A Novel Elastoplasticity Cap Model for Hydrogen-Softening Metal Alloy Powders

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INTRODUCTION

The existence of hydrogen solute atoms leads to the increase of dislocation mobility at the microscale in metals and alloys. This hydrogen-assisted microscale mechanism can contribute to macroscopic plasticity instability, which is termed as hydrogen enbrittlement or hydrogen softening. Considering this localised ductile process, a low-cost powder metallurgy—the thermohydrogen processing for metal alloys is currently under development. In the project, to precisely describe the hydrogen-softening effect on metal alloy powders, on the basis of the hydrogen enhanced localized plasticity theory and the modified Drucker-Prager cap model for granular materials, a novel elasoplasticity cap model considering hydrogen-softening effect is developed.

DESCRIPTION OF HYDROGEN SOFTENING

Hydrogen concentration in normal interstitial lattice sites and trapping sites under equilibrium conditions:

$$c = \beta\left[\theta_L\left(\sigma_{kk}\right) + \theta_{TL}\left(\sigma_{kk}, \varepsilon^p\right)\right]$$

$$\theta_L\left(\sigma_{kk}\right) = \theta_L^0 K_L / \left[\left(1-\theta_L^0\right) + \theta_L^0 K_L\right]$$

$$\theta_{TL}\left(\sigma_{kk}, \varepsilon^p\right) = \frac{\alpha}{\beta}\frac{N_T\left(\varepsilon^p\right)}{N_L}\frac{K_T\theta_L\left(\sigma_{kk}\right)}{1-\theta_L\left(\sigma_{kk}\right)+K_T\theta_L\left(\sigma_{kk}\right)}$$

According to the hydrogen enhanced localized plasticity (HELP) theory, the continuum description of hydrogen softening effect can be given as follows:

$$\sigma_Y = \sigma_0^H\left(1+\frac{\varepsilon^p}{\varepsilon_0}\right)^n$$

$$\sigma_0^H = \phi(c)\sigma_0 \qquad \phi(c) = \left(\xi - 1\right)c + 1$$

ELASTOPLASTIC CONSTITUTIVE LAW

Further, the total deformation rate tensor is written as the sum of an elastic part, a part due to the existence of hydrogen and a plastic part:

$$D_{ij} = D_{ij}^e + D_{ij}^h + D_{ij}^p$$

$$D_{ij}^e = \frac{1}{2G}\left(\overset{\nabla}{\sigma}_{ij} - \overset{\nabla}{\sigma}_{kk}\,\delta_{ij}/3\right) + \frac{1}{9K}\overset{\nabla}{\sigma}_{kk}\,\delta_{ij}$$

$$D_{ij}^h = \frac{1}{3}\frac{\lambda}{1+\lambda(c-c_0)/3}\dot{c}\delta_{ij}$$

$$D_{ij}^p = \dot{\varepsilon}^p\frac{\partial f}{\partial \sigma_{ij}}, \text{ where } f \text{ is the yield criterion.}$$

MODIFIED DRUCKER-PRAGER CAP MODEL

The yield surface in the modified Drucker-Prager Cap model is expressed by two segments: a shear failure surface and a cap that intersects the equivalent pressure axis as shown in Figure 1.

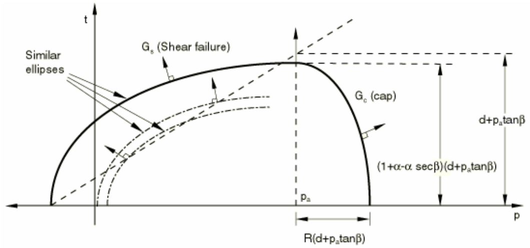

Figure 1. Modified Drucker-Prager Cap model

The equations of the shear failure surface, cap surface and transition surface are

$$F_S = t - p\tan\beta - d = 0$$

$$F_C = \sqrt{(p-p_a)^2 + \left[\frac{Rt}{1+\alpha-\alpha/\cos\beta}\right]^2} - R(d+p_a\tan\beta)$$

$$F_T = \sqrt{(p-p_a)^2 + \left[t-\left(1-\frac{\alpha}{\cos\beta}\right)(d+p_a\tan\beta)\right]^2} - \alpha(d+p_a\tan\beta) = 0$$

NUMERICAL EXAMPLES AND RESULTS

To verify the proposed elastoplasticity cap model, a specimen strained homogeneously in plane strain by displacement increment was investigated, depicted in Fig.2.

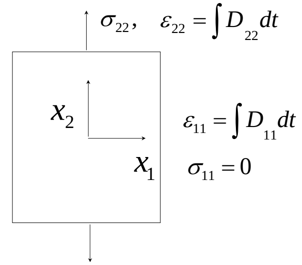

Figure 2. 2-D problem of a plate subject to uniform uniaxial tensile.

Figure 3 shows the normalized stress σ_{22}/σ_0 and normalized hydrogen concentration c/c_0 versus plastic strain ε_p and as the initial hydrogen concentration increases, the material becomes softer with decreasing tangent modulus.

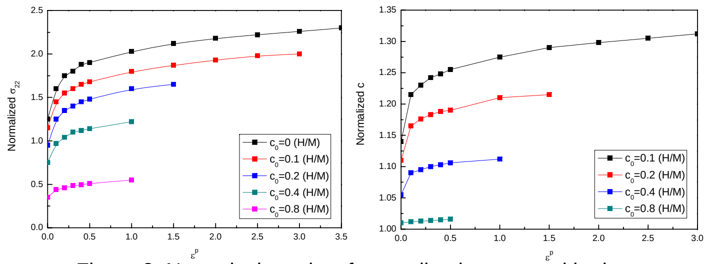

Figure 3. Numerical results of normalized stress and hydrogen concentration

SUMMARY

A novel elastoplasticity cap model for metal ally powders subject to hydrogen-softening is developed for hydrogen-softening metal alloy powders in the present study. The porous elasticity will be further integrated into this model in the future work.

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