THE SUMMARY OF Ph.D. DISSERTATION

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Title

Thermodynamic Modeling and Finite Element Simulation of Viscoplastic Large Deformation with Shear Band Propagation for Polymeric Materials

Abstract

Polymeric materials have remarkable strain rate dependence (viscoplasticity) and stable neck propagation property. These characteristics are applied widely to the production of film, fiber, etc. Recently engineering plastics have been developed as substitute materials of metal and often used for structural members under mechanically severe conditions, e.g., trims and impact absorbers of vehicle and components of aircrafts. The mechanical clarification of large deformation of polymer is greatly expected from standpoint of engineering. Viscoplastic deformation behavior has been usually modeled by a constitutive equation based on the flow or deformation theory of plasticity with a strain rate hardening law. However such modelings are not consistent with thermodynamics. The conventional theories including corner theory of plasticity have both merits and demerits in terms of constitutive non-coaxiality predicting shear band formation, continuous transition from loading to unloading, and magnitude agreement of both sides of constitutive equation. In order to solve these problems, in this study a constitutive equation of viscoplasticity is developed on the basis of fundamental laws of thermodynamics and large deformation behavior of polymer is simulated more accurately by finite element analyses.

Chapter 1 is an introduction summarizing the background and problems of previous studies, and describing aims and architecture of this thesis.

In chapter 2, deformation process is decomposed into four configurations by adopting a material independent spin as a co-rotational spin of objective stress rate.

In chapter 3, a plastic deformation rate tensor is introduced as an internal variable into a total free energy and thermodynamic forces conjugate to the arguments of free energy are defined. Balance equations are derived in updated Lagrangian description from the principle of virtual power.

Chapter 4 devotes the derivation of constitutive equation. On the basis of the principle of increase of entropy and one of maximal dissipation rate, a non-coaxial constitutive equation of viscoplasticity is derived as a flow rule in which a dissipation function plays the role of plastic potential. This equation is represented as a vertex model on dissipation surface by use of magnitude and direction of plastic deformation rate. The material moduli are determined by modeling the relation between directions of stress, stress rate and plastic deformation rate by means of current loading state and strain rate sensitivity of a material. The present constitutive equation satisfies the conditions of magnitude agreement and continuous loading transition. Thus the present new vertex model of viscoplasticity is generalized to be applicable not only to polymer but also to the strain rate independent materials such as metal at ordinary temperature.

In chapter 5, a hardening law of polypropylene is identified from experimental data. It is expressed as three stress stages, i.e., the n-power law like increase stage of initial hardening, the gradual decrease stage of softening and the exponential increase stage of subsequent hardening.

Chapter 6 devotes finite element analyses carried out under a plane strain tension of a polypropylene sheet. It is clarified that the present model gives more realistic response of load versus elongation, the shear band corresponding to strain rate sensitivity can be predicted, and the stable neck propagation with disappearing shear band is governed by the re-hardening.

Chapter 7 describes conclusions of this study.