Overview

ASTM Special Technical Publications relate a long tradition of fundamental contributions to the disciplines of fatigue life prediction and fracture mechanics, with an emphasis on the understanding of the physics of these phenomena and development of appropriate experimental techniques. Some of the earliest, most significant contributions to fracture mechanics, for example, were relayed through ASTM symposia and resulting publications. The discipline of continuum damage mechanics (CDM), essentially the application of internal state variable concepts of nonequilibrium continuum thermodynamics of solids, has received increasing international attention in addressing fatigue and fracture issues in broad classes of materials. To date, CDM has received most attention abroad with particularly significant advances in Europe. One of the primary goals of the *Symposium on Applications of Continuum Damage Mechanics to Fatigue and Fracture*, held 21 May 1996 in Orlando, Florida was to summarize the state-of-the-art in application of damage mechanics to fatigue and fracture problems. As the field advances and its domain of fruitful applications are better understood, it is envisioned that the fatigue and fracture communities will embrace it to address many complex issues such as crack tip process zone mechanics, size and constraint effects, interaction of multiple damage modes, length scale issues in mechanics of fatigue and fracture, and so on.

There are several important characteristics of CDM. In this approach, various forms of distributed damage are represented by smooth, continuous field quantities. As damage accumulates, the elastic and/or elastic-plastic stiffness degrades. The evolution of damage is typically specified through a set of first order rate equations. Multiple damage mechanics may be coupled with the thermomechanical deformation response. The CDM constitutive description is inevitably integrated within a computationally-based framework along with the governing equations of conservation of mass, momentum and energy, so that notions of ''global'' parameters which have prevailed in the early years of fracture and fatigue mechanics yield to more detailed, mechanistic local descriptions. The limitations of global approaches, which are recognized as efficient engineering tools, therefore, will be much better understood with the advent of more and more CDM applications. In some cases, computational CDM approaches will form the basis for materials design and selection for given applications.

It is instructive to contrast CDM with ''micromechanics,'' another contemporary treatment of heterogeneous materials such as composites. Micromechanics typically involves application of continuum elasticity or plasticity theories to each of the individual constituents, with volume averaging over a unit cell or a representative volume element to achieve an equivalent homogeneous description at a higher length scale. The derivation of void growth theories in ductile elasto-plastic solids is a good example, as is the theory of multiple microcracked brittle solids based on Green's functions. In some cases, micromechanics involves a local analysis of a dominant deformation or failure mechanism, without volume averaging; these solutions are sometimes useful in tailoring particular features of material microstructure to impart improved resistance to deformation or failure. They can also provide detailed information regarding the driving forces for evolution of damage. CDM may incorporate micromechanics results into its overall structure, as in the case of the aforementioned void growth theories, but has greater breadth of scope, also potentially incorporating statistical mechanics aspects of evolution of damage and experimentally measured/inferred information. In fact, the overall framework of CDM, based on the use of internal state variables to represent evolving structure of the material, appeals strongly to irreversible statistical thermodynamics. CDM relations can also be constructed from experiments, which can yield information regarding the proper choice of internal state variables and their evolution. Invariably, experiments form the basis for validating CDM models built up from micromechanics approaches at lower length scales. Hence, CDM is typically a hybrid approach, blending observation with some degree of empiricism along with idealized analyses of specific mechanisms.

These features render the framework of CDM useful for applications involving distributed defects in the presence of nonlinearities of various sorts such as inelastic flow, distributed frictional effects, and complex many-body interaction problems at various length scales. These sorts of problems are extremely difficult to pose properly for analytic micromechanical solution, notwithstanding whether the solution can be reasonably obtained for even well-posed problems. CDM is often useful as a constitutive framework for structural analysis, including *changes* of average local properties with evolution of damage.

In some cases where micromechanics solutions are abundant and where certain average properties are assumed, these solutions may be *explicitly* incorporated into CDM. Indeed, this is highlighted in some of the composites papers presented at this Symposium.

Some of the more difficult challenges facing CDM are shared with other constitutive equations in continuum theories which seek to model effects of distributed sources of irreversible behavior. For example, local theories of CDM are subject to dependence upon the details of the numerical mesh and degree of refinement. Some current research aims to introduce material length scales which are associated with the mesh, or to introduce nonlocal effects through gradient terms in the CDM formulation or through mesh averaging procedures. Weighting the influence of distributed damage at the microscale on the collective macroscale stiffness and evolution of damage is a challenge as well.

Effective medium approaches have been well-established in micromechanics to model the change of stiffness associated with a given state of damage. However, the evolution of damage remains a fertile subject for new developments. Generalization of energy release rate concepts to distributed damage is a natural feature of CDM, but distribution effects which depend strongly on nearest neighbor or second nearest neighbor spacing and clustering of defects have not been fully incorporated. Furthermore, many constitutive laws for engineering materials require a description of the effects of damage occurring at multiple length scales, with couplings between these scales. A good example is the influence in in situ matrix heterogeneity, microstructure and residual stresses on load transfer, and interface damage in composites. Defects are rarely observed to be periodically distributed in the material; rigorous treatment of nonuniformly distributed defects requires tools not yet fully developed in CDM.

A number of technologies have already benefited from the use of CDM, such as constraint effects in ductile fracture, modeling formability and impact damage, dynamic fracture, time dependent crack growth, fatigue crack initiation, creep-fatigue interaction and distributed damage in composites. Potential areas of application that might interest readers of this STP abound. These include, among others, crack tip process zone studies in fracture, crack growth history effects, validity limits of fracture mechanics (LEFM, EPFM and TDFM), fracture in heterogeneous materials, tailoring microstructures and reinforcement architectures of advanced materials for fracture and fatigue resistance, and modeling process-induced damage during primary forming, machining, solidification, or welding/joining.

Among the authors of this volume are some of the pioneers of CDM as applied to fatigue and fracture problems involving both monolithic and composite materials. This field first emerged from development of continuum theories for creep damage evolution in the late 1950s, and its development flourished in the European community. Within the past few decades, it has received increased attention in the fields of fracture and fatigue of materials. This realm of applications are the focus of this Special Technical Publication.

This Symposium sought to explore the state-of-the-art in CDM model development as well as its industrial usage, both in the United States and abroad. The integration of CDM into tools for assessing effects of processing, deformation and constraint on fracture was one arena of direct applicability to recent ASTM E8 technical thrusts. Applications involving the use of standard and nonstandard experiments to characterize CDM parameters were also an area of exploration.

The papers in this STP are organized into several categories. The first set of papers deal with various aspects of modeling damage in composite materials. Some of the papers concern effects of high temperature environmental degradation, fatigue and viscous damage in metal and ceramic matrix composites. Theories are introduced which account for anisotropy, matrix microcracking, and delamination of composite layups. Here, we see examples of the use of micromechanics and experimental observations to construct useful damage mechanics relations for composites, including evolution of damage as well as relations for stiffness degradation.

A second set of papers deals with some of the issues related to the scaling of effects of distributed damage on behavior at a higher length scale, for example, macroscopic. Special attention is focused on the dependence of the evolution of damage on nonuniformity of its distribution. Finally, a set of papers deals with various application examples of CDM, including particle erosion damage, fracture of weldments, and impact damage. We trust that this Special Technical Publication will provide valuable insight into the capabilities of CDM, as well as its future possibilities for fruitful application to the subjects of fracture and fatigue.

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