The micromorphic approach for plasticity, damage and evolution of microstructures

Samuel Forest[1]
Mines Paris, Paristech
CNRS UMR 7633, BP 87, 91003 Evry Cedex, France

Abstract

A unifying thermomechanical framework is presented that reconciles several classes of gradient elastoviscoplasticity and damage models proposed in the literature during the last 40 years. It is based on the introduction of the micromorphic counterpart ${}^{\chi}\phi$ of a selected state or internal variable ϕ in a standard constitutive model. In addition to the classical balance of momentum equation, a balance of micromorphic momentum is derived that involves generalized stress tensors. The corresponding additional boundary conditions are also deduced from the procedure. The power of generalized forces is assumed to contribute to the energy balance equation. The free energy density function is then chosen to depend on the relative generalized strain $\phi - {}^{\chi}\phi$ and the microstrain gradient $\nabla^{\chi}\phi$. When applied to the deformation gradient itself, $\phi \equiv \underset{\sim}{\boldsymbol{F}}$, the method yields the micromorphic theory according to Eringen and Mindlin, together with its extension to finite deformation elastoviscoplasticity [1, 2]. If the selected variable is the cumulative plastic strain, the theory reduces to the so–called "nonlocal implicit gradient–enhanced elastoplasticity model" provided that simplified linear relationships are adopted between generalized stresses and strains [3]. The same holds if the micromorphic variable coincides with a microdamage variable.

If the internal constraint is introduced that the micromorphic variable ${}^{\chi}\phi$ remains as close as possible to the macroscopic variable ϕ, the micromorphic model reduces to the second gradient or gradient of internal variable approach as defined in [4]. If the selected variable is the cumulative plastic strain or the full plastic strain tensor, the constrained micromorphic theory delivers Aifantis–like strain gradient plasticity models according to [5, 6].

The advantage of the micromorphic approach is that it provides the generalized balance equation under non–isothermal conditions and offers the setting for anisotropic nonlinear constitutive relations between generalized stress and strains in contrast to most existing models. In rate–independent plasticity, it is shown that there is generally no need for a variational formulation of the yield condition.

Applications will be presented concerning the mechanical behaviour of metallic foams for filter and battery applications.

References

[1] S. Forest and R. Sievert. Elastoviscoplastic constitutive frameworks for generalized continua. *Acta Mechanica*, 160:71–111, 2003.

[2] S. Forest and R. Sievert. Nonlinear microstrain theories. *International Journal of Solids and Structures*, 43:7224–7245, 2006.

[3] R.A.B. Engelen, M.G.D. Geers, and F.P.T. Baaijens. Nonlocal implicit gradient-enhanced elasto-plasticity for the modelling of softening behaviour. *International Journal of Plasticity*, 19:403–433, 2003.

[4] G.A. Maugin. Internal variables and dissipative structures. *J. Non–Equilib. Thermodyn.*, 15:173–192, 1990.

[5] E.C. Aifantis. The physics of plastic deformation. *International Journal of Plasticity*, 3:211–248, 1987.

[6] M.E. Gurtin. On a framework for small–deformation viscoplasticity: free energy, microforces, strain gradients. *International Journal of Plasticity*, 19:47–90, 2003.

[1] Corresponding author. Tel.: +33-1-60-76-30-51; Fax: +33-1-60-76-31-50, samuel.forest@ensmp.fr