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Multiphysics modeling of adhesive interface with damage and healing

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The nuclear fuel elements of fast reactors summarily consist of a pile of cylindrical mixed oxide fuel pellets, $(U, Pu)O_2$, surrounded by a stainless steel cladding. The fuel pellets are initially separated from cladding by a small radial gap of about 100 μm that can be closed during irradiation because of physical, mechanical and chemical phenomena activated by the temperature and its radial gradient in the pellets and the cladding.
On the one hand, an adhesive phenomenon can be observed at the pellet-to-clad interface after an irradiation under specific conditions: a lasting contact, a temperature at the interface ranging between 500 and 700 °C, a closed gap with a low contact pressure (about 10 MPa), the presence of fission products and of a corrosion layer [1]. On the other hand, the different power cycles along irradiation impose stresses at the interface that can successively lead to an adhesive rupture (loss of contact), a new adhesive interface (after a previous rupture) and damage (modification of the interface physicochemical state). We propose here a multiphysics approach to model this adhesive interface. We are particularly interested in mechanical damage and thermo-chemical effects.

The modeling strategy is as follows: we propose to use cohesive elements with a continuum approach [2]. Constitutive relations between strain and stress in the cohesive elements are defined from thermodynamic potentials with the help of supplementary internal variables, in order to take into account damage and chemical conversion [3]. The chemical conversion allows to model the creation or re-creation (healing) of adhesive bonds and is coupled to the thermo-mechanical state. Damage is taken into account with a progressive and continuum damage law. Damage is also coupled to the thermo-mechanical state and it only takes place in traction or shear of the interface. The chemical conversion is only allowed when a sufficient level of compression is reached. The constitutive model is implemented in a Finite element software.

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