CONTINUUM DAMAGE MECHANICS: A MODELING APPROACH FOR COMPREHENSIVE ASSESSMENT OF SUBCRITICAL DAMAGE IN COMPOSITES

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Abstract

The concept of "failure" has served the engineering practice well for designing structures to perform safely in service environments. Historically, this concept has its roots in experience with metals where the onset of undesirable material condition is yielding followed ultimately by unstable behavior characterized by maximum load carrying capacity. This classical concept of material failure was subsequently broadened to include fracture, which deals with onset and instability of growth of a preexisting flaw. In heterogeneous materials, particularly in composites, where multiple materials exist, the failure and fracture concepts are not as straightforward. The concept of damage is instead more useful, with its onset and criticality as two end conditions.

The first author of this paper presented a systematic development for characterizing damage in composite materials, putting forward definitions of damage and damage modes motivated by concepts of irreversible thermodynamics [1]. A vector-valued representation of damage used in that paper served as internal variables in a continuum formulation leading to a set of relationships between the state of damage and its effects on elastic properties averaged over a representative volume element (RVE). Later, for better consistency, the vectorial characterization of damage was replaced by a second order tensor characterization [2] and the resulting formulation was extended and applied to ceramic matrix composites [3], and several cases of polymer matrix laminates [4].

A characteristic feature of the continuum damage mechanics (CDM) model mentioned above was the appearance in the stiffness-damage relationships of certain material constants, in addition to the elasticity constants, that needed evaluation by experimental data. Although theoretically these constants would be different for every laminate configuration, in reality they showed little sensitivity to the laminate configuration, but changed with the constitution of the basic lamina, e.g. being different for glass/epoxy and carbon/epoxy laminae. Still, a parameter called "constraint parameter" introduced in the damage characterization to carry the influence of the plies neighboring to those with matrix cracks on the crack surface displacement had to be evaluated. This problem was alleviated by setting the crack opening displacement (COD) in a cross ply laminate as reference and relative to this evaluating CODs for other laminates by analytical or numerical micromechanics. This synergism of CDM and micromechanics, named synergistic damage mechanics (SDM) was demonstrated for various cases of elastic and viscoelastic composites [5, 6].

The real advantage of CDM (and SDM) lies in its ability to treat multiple cracking modes such as in a commonly used $[0/\pm45/90]_s$ laminate, where the micromechanics type of approaches face difficulties. A CDM formulation can formally express RVE-averaged changes in laminate elastic properties caused by cracking in any number of cracking modes, but the practical application of such relationships would depend on the evaluation of the material constants involved. Our ongoing work with SDM has made significant progress in this respect recently, and these results will be presented in the paper. One complicating aspect, which does not seem to have received much attention, is the changes in the deformational response of laminates induced by shear stresses in the off-axis plies. Some new results on this aspect will also be presented.

Looking ahead, we will argue that CDM based modeling has the most potential to provide a comprehensive approach for assessment of subcritical damage in composite laminates. Aided by judicial input from micromechanics, such as in SDM, and damage evolution analysis, this approach will ultimately form the basis for integrity and durability assessment of composite structures.

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