Engineering Damage Mechanics

Ductile, Creep, Fatigue and Brittle Failures

Bearbeitet von
Jean Lemaitre, Rodrigue Desmorat

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Introduction

The single apple has become a tree, an apple tree painted by Annie Lemaitre from which two apples fell on the cover page! A decade after "A Course on Damage Mechanics" the topic has grown up to reach the field of applications. Aircraft engines and, more generally, aeronautics, nuclear power plants, metal forming, civil engineering, and the automotive industry have already developed and benifited from damage-based methods to increase performance and security. The time has come to propose simplified or more advanced methods, structured in a unified framework to designers of any mechanical components such as early design with fast calculation of structural failures by closed-form solutions and final validation of solutions by numerical failures analysis. This was the ambition for this book!

This is the reason for having many basic examples and insisting on practical methods such as the difficult problem of the material parameters identification for which a systematic sensitivity analysis is performed for each type of application. Very accurate calculations are too often made with a very poor accuracy of the material parameters! To help, probability concepts are introduced either for random loadings or scatter due to microdefects in the materials. This is done mainly for fatigue failure phenomena and brittle materials but may apply to other cases.

Damage mechanics applies to all materials, including metals and alloys, polymers, elastomers, composites, and concrete, because even if the mechanisms are different on a microscale, they have more or less the same qualitative behaviors on meso- or macroscales. Nevertheless, due to data availability most quantitative examples are related to metals.

- The first chapter reassembles the main concepts of Continuum Damage Mechanics, that is the theoretical tools to apply to specific cases: damage variable, isotropic and anisotropic description, thermodynamics which yields methods of damage measurements, damage laws, coupling with strain behavior, localization, and mesocrack initiation.
- The second chapter is a set of numerical tools for solving the nonlinear problems related to damage evaluation in structures. Post-processing clas-

sical structure analysis, either by the time integration of a damage law, solving a micromechanical two-scale damage model, or when damage is not localized, by solving fully coupled strain-damage structural problems.

- The five following chapters are organized in the same way: four sections from the simplest methods with closed-form solutions to more advanced numerical analyses. The first sections "Engineering Considerations" give the domain of application of the chapter. The second sections "Fast Calculations of Structural Failures" describe some simplified methods to be used in early design. They are applied in the third sections "Basic Engineering Examples" to damage failures of members having stress concentration zones, pressurized cylinders and beams in bending. The fourth sections "Numerical Failure Analysis" describe, using examples, more accurate methods for numerical calculations with computers.
  - The third chapter is devoted to ductile failures involving large deformations for applications in metal forming processes or effects of large overloadings on structures in service.
  - The fourth chapter deals with low-cycle fatigue involving important coupling between damage and plasticity for applications on structures heavily burdened by cyclic loadings.
  - The fifth chapter introduces the effects of temperature-inducing creep and its nonlinear interaction with damage for applications on structures loaded statically or cyclically at elevated temperature, or dynamically.
  - The sixth chapter concerns high-cycle fatigue which uses a two-scale damage model of an elasto-plastic damaged inclusion in an elastic matrix with "elastic fatigue" applications from complex histories of loading to three-dimensional and random loadings.
  - The seventh chapter is devoted to brittle and quasi-brittle materials: quasi-brittle when an irreversible process induces damage, brittle when the fracture occurs without any measurable precursor. Statistical and probabilistic methods are used to represent the large scatter generally observed in the failure of these materials. Their applications concern structures made of concrete, ceramics or composite materials.

How should you use the book? As you like it of course but be aware that each chapter is more or less self-contained, with many referrals to the two first chapters of basic concepts of damage mechanics and its numerical processing. Furthermore, at the end of each chapter on applications, the section "Hierachic Approach" is more or less a summary of the chapter with indications on the domain of validity of each model or method. To help engineers, researchers, students, beginners or not, each section is categorized by the number of apples:

🍎 means easy to read, easy to apply.

🍎🍎 means a read with attention and an application with care.

🍎🍎🍎 means a more advanced theory needing a numerical analysis.

Of course this classification is subjective but it has been checked by some friends working mostly in industry: J. Besson from ENSMP Centre des matériaux (Chap. 1), E. Lorentz from Electricité de France (Chap. 2), F. Moussy from Renault (Chap. 3), J.P. Sermage from E.D.F. SEPTEN (Chap. 4), B. Dambrine from SNECMA (Chap. 5), A. Galtier from ARCELOR for (Chap. 6), B. Bary from C.E.A. (Chap. 7), A. Benallal from C.N.R.S.-LMT Cachan and M. Elgueta from Chili University (overall book), and A. Needleman from Brown University who wrote the foreword. Our thanks to all of them for their expertise and advice. "Merci" also to our friends from "Laboratoire de Mécanique et Technologie" at Cachan who participated in the birth of many parts of this book and particularly to Catherine Génin.

Bon courage pour une lecture fructueuse

LMT Cachan, France

Jean Lemaitre
Rodrigue Desmorat