# Preface

This monograph is focused on constitutive description of mechanical behavior of engineering materials: both conventional (e.g., polycrystalline homogeneous isotropic or anisotropic metallic materials) and nonconventional ones (e.g., heterogeneous multicomponent, usually anisotropic composite materials) fabricated by modern material engineering. Effective material properties at the macrolevel depend on both the material microstructure (isotropic or originally anisotropic in general case) as well as dissipative phenomena occurred on fabrication and consecutive loading phase, resulting in irreversible microstructure changes. The material symmetry is a background and anisotropy is a core around which the book is formed. Revision of classical rules of enhanced constitutive description of materials, capable of capturing virgin or acquired anisotropy, hydrostatic pressure dependence, distortion of initial and subsequent yield/failure surfaces, as well as coupled several dissipative phenomena, such as (thermo)elastic, viscoelastic, elastic-plastic-damage, is necessary.

In the past decade new developed technologies for manufacturing of advanced engineering materials have stimulated numerous original papers addressed to more enhanced and rigorous constitutive description and its experimental verification. Among the recent books attempting to combine a progress in constitutive description of complex materials with modern engineering expectations, some can be mentioned. These are: *The Mechanics of Constitutive Modeling* by Ottosen and Ristinmaa, Elsevier 2005; *Advanced Materials and Structures for Extreme Operating Conditions* by Skrzypek, Ganczarski, Rustichelli and Egner, Springer 2008; *Innovative Technological Materials*, Eds. Rustichelli and Skrzypek, Springer 2010; *Continuum Damage Mechanics* by Murakami, Springer 2012; *Damage Mechanics in Metal Forming* by Saanouni, Wiley 2012; *Micromechanics of Composite Materials* by Aboudi, Arnold and Bednarcyk, Elsevier 2013; *Plasticity of Pressure Sensitive Materials*, Eds. Altenbach and Öchsner, Springer 2014, to mention only a few of them. A variety of pioneering original papers given by, e.g., Chaboche, Voyiadjis, Aboudi, Barlat, Khan, and many others, need to be summarized and presented in a comparative way, to emphasize their significance in a growth of knowledge in the field addressed. The present monograph is an attempt to build a bridge between a large number of the new technology inspired and well-experimented established research papers on one hand, and the systematic and comparative study from the viewpoint of rigorous classical thermodynamics-based constitutive descriptions of anisotropic materials on the other hand.

A concise classification of anisotropic materials with respect to symmetry of elastic matrices referred to as crystal lattice symmetry, and the extended analogy between symmetries of constitutive material matrices (elastic and yield/failure), are discussed in Chap. 1. This chapter provides necessary tools for enhanced constitutive description of materials which exhibit the virgin anisotropy or the damage or phase change acquired anisotropy, following microstructural changes. Apart from classical definitions of single tensor invariants, the choice of state variables necessary to describe irreversible microstructural changes accompanying coupled dissipative phenomena, as well as basic definitions of common invariants of either two second-order tensors (e.g., stress/strain and damage tensors) or two different-order tensors (e.g., stress/strain and fourth-order structural tensors), are given.

The aim of Chap. 2 is to show useful enhancement of the Alfrey–Hoff analogy to a broader class of material anisotropy, for which separation of the volumetric and shape change effects from total viscoelastic deformation does not occur. Such extension requires use of the vector–matrix notation for description of the general constitutive response of anisotropic linear viscoelastic material. When implemented to anisotropic composite materials, which exhibit linear viscoelastic response, the classically used homogenization techniques for averaged elastic matrix can be implemented to viscoelastic work-regime for associated fictitious elastic Representative Unit Cell of composite material. Next, subsequent application of the inverse Laplace transformation (cf. Haasemann and Ulbricht) is applied. Similarly, the well-established Hill upper and lower bounds for effective elastic matrices can be extended to anisotropic linear viscoelastic composite materials. In the space of transformed variable, instead of time space, the classical homogenization rules for fictitious elastic composite materials can be adopted.

Mechanics of composite materials in the past decade was one of the most rapidly explored and developed engineering areas, basically due to huge progress in composite fabrication and engineering use. The main problem related to Chap. 3 is focused on and how to correctly predict averaged effective properties by implementation of numerous homogenization techniques. Useful classification of composites with respect to the format of effective stiffness matrix, based on analogy between the crystal lattice symmetry and respective configuration of reinforcement in the RUC, is given. The conventionally used Hill theorem on upper and lower bounds by Voigt and Reuss isotropic estimates, for approximate determination of stiffness and compliance matrices of anisotropic composite, is studied. A consistent application of the Hill theorem to the elements of elastic stiffness or compliance matrices enables to rule out some peculiarities of the Poisson ratio diagrams met in the respective bibliography. The new effective approximation of the mechanical modules of unidirectionally reinforced composites by use of weighted average between the Voigt and Reuss upper and lower estimates is also proposed.

The general nature of yield or failure criteria terminating elastic range of isotropic or anisotropic materials is discussed in Chap. 4. The hydrostatic pressure sensitivity of anisotropic materials can be captured either by the first stress and second common deviatoric invariants' direct use, or by the second common stress invariant use in an indirect fashion. Tension/compression asymmetry in anisotropic materials is accounted for either by presence of the first common invariant (translation only) or third common invariant (distortion). Comparison of two ways to capture anisotropic response: more rigorous explicit common invariant formulations, or implicit approaches based on extension of traditional isotropic criteria in terms of transformed invariants capable of capturing a complete distortion (Barlat, Khan, etc.), is shown. Convexity requirement of limit surfaces is discussed and compared for two material behaviors by use of: Drucker's material stability postulate extended to multi-dissipative response, or Sylvester's stability condition based on positive definiteness of the tangent stiffness or compliance matrices of hyperelastic material. Generalized Drucker's postulate based on elastic-plastic stiffness matrix is also shown.

Basic features of isotropic or anisotropic initial yield criteria are discussed in Chap. 5 following explicit versus implicit formulations. The explicit description of anisotropy is rigorously based on theory of common invariants. The implicit approach involves linear transformation tensor of the Cauchy stress to enhance the classical isotropic criteria for capturing anisotropy, hydrostatic pressure sensitivity, and asymmetry of yield surface. The advantages and differences of both formulations are critically presented. Incidental convexity loss of the classical Hill'48 yield surface in the case of strong orthotropy is examined and highlighted in contrast to unconditionally stable von Mises–Hu–Marin criterion. Different transversely isotropic yield criteria are distinguished in light of irreducibility or reducibility to the isotropic Huber–von Mises criterion in the transverse isotropy plane, and the appropriate class of tetragonal symmetry (classical Hill's formulation) or hexagonal symmetry (hexagonal Hill or von Mises–Hu–Marin criteria) are considered. The new hybrid formulation, applicable for some engineering materials based on additional bulge test, is also proposed.

Chapter 6 comprises yield/failure initiation criteria, discussed in detail with respect to the three following effects: the hydrostatic pressure dependence, tension/compression asymmetry, isotropic or anisotropic response. In case of anisotropic materials the explicit formulation, based on either all three common invariants or first and second common invariants, are addressed especially to case of transverse isotropy where difference between tetragonal versus hexagonal symmetry is highlighted. A mixed approach to formulate the pressure sensitive and tension/compression asymmetric initial failure criteria, capable to describe fully distorted limit surfaces, which are based on both all stress invariants and the second common invariant, are proposed. It is particularly addressed to orthotropic materials where fourth-order linear transformation tensors are used to achieve extension of the respective isotropic criteria.

Chapter 7 presents the general features of thermodynamically based constitutive modeling. The type of constitutive modeling, based on a hypothesis that the state of a material is entirely determined by certain values of some variables of state, is well adapted to the formulation of constitutive equations for deformable solids with several dissipative phenomena. The classification of constitutive equations is presented for the following materials: elastic-damage, elastic-plastic, thermo-elastic-(visco)plastic, and elastic-plastic-damage, in a critical and comparative way. Damage acquired anisotropy and unilateral damage effect are accounted for. When plasticity is considered, an alternative multiscale approach, based on polycrystalline calculations for the description of yield anisotropy and its evolution with accumulated deformation, is also discussed. As an example of thermo-plastic coupling, the fatigue behavior in nonisothermal conditions is analyzed. Numerical simulations which indicate the significant influence of temperature rate on the response of constitutive model when cyclic thermo-mechanical loading is considered, are performed.

Finally, all recent trends to account for modeling material anisotropy and coupling of dissipative phenomena have been highlighted and compared. The advantages and difficulties of both a traditional explicit concept of consistent common invariant-based polynomial formulation versus recently dynamically developed implicit approach by extension of isotropic criteria with use of linear transformation of the Cauchy stress tensor, are critically reviewed. Formal and complete analysis of couplings between several dissipative phenomena (e.g., thermo-plastic coupling, damage-plasticity coupling, nonisothermal thermo-damage-plasticity coupling, etc.) are systematically analyzed in frame of irreversible thermodynamics including internal variables.

Jacek J. Skrzypek
Artur W. Ganczarski

Springer

http://www.springer.com/978-3-319-17159-3

Mechanics of Anisotropic Materials
J. Skrzypek, J.; W. Ganczarski, A.W. (Eds.)
2015, XXIII, 311 p. 191 illus., 14 illus. in color.,
Hardcover
ISBN: 978-3-319-17159-3