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# UNIFIED CONSTITUTIVE MODEL DEVELOPMENT FOR METAL MATRIX COMPOSITES AT HIGH TEMPERATURE

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## INTRODUCTION

Structural alloys used in high temperature applications exhibit complex thermomechanical behavior that is time-dependent and hereditary. Recent attention is being focused on metal-matrix composite materials for high-temperature applications (e.g., in aerospace) where they exhibit all the complexities of conventional alloys (creep, relaxation, recovery, rate sensitivity, etc.) and their strong anisotropy adds further complexities.

A unified continuum theory is being developed for representing the high-temperature deformation behavior of metallic composites that can be idealized as pseudohomogeneous continua with locally definable directional characteristics. Treatment of textured materials (molecular, granular, and fibrous) as pseudohomogeneous and the applicability of continuum mechanics depend relatively upon characteristic structural dimensions, the severity of gradients (stress, temperature, etc.), and the size of the internal structure (cell size) of the material. The appropriate conditions are met in a sufficiently large class of anticipated aerospace applications of metallic composites to justify research into the formulation of continuum based theories.

The point of view taken in this research is that the composite is a material in its own right, with its own properties, and that these properties can be measured and specified. Experiments for this purpose are discussed by Robinson et al. (1987). This viewpoint is aimed at satisfying the design engineer who needs reasonably simple methods of structural analysis to predict deformation behavior, particularly at high temperatures where material response is enormously complex. Indeed, the prediction of component lifetime depends critically on the accurate prediction of deformation behavior.

Here, a proven constitutive model for isotropic materials in which the inelastic strain rate and internal state are expressible as gradients of a dissipation potential is taken to depend on invariants that reflect local transverse isotropy. Applications (Arya, 1988; and Arya and Robinson, 1988) illustrate the capability of the theory of representing the time-dependent, hereditary, anisotropic behavior typical of these materials at high temperature.

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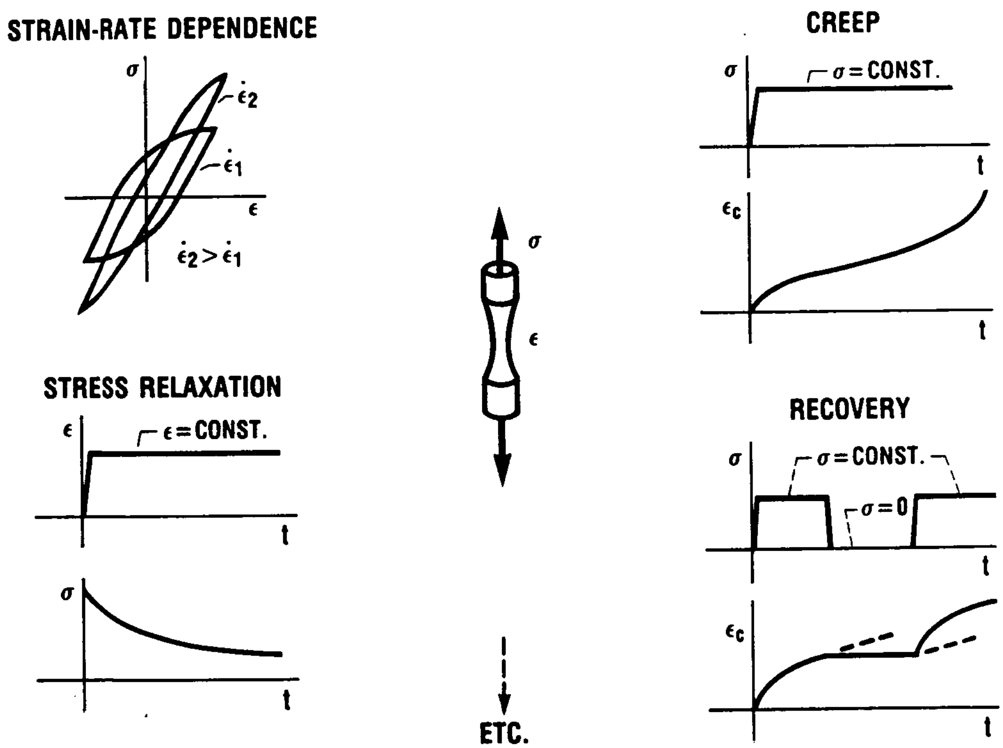
## HIGH-TEMPERATURE BEHAVIOR OF COMPOSITE CONSTITUENTS

Metals used as constituents of composite materials exhibit all of the high-temperature behavioral complexities of metals used conventionally. Intense effort has been devoted over the past decade (e.g., NASA's HOST Project) in understanding and representing such behavior.

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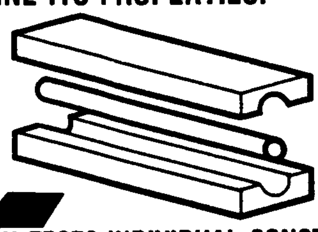
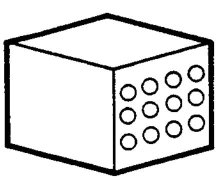
**WITH ONE OR BOTH CONSTITUENTS OF THE COMPOSITE BEHAVING AS IN FIG. 1, MICROMECHANICS HAS DIFFICULTY PREDICTING OVERALL BEHAVIOR. THE MACROMECHANICS OR CONTINUUM APPROACH VIEWS THE COMPOSITE AS A MATERIAL (PSEUDOHOMOGENEOUS, ANISOTROPIC). TESTS ARE CONDUCTED ON THE COMPOSITE TO DETERMINE ITS PROPERTIES.**



**THE MICROMECHANICAL APPROACH TESTS INDIVIDUAL CONSTITUENTS TO DETERMINE "PROPERTIES". OVERALL BEHAVIOR OF THE COMPOSITE IS THEN PREDICTED.**



**THE CONTINUUM APPROACH RELIES ON TESTS DONE AT THIS LEVEL TO DETERMINE BEHAVIORAL AND DIRECTIONAL PROPERTIES OF THE COMPOSITE. THIS ALLOWS USE OF THE VAST RESEARCH (E.G., HOST RESULTS) ON REPRESENTING COMPLEX THERMOMECHANICAL BEHAVIOR OF METALS— UNIFIED VISCOPLASTICITY THEORIES.**

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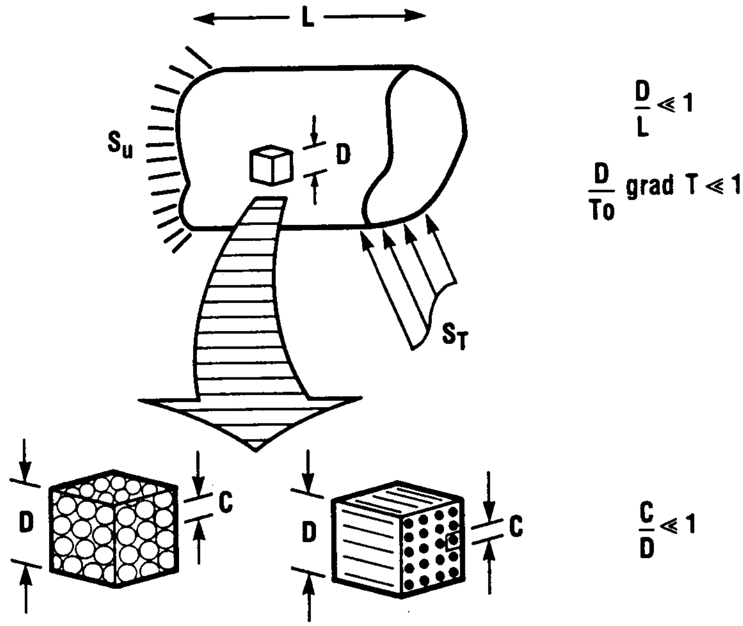
APPLICABILITY OF CONTINUUM CONCEPTS

The application of continuum theories to structured materials requires identification of a continuum element D that is small compared with characteristic structural dimensions and gradients, but large compared with cell size dimensions.




CONTINUUM ELEMENT
GRANULAR MATERIAL

CONTINUUM ELEMENT
FIBROUS MATERIAL

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## EXTENSION OF UNIFIED THEORIES TO COMPOSITES

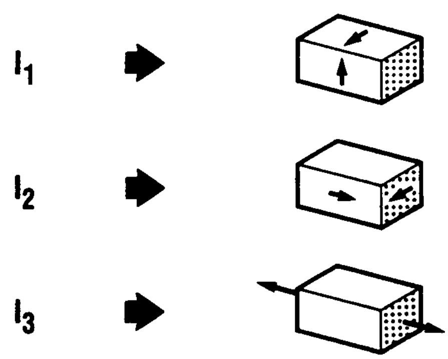
Unified viscoplasticity theories appropriate for isotropic metals are modified for metallic composites by taking advantage of well-established disciplines (mathematical invariant theory) and the wealth of research conducted over the past decade (e.g., HOST, etc.).

Familiar quantities in isotropic representations such as effective stress get replaced by effective stress measures involving other invariants that reflect the appropriate directional properties of the composite.

$$\bar{\sigma} = \sqrt{J_2}$$

**WHERE $J_2$ = SECOND PRINCIPAL INVARIANT OF DEVIATORIC STRESS.**

$$\bar{\sigma} = \sqrt{I_1 + \alpha I_2 + \beta I_3}$$

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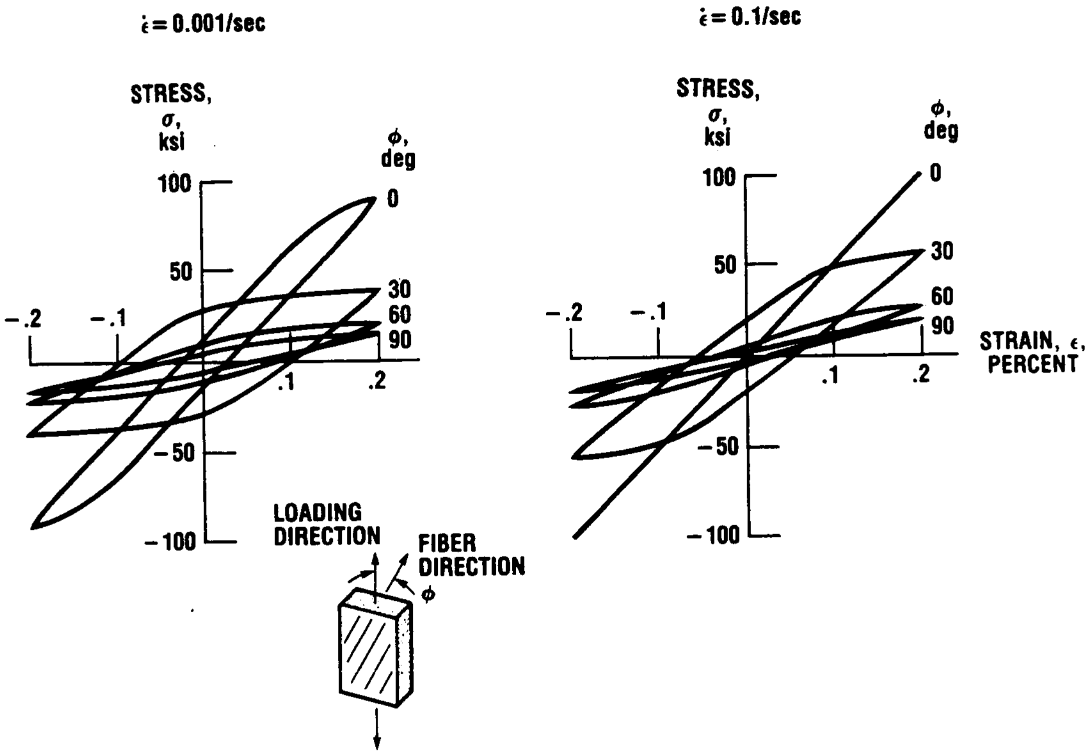
STRAIN RATE DEPENDENCE IN METALLIC COMPOSITES

Continuum deformation theories for metallic composites are readily implemented into existing structural analysis codes. The present theory has been implemented into MARC (Arya, 1988) and several uniaxial and multiaxial structural analyses have been performed.

Predictions of uniaxial constant-strain-range - constant-strain-rate cycling show the expected directional features and the appropriate strain-rate dependence.

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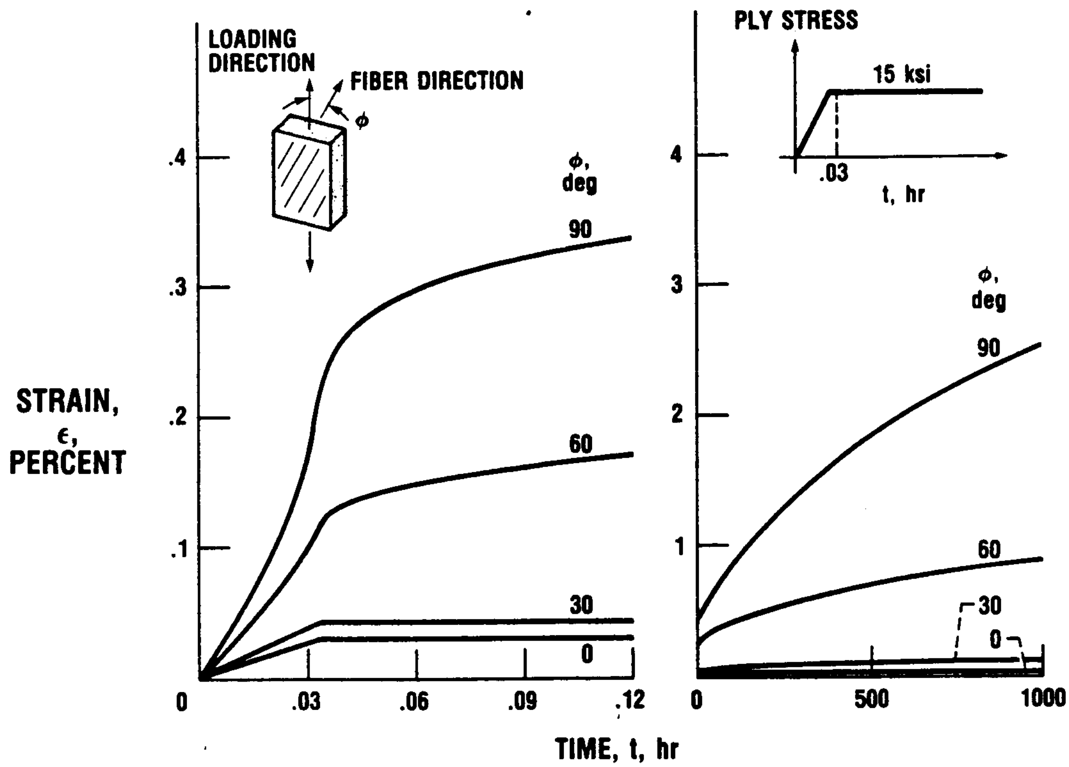
CREEP OF METALLIC COMPOSITES

The same model (no change in material constants) predicts the correct qualitative features of creep and relaxation observed in metallic composites. See Arya (1988) for other uniaxial and multiaxial predictions.

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## REFERENCES

Arya, V.K., 1988, "Finite Element (MARC) Solution Technologies For Viscoplastic Analyses," Lewis Structures Technology '88, NASA Lewis Research Center, May 24-25.

Robinson, D.N., Duffy, S.F., and Ellis, J.R., 1987, "A Viscoplastic Constitutive Theory for Metal Matrix Composites at High Temperature," Thermal Stress. Material Deformation and Thermo-Mechanical Fatigue, ed. Sehitoglu, Zamrik, ASME, Vol. 123.

Robinson, D.N., and Duffy, S.F., 1988, "A Continuum Deformation Theory for Metal-Matrix Composites at High Temperature," submitted to J. of Mech. and Physics of Solids.