A multi-scale model for interfaces with a jagged deformation and failure mechanism

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Damage initiation in many multi-phase materials can be attributed to a peculiar deformation mode, where one of the phases deforms anisotropically by forming serrated, jagged, interface impinging on another (approximately isotropic) phase. This locally induces large strain concentrations at the fine scale in the near-interface second phase, where nano-voids can form and grow, leading to damage and crack formation. Examples include twins impinging on a grain boundary [1], crystalline-amorphous interface [2] or martensite-ferrite interface in advanced multi-phase steels, where martensite islands typically deform by sliding on the retained austenite films [3].

The cohesive zone modelling is by now a well established approach for modelling interface decohesion and damage, avoiding detailed resolution of the detailed micro-(nano-)scale effects. When the interface damage mode involves pure displacement opening (normal and/or tangential to the interface), procedures for phenomenological or multi-scale identification of the cohesive zone law have been well established in the literature. However, to the best of our knowledge, interface damage resulting from the jagged sliding of one of the phase has not yet been considered in the context of interface modelling.

In this contribution, we propose a novel multi-scale, computational homogenization based approach for such interfaces. At the mesoscale, a two-phase mesostructure is considered. The kinematics of the mesoscopic interfacial zone entails an interface separation, which includes the contributions of the jagged sliding active and inactive modes. The inactive mode contribution follows the classical cohesive interface description, while the active mode is driven by the near-interface jagged deformation of the anisotropic phase, leading to an enhanced cohesive interface description. At the microscale, an interfacial zone unit cell resolving the substructure and anisotropic, discrete deformation mode is considered. To describe the formation and growth of the nano-voids in the second phase, a continuum damage model incorporating volumetric and deviatoric damage is adopted. Two effective interface separation quantities associated with the jagged deformation inactive and active modes, are defined and computed from the correlated micro-fluctuations within the interfacial unit cell. Applying the extended Hill-Mandel condition yields the generalized tractions conjugated to these interface kinematic quantities. Relating the effective quantities, leads to an enhanced cohesive law. This microphysics-based effective interface model is fully identified using a set of “off-line” representative unit cell simulations.

The developed effective interface model is numerically validated against fully resolved modelling of infinite mesoscopic interfacial zones. As an example, the model is applied to modelling interface damage in a dual-phase (DP) steel microstructure, where the model performance is validated against microscale experimental results.

References

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