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TIME DEPENDENT INELASTIC BEHAVIOR OF MATERIALS

1 July 1980 - 30 June 1981

by

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This report reviews the program of work performed under Grant AFOSR-80-0214, sponsored by the United States Air Force Office of Scientific Research through the European Office of Aerospace Research and Development (EOARD) during the peiord 1 Jul 80 to 30 Jun 81. This period of the research program was devoted to solving problems of the inelastic response of composite elements under dynamic loading, examining wave propagation in rate dependent inelastic media, and studying the creep response of metals. The reference material representa-

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TIME DEPENDENT INELASTIC BEHAVIOR OF MATERIALS

1 July 1980 - 30 June 1981

by

Sol R. Bodner*

Principal Investigator

Abstract

This report reviews the program of work performed under Grant AFOSR-80-0214 sponsored by the United States Air Force Office of Scientific Research through the European Office of Aerospace Research and Development (EOARD) during the period 1 July 1980 to 30 June 1981. This period of the research program was devoted to solving problems of the inelastic response of composite elements under dynamic loading, examining wave propagation in rate dependent inelastic media, and studying the creep response of metals. The reference material representation was taken to be the constitutive equations of Bodner-Partom for elastic-viscoplastic work-hardening materials. In particular, a theory for the dynamic behavior of laminated slabs of elastic-viscoplastic materials has been developed. In addition, the constitutive equations were shown to provide realistic characterization of the time dependent inelastic behavior of metals ranging from creep to wave propagation conditions.

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Further work on the damage problem under the AFOSR research program is being directed at consideration of anisotropic damage development and its incorporation into a general anisotropic formulation of the constitutive equations.

An extension of the constitutive equations to include anisotropic work-hardening had been developed by Stouffer and Bodner in 1979. That theory has recently been critically reviewed by those authors who have found that it is consistent and leads to stress and strain fields that are essentially correct, but that it requires modification to enforce the condition of zero volume change due to plastic deformation. The resulting general theory, [Related Public. No.7], is capable of including anisotropic work-hardening, anisotropic damage, and pressure dependence of plastic flow in conjunction with plastic incompressibility. It could, therefore, serve as a basis for material characterization in problems that involve those effects. Some new experimental work to examine the anisotropic work-hardening theory has recently been carried out at the Technion, and the preliminary results tend to agree with predictions based on the theory.

At the other extreme of the loading spectrum, i.e. dynamic and impact loading, the constitutive equations have been used as the material characterization in an investigation of wave propagation in bars. This much studied subject still has a number of unresolved points which have led to some controversy since certain response characteristics are sensitive to the details of the material characterization while others are insensitive to gross variations of the modeling.

The other principal activity of the research program has been the step by step formulation of a theory for the mechanical behavior of composite structural elements formed of elastic-viscoplastic work-hardening constituents. Although there have been a large number of investigations on the response of laminated and fiber reinforced elastic elements to loading, almost no work seems to have been done on the properties of composites in the time dependent inelastic range. In the present research program, an effective stiffness theory was developed for a laminated slab consisting of bonded alternate layers of two different elastic-viscoplastic materials. Each constituent was modeled by the Bodner-Partom constitutive equations using the appropriate constants for the material. Details of microstructural interactions between the layers were considered to first order terms in the formulation, which led to a set of equations and boundary and initial conditions for the determination of the response of the laminated slab to dynamic loading [Public. No.1]. A further extension of the work to include a higher degree of accuracy of the microstructural effects is reported in Publication No.2.

Fiber reinforced metal matrix composites are also of considerable practical interest, and a working theory of the inelastic behavior of such composites would be very useful. A first step in the formulation of such a theory is given in Public. No.5,

Personnel

In addition to the Principal Investigator, Professor S.R. Bodner, the following persons were engaged on the research program:

Professor Jacob Aboudi (Tel Aviv University)
Associate Professor Assa Rotem (Technion)
Dr. Anthony Merzer (Technion)
Mr. Zvi Zaphir (Graduate Student)

Prof. Bodner was a Visiting Professor at the University of Illinois, Urbana,IL during August 1980 (with Prof. F.A.Leckie), and at the University of Cincinnati, Cincinnati, Ohio during September 1980 (with Prof. D.C.Stouffer).

3. "Steady and Transient Creep Behavior Based on Unified Constitutive Equations", A.M.Merzer, ASME Journal of Engineering Materials and Technology (submitted for publication).

Abstract - A set of constitutive equations, which has been used to describe a variety of quasi-static and dynamic viscoplastic phenomena, is applied to creep problems. Simulations of steady and transient creep at constant stress are obtained which compare well with experimental results both qualitatively and quantitatively. Simulations of creep resulting from rapid changes in the applied stress also compare well with observations. The constitutive equations can be used to describe logarithmic creep. These latter predictions are compatible with experimental results in considerable detail.

4. "Stress Wave Propagation in Bars of Elastic-Viscoplastic Material," S.R.Bodner and J.Aboudi,(to be presented at the 1981 Conference of the Society of Engineering Science and to be submitted for publication).

Abstract - A number of uniaxial stress wave propagation problems are solved based on the unified, multi-dimensional, elastic-viscoplastic constitutive equations of Bodner-Partom and a finite difference numerical procedure. Solutions are obtained for cases of a velocity imposed for a time period or indefinitely at the end of semi-infinite and finite bars and for the condition of a high velocity superimposed on an applied low velocity after a time interval. Work-hardening is taken to be isotropic for stress of constant sign, while an isochoric, anisotropic work-hardening formulation is employed for problems involving stresses of reversed sign due to unloading or reflections. The numerical results are compared to experimental data and to the predictions of the more classical plasticity theories.

5. "Generalized Effective Stiffness Theory for the Modeling of Fiber-Reinforced Composites," J.Aboudi, International Journal of Solids and Structures (in press).

Abstract - Effective stiffness theory of the N-th order is derived for the modeling of the three-dimensional time-dependent motion of a fiber-reinforced composite. The fibers are assumed to be of a rectangular cross section and are imbedded in the matrix in the form of a doubly periodic array. The resulting theory represents the composite as a higher order homogenous continuum with microstructure whose motion is governed by higher order displacements. The derivation is systematic and can be applied to elastic as well as anelastic composites to the desired degree of accuracy.

Publication during current year of results obtained in previous research program with AFOSR (Contract F49620-79-C-0196)

1. "Dynamic Response of a Slab of Elastic-Viscoplastic Material that Exhibits Induced Plastic Anisotropy," J.Aboudi and S.R.Bodner, International Journal of Engineering Science, vo.18,1980,pp.801-813.

2. "An Average Theory for the Dynamic Behavior of a Laminated Elastic-Viscoplastic Medium under General Loading,"J.Aboudi and Y.Benveniste, International Journal of Solids and Structures, vol.17,1981,pp.11-27.

3. "An Average Theory for the Dynamic Behavior of a Laminated Elastic-Viscoplastic Work-Hardening Medium," J.Aboudi and Y.Benveniste, Journal of Applied Mathematics and Mechanics (ZAMM), vol.61,1981.

Other Publications Related to Research Program

1. "A Procedure for Including Damage in Constitutive Equations for Elastic-Viscoplastic Work-Hardening Materials," S.R.Bodner, Proc. IUTAM Symposium on Physical Non-Linearities in Structural Analysis," Springer-Verlag, Pub.,1981.

2. "A Relationship Between Theory and Experiment for a State Variable Constitutive Equation," D.C.Stouffer and S.R.Bodner, Proc. Symposium on Deformation Modeling, ASTM Special Publication, 1981.

3. "Rapid Mode-III Crack Propagation in a Strip of Viscoplastic Work-Hardening Material," J.Aboudi and J.D.Achenbach, International Journal of Solids and Structures (in press).

4. "Numerical Analysis of Fast Mode-I Fracture of a Strip of Viscoplastic Work-Hardening Material, J.Aboudi and J.D.Achenbach, International Journal of Fracture (in press).

5. "Arrest of Mode-III Fast Fracture by a Transition from Elastic to Viscoplastic Material Properties," J.Aboudi and J.D.Achenbach, ASME Journal of Applied Mechanics (in press).

6. "Transition from Brittle to Ductile Fracture for a Rapidly Propagating Crack," J.Aboudi and J.D.Achenbach, ASME Journal of Pressure Vessel Technology, (in press).

7. "Anisotropic Plastic Flow, Pressure Dependence, and Incompressibility," S.R.Bodner and D.C.Stouffer (in preparation).