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A closed-form solution for temperature-dependent elastoplastic problems using the Prandtl operator approach. (English) Zbl 1464.74032

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Summary: Finite element simulations of the temperature-dependent stress-strain response in the elastoplastic region of a material usually involve incremental procedures based on the Newton-Raphson iterative scheme. Although essential to obtaining the correct result, iterations inherently extend the computational time of the simulations. In order to increase the computational effectiveness of such finite element simulations, a novel solution technique is presented here, which introduces a closed-form determination of the elastoplastic stress-strain response using the Prandtl operator approach. Using this solution, the iterative procedure is no longer required. The positions of the tensile-compressive and shear meridians of the Haigh-Westergaard coordinate space are first conveniently modified, which then enables the configuration of coordinate-independent play operators. These play operators connect the stress and the strain tensors in a unique closed-form solution that significantly increases the computational power of the simulations, while retaining both the vigorous stability of the procedure and the high accuracy of the results. The method is successfully validated on several load cases, consisting of variable tensile, shear and combined thermomechanical load histories. Limitations of the current version of the approach, that are a part of on-going research, include extremely low values of the third deviatoric strain-invariant increments, in which the directions of movement of the yield surfaces can be changed. Furthermore, the discretisation of the cyclic stress-strain curves plays an important role. The optimal positions of the yield strains are hence another important issue for future studies. Additionally, the consistent material Jacobian results in an unsymmetric form in e.g. Abaqus when engineering shear strains are provided in the simulations and thus the computational power is not fully used. Nevertheless, the results using the Prandtl operator approach, when compared to the results obtained using the conventional, Besseling material model, show excellent agreement, while substantially reducing the computational time by up to 45%.

MSC:

74C05 Small-strain, rate-independent theories of plasticity (including rigid-plastic and elasto-plastic materials)
74S05 Finite element methods applied to problems in solid mechanics
74F05 Thermal effects in solid mechanics

Keywords:

Prandtl operator; finite element method; thermomechanical loading; uniaxial load; stress-strain response

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