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Analysis of Large, Non-Isothermal Elastic-Visco-Plastic Deformations

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Abstract

The prediction of inelastic behavior of metallic materials at elevated temperature has increased in importance in recent years. Many important engineering applications involve the use of structural components subjected to large transient, cyclic or static thermomechanical loads, e.g., hot section components of turbopump turbine engines, nuclear reactor components, etc. These materials exhibit substantial complexity in their thermomechanical constitution. In fact, so complex is their material response that it could be argued that without useful a priori information, experimental characterization is futile. It is, therefore, important to be able to model accurately the nonelastic behavior of these structures under mechanical and thermal loading at temperature levels for which creep and recovery are significant response phenomena. Under this kind of severe loading conditions, the real world of structural behavior is highly nonlinear due to the combined action of geometrical and physical nonlinearities. On one side finite deformation in a stressed structure introduces nonlinear geometric effects. On the other side, physical nonlinearities arise even in small strain regimes, whereby inelastic

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Structures
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phenomena play a particularly important role. From a theoretical standpoint, nonlinear constitutive equations should be applied only in connection with nonlinear transformation (the word implies both deformations and rotations) measures. However, in almost all of the work in this area (see Ref. 1) the two sources of nonlinearities are separated yielding at one end of the spectrum large transformation problems while at the other end viscous and/or non-isothermal analyses are made in the presence of small strain.

Hence, the present paper focuses on the development of a general mathematical model and solutions of test problems for analyzing large non-isothermal elastic-visco-plastic deformations of structures. Thus, geometric as well as material-type nonlinearities of higher order are present in the development of the mathematical model and consequently in the developed solution methodology.

For this purpose a complete true ab-initio rate theory of kinematics and kinetics for continuum with application of one-dimensional problem, without any restriction on the magnitude of the strain or the deformation was formulated. The time dependence and large strain behavior were incorporated through the introduction of the time rates of the metric in two systems. The relations between the time derivative and the covariant derivative (gradient) have been developed for space and motion, so the velocity components supply the connection between the equations of motion and the time rates of change of the metric and curvature tensors.[2]

The metric tensor (time rate of change) in the convected material coordinate system is linearly decomposed into elastic and plastic parts[3,4]. As opposed to all the other "unified theories"[1], in this formulation a yield function is assumed, which is dependent on the rate of change of stress, metric, temperature and a set of internal variable. Moreover, a hypo-elastic law is chosen to describe the thermo-elastic part of the deformation.

Based on the laws of thermodynamics a time and temperature dependent "unified viscoplastic" model is formulated, in this convected material system, to account for finite strains. The non-isothermal elasto-viscoplastic deformation process is described completely by "thermodynamic state" equations, while the history and the temperatures dependence are incorporated through the introduction of two internal variables.

One of the most challenging aspects of finite strain formulations is to locate a analytical solutions with which to compare a proposed formulation. Typically, as a first problem, a large strain uniaxial test case is analyzed. The case considered examines the rate-dependent plastic response to a deformation history that includes segments of loading, unloading, and reloading, each occuring at varying strain and temperatures rates, for a bar. Then, as a second problem, the proposed formulation is shown to generate no strain energy under a pure rigid body rotation. These are surely important problems to be considered; however, they only represent a partial test because the principal stretch directions remain constant. Finally, a problem which was discussed by Nagtegaal and de Jong[5] and others[6] as a problem which demonstrates limitations of the constitutive models in many finite strain formulations is the Couette flow problem. This problem is solved as the last example. The results of the test problems show that:

- The formulation can accommodate very large strain and rotations.
- The formulation does not display the oscillatory behavior in the stresses of the Couette flow problem.
- The model incorporates the simplications associated with rate-insensitive elastic response without losing the ability to model a rate-temperature dependent yield strength and plasticity.

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References

1. Chan, K. S., Bodner, S. R., Walker, K. P., and Lindholm, U. S., "A Survey of Unified Constitutive Theories", NASA Contract Report, NASA-223925, 1984.

2. Mendelssohn, E., and Baruch, M., "Development of Rate Tensor Operators in Conjunction with the Principles of Solids Mechanics", TAE 415, Technion, Haifa, Israel, 1980.

3. Lee, E. H., "Elastic-Plastic Deformation at Finite Strain", J. Apl. Mech. Vol. 36, 1969, pp. 1-6.

4. Sedov, L. I., "Foundation of the Non-Linear Mechanics of Continua" Pergamon Press, 1966.

5. Nagtegaal, J C., and de Jong, J. E., "Some Aspects of Non-Isotropic Workhardening in Finite Strain Plasticity", in Plasticity of Metals at Finite Strain: Theory, Experiment and Computation (E. H. Lee and R. L. Mallett; eds.) Proceedings of Research Workshop, Stanford University, Palo-Alto, CA., July 1982.

6. Rolph III, W. D., and Bathe, K. J., "On a Large Strain Finite Element Formulation for Elasto-Plastic Analysis", in Constitutive Equations: Macro and Computational Aspects, (K. J. William ed.) Proceedings of Winter Annual Meeting of ASME, New Orleans, Louisiana, December 1984.