 10] do not account for the finite size of the asperities on the interface; this leads to infinite dilatancy and therefore restricts the range of validity of the formulation. Methods to overcome this shortcoming will be presented and discussed together with their numerical and experimental validation.

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