Constitutive modelling of viscoelastic materials coupling damage and healing

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Abstract

Viscoelastic (VE) materials are widely used in many engineering applications, such as aerospace, civil, automobile and medical fields (human skin and bone behave as VE material). These materials show change in their stress response with time, often termed as ageing, due to micro-structural changes. Such changes have a considerable effect on the subsequent degradation and macro-scale failure of the material. Recently, self-healing materials have been developed that can decrease or sometimes completely remove the local damage thereby recovering the original material stiffness (intrinsic and extrinsic self-healing approaches in the absence of material ageing). A damaged VE material, when undergoes healing over a long period of time, the final material properties are influenced by the combined effect of ageing and healing, thus resulting in a stiffness not exactly equal to the virgin material. A broader VE material constitutive model is thus required to capture the combined effects of damage, healing, and ageing. However, at present a model that accurately captures all the said effects is unavailable.

An irreversible thermodynamics-based formulation is adopted in this work to obtain the constitutive response of VE material. A novel form of Helmholtz free energy is proposed (motivated by Simo's approach) accounting viscoelasticity, damage, healing, and ageing effects. Strain energy equivalence for VE material, from continuum damage mechanics (CDM), is employed to relate the current and effective configurations in the presence of damage, ageing, and healing. The stress field in the current configuration thus relates with the corresponding field in the effective configuration through the damage effect tensor. The proposed formulation is also amenable to characterise the damage evolution parameters (capturing hardening, softening, and tertiary creep) from an experimental stress history.

The healing can occur both in the presence and absence of stress. There are several works in literature to model healing in the former case. In this work, the model for the latter case is motivated by the diffusion-based mechanism of healing agent, in the presence of microcapsules (extrinsic healing) containing the healing agent, present in a material. Coupling of stress-free healing with the proposed VE formulation is able to capture the healing process happening in the damaged VE material during rest periods. The resulting VE constitutive and evolution equations are numerically discretized into an incremental form and implemented in the *in-house* developed nonlinear finite element method (FEM) code while solving several boundary value problems (e.g., uniaxial and bi-axial tension, creep test and open hole tests). Physically realistic macro-scale diffused crack paths are thus obtained under various loading and boundary conditions.

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The developed model is also applied to simulate the stress-free healing in the presence of an existing damage (localized damage). The developed model will also be extended in future to study the failures in polymer-based composite (aged and unaged).