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A finite deformation nonlinear thermo-elastic model that mimics plasticity during monotonic loading

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ABSTRACT

We present and study a nonlinear thermo-elastic constitutive model that under monotonic loading closely reproduces the response seen in plasticity, showing the initial stiff elastic response, kneeing as if yielding, and then showing response resembling post-yield hardening. The proposed large deformation thermo-elastic response model is constructed based on four physically identifiable mechanical parameters, that are closely related to the parameters used to construct plasticity models, thermal expansion parameters and two thermodynamic parameters. The four mechanical parameters are the initial elastic shear and bulk moduli, the yield point in shear, the hardening slope in shear. The thermodynamic parameters are the heat capacity at a reference temperature and its rate of change with changes of temperature. The model can be considered an alternate to deformation plasticity models currently used and, as such, can be used as a lightweight substitute for plasticity modeling in certain analysis. Since the proposed model is thermodynamically based, not only thermal effects are integrated into the model, but also the stress is calculated in terms of the applied deformation, allowing the model to be integrated with other models when conducting numerical analysis. We study the response of the proposed model under simple shear, uniaxial extension, confined compression, partially-confined compression, and biaxial extension. We incorporate the elastic model into ABAQUS using its UMAT subroutine for solid elements and using UHYPER for shell elements. We compare the large deformation response from the proposed elastic model with J2-plasticity, and with plasticity and deformation plasticity models implemented in ABAQUS. The model in most cases compares very favorably to all such models. This comparison is done for both homogeneous and non-homogeneous problems including the case of a cantilever beam under tip loading. We show that for the problems that it applies to, the models run in approximately one tenth the computational time and with one tenth the number of iterations needed to conduct the analysis using the plasticity model in ABAQUS.

1. Introduction

We propose a thermo-elastic model that closely resembles the response seen in materials undergoing elastic–plastic deformation and study this model under different finite deformation loading conditions to show its close similarity to traditional elastic-plastic response models and show its particular advantages.

When only considering monotonic loading, one can use deformation plasticity, in place of real plasticity, to capture the same effects that are associated with plastic flow. The reason for the use of deformation plasticity is the relatively low computational cost associated with the elasticity analysis needed for deformation plasticity compared to the much more expensive computational cost associated with true plasticity analysis. As a result, deformation plasticity is normally provided in most finite element analysis tools such as ABAQUS. The deformation plasticity model is a purely mechanical elasticity model, but, as will be shown, we can construct a thermodynamically based thermo-elasticity model that also mimics plasticity under monotonic loading, and provides the same advantages in analysis that come with deformation plasticity. As expected, this model will unload on the same path as the loading, so that it would not be able to characterize any process that includes unloading.

One key disadvantage of deformation plasticity is the fact that the strain is calculated in terms of stress, and, as a result, in must numerical implementations cannot be combined with other models. Since the proposed model is thermodynamically based, one result is that the stress is calculated from the deformation so it avoids this shortcoming, yet functions, as will be shown, with approximately the same efficiency as deformation plasticity analysis.

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