Implementing continuum damage-healing mechanics within a multiscale finite element setting

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ABSTRACT

Self-healing materials are a subclass of smart materials that have the ability to repair damage inflicted by various external stimuli e.g. mechanical, chemical, thermal and ballistic amongst many. The self-healing mechanism acts either autonomously and independently (active autonomous systems) or through the action of external stimuli after damage has been detected (passive systems) [1]. The overall dynamic response of structures and structural components consisting of self-healing materials is an intrinsically multiscale phenomenon. A hierarchical scheme emerges that communicates information patterns across different structural scales. A force applied at the macro (structural) scale induces a micro-cracking pattern that in returns triggers the healing agents in the micro-scale. The latter re-define the micro-structural pattern and consequently alter the macroscopically observed structural response, e.g. the measured displacement. Analysis of the effectiveness of various self-healing agents is mainly performed through experimentation while numerical simulation of the process at the material level is performed using Molecular Dynamics [2]. Modelling and simulation of the self-healing process at the structural scale is mainly performed using the Finite Element method and appropriate homogenization procedures [3]. Nevertheless, the complexity of the underlying physical behaviour poses important limitations on the size of the finite element model to be analysed.

In this work a new approach is investigated for the analysis of heterogeneous structures comprising self-healing materials. The method presented is based on the two-level hysteretic multiscale finite element procedure [4]. In this, the damage self-healing mechanism is introduced at the meso-scale by properly defining a set of phenomenological internal variables. The evolution of the latter is based on the theory of continuum damage-healing mechanics [5]. Using a set of numerically evaluated shape-functions, meso-scale information is mapped at the macro scale where solution of the governing equations is performed at a reduced computational cost. Examples are presented to validate the proposed method and assess its merits and drawbacks for the analysis of structural problems.

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