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An entropy-driven approach to thermo-mechanical degradation in metallic structures

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Metallic structures subjected to severe thermal transients experience irreversible thermo-mechanical effects driven by localized plastic deformation and transient heat transfer. Conventional strain-based damage models are effective in describing ductile degradation driven by plastic flow, although they do not explicitly account for the thermodynamic nature of irreversible dissipation. In the present work, an entropy-based framework for thermo-mechanical degradation assessment is proposed and implemented within a finite element environment through a user-defined subroutine. The formulation combines entropy generation associated with plastic dissipation and conductive heat transfer, allowing both mechanical and thermal irreversible processes to be considered within a unified nonlinear framework. Temperature-dependent constitutive parameters and toughness-related quantities are included to describe the progressive degradation of the material during transient thermo-mechanical loading. The methodology is applied to a radiation-cooled metallic thruster subjected to severe thermal shock. The comparison with a conventional strain-based damage model shows a close agreement in regions dominated by plastic deformation, whereas the entropy-based formulation remains sensitive to irreversible effects associated with thermal gradients in regions with limited plasticity. The proposed formulation provides a physically consistent and computationally efficient tool for thermo-mechanical degradation assessment in high-temperature metallic structures.

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