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A DIFFERENTIAL FLOW MODEL FOR POLYCRYSTALLINE ICE

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ABSTRACT

A differential model is proposed for the pure flow of polycrystalline ice. The theory is based on the concept of state variables and accounts for two deformation-rate mechanisms: (i) transient flow, associated with generally reversible isotropic and kinematic hardening, and (ii) steady-state flow, associated with irreversible viscous deformation. Dimensional requirements for creep as well as constant deformation-rate stress–strain response are satisfied. Correspondence is established between constant-stress creep and constant strain-rate tests. The uniaxial model contains a total of six parameters and follows experimental data on the creep of fresh-water polycrystalline ice obtained by Jacka (1984), Sinha (1978), and Brill and Camp (reproduced in Sinha, 1979).

1. INTRODUCTION

Boundary value problems in applied ice mechanics involving multiaxial states of stress and complex loading histories, such as those encountered during ice–structure interaction, are increasingly being solved using numerical models including the finite element method (Jordaan, 1986). Constitutive models are required to characterize the ice deformation by viscoelastic flow in numerical simulations.

In problems where only "steady-state" flow is of interest, an elastic power-law creep model of ice (sometimes without the elastic component) is adequate. Glen's (1955) power-law is commonly used in engineering applications where compressive stresses lie in the range of 0.2 to 2 MPa. Palmer (1967) has presented the multiaxial generalization of the power-law for incompressible flow of isotropic ice. By defining a scalar-valued potential function for power-law creep that is analogous to the Hill-criterion of plastic yield, Shyam Sunder et al. (1987) have presented an orthotropic model of incompressible flow.

Both the elastic and "transient" flow behavior of ice, however, are of great importance in a broad range of ice mechanics problems (Gold, 1977, Sinha et al., 1987). Several investigators have studied this problem in recent years. For example, Sinha (1978, 1979) has proposed a creep-compliance function for fresh-water polycrystalline (S-2) ice that is nonlinearly dependent on time. For loading conditions other than constant-stress creep, Sinha (1983) adopts a particular generalization of Boltzmann's superposition principle. On the other hand, Le Gac and Duval (1980) have proposed multiaxial constitutive relations based on state variable theory for modeling the isotropic and kinematic hardening phenomena governing nonelastic deformation in polycrystalline ice. Considering deformation mechanisms in ice, Ashby and Duval (1985) have subsequently developed a spring–dashpot model based on a two-bar truss analogy which they show to be equivalent to a kinematic hardening model.

Constitutive models for describing isotropic and kinematic hardening in materials undergoing deformation originated from the work of Hill (1950), Prager (1955) and Hodge (1957) on incremental visco-plasticity. More recent developments based on state variable theory are associated with Chaboche and Rousselier (1983), Miller (1976), and Hart (1976). Le Gac and Duval (1980) explicitly refer

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