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A Multiaxial Differential Model of Flow in Orthotropic Polycrystalline Ice

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ABSTRACT

A multiaxial differential model is proposed for pure flow in orthotropic polycrystalline ice. The derivation of the constitutive equations is based on thermodynamics with internal state variables. The model equations consist of the equations-of-state and evolution equations for the internal variables and a nonelastic deformation variable. The internal state of the material is described in terms of a scalar and a second rank tensor, which represent isotropic and kinematic hardening in the material, respectively. The nonelastic deformation-rate tensor is additively decomposed into transient and steady-state components. The orthotropic texture of ice during incompressible flow is characterized by five material parameters which define appropriate measures of the thermodynamic forces and deformations. Conventionally used mechanical tests under constant-stress creep and constant strain-rate loading are sufficient to determine these parameters.

1. INTRODUCTION

The mechanical behavior of ice is rate and temperature dependent since it is generally present in nature at very high homologous temperatures. Solutions to complex problems in applied ice mechanics, involving multiaxial states of stress and which recognize this rate-dependence, are based on a generalization of Glen's (1955) power-law model of steady-flow that assumes polycrystalline ice to be isotropic and incompressible. Such a generalization has been proposed for glacier-flow problems by Palmer (1967) and applied to ice-indentation problems by Ponter et al. (1983).

Ice, however, is not isotropic in many engineering problems. The most prevalent polymorphic form of ice, Ice-Ih, has a hexagonal crystal structure (Hobbs, 1974). The oxygen atoms are all concentrated along basal planes perpendicular to the principal hexagonal axis, called the c-axis. Single crystals of this type of ice are cross-anisotropic or transversely-isotropic because of hexagonal symmetry about the c-axis. The c-axes of different crystals in polycrystalline ice can exhibit various degrees of alignment, thereby imparting a definite crystallographic texture or fabric to the solid.

The individual crystals in polycrystalline ice may be granular, columnar, or in one of many other, generally, less common forms. Granular ice is typically isotropic. On the other hand, the texture of columnar ice may be isotropic, transversely-isotropic, or more generally anisotropic. According to the classification of fresh-water polycrystalline ice by Michel and Ramseier (1971), transverse-isotropy is exhibited by S-2 ice, which is commonly encountered in ice engineering problems, while more general anisotropy is exhibited by S-3 ice. The power-law model of steady-flow has been generalized for