Constitutive modelling of shear bands effect in ductile materials: formulation and computational aspects

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Abstract

The main objective of the present paper is the presentation of the viscoplasticity model accounting for shear banding proposed and the identification procedure of the parameters and material functions. The shear banding contribution function, which was introduced formerly by Pęcherski and applied in continuum plasticity accounting for shear banding in [1] and [2] as well as in Nowak et al. [3] plays key role in the viscoplasticity model. The derived constitutive equations are applied for solution of channel-die an inverse problem as well as for verification with use of other independent experimental test.

The derived constitutive equations were identified and verified with application of experimental data provided in paper by Bronkhorst et al. [4] for OFHC copper, where channel-die test was reported.

The shape of the contribution function f_{SB} is proposed, accounting to the studies in [1, 2] and supported by the numerical identification and verification in [3], in the form of logistic function:

$$f_{SB} = \frac{f_{SB}^{\infty}}{1 + \exp(a - b\bar{\varepsilon}^{p})}$$

where f_{SB}^{∞} , a, b are material parameters to be specified.

The total viscoplastic shear strain rate flow produced by instantaneous and volumetric shear banding can be expressed as follows:

$$\dot{\gamma}(1-f_{SB})=\dot{\gamma}_S,\quad 0\le f_{SB}<1,\quad f_{SB}=\frac{\dot{\gamma}_{SB}}{\dot{\gamma}},\ f_{SB}^V=\frac{V_{SB}}{V}$$

$$\dot{\gamma}_s=\dot{\gamma}_o\langle\Phi\left(\frac{F(\sigma)}{k}-1\right)\rangle\quad \textit{Perzyna}\ \mathrm{mod}\,el$$

$$\dot{\gamma}=\frac{\dot{\gamma}_0}{(1-f_{SB})}\langle\Phi\left(\frac{F(\sigma)}{k_s(1-f_{SB})(1-f_{SB}^V)}-1\right)\rangle$$

$$k_s=K\left(\bar{\varepsilon}^p,\dot{\bar{\varepsilon}}^p,\vartheta\right),\ \bar{\varepsilon}^p=\int_0^t\left(\frac{2}{3}\dot{\varepsilon}_{ij}^p\dot{\varepsilon}_{ij}^p\right)^{\frac{1}{2}}dt,$$

$$F(\sigma)=\sigma_e,\sigma_e=\sqrt{\frac{3}{2}s_{ij}s_{ij}}$$

To solve the system of equations, the Newton-Raphson scheme is applied.

$$\bar{\varepsilon}_{n+1}^p=\bar{\varepsilon}_n^p+\Delta\lambda$$

$$\Delta\lambda=\Delta t\dot{\bar{\varepsilon}}_0\left[\left(\frac{\sigma_{eq}}{\sigma_Y(\bar{\varepsilon}^p)}-1\right)^s\right]$$

$$\sigma_{eq}^{n+1}=\sigma_Y(\bar{\varepsilon}^p)\left[1+\frac{\Delta\bar{\varepsilon}^p(1-f_{ms}(\bar{\varepsilon}^p))}{\Delta t\dot{\bar{\varepsilon}}_0}\right]^{\frac{1}{s}}$$

$$\Phi\left(\boldsymbol{s}_{n+1}^{trial},\ \kappa^{trial}\right)\le 0\qquad \text{Elastic trial state}$$
$$\Phi\left(\boldsymbol{s}_{n+1}^{trial},\ \kappa^{trial}\right)>0\qquad \text{Viscoplastic corrector step}$$

Once the solution is obtained, all variables and stress field are updated using the relevant equations.

The possibilities of the application of the proposed description for numerical simulation of deformation processes of nanometals, high-strength steels and other hard deformable metals, as well as, polymers are discussed.

References

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