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A MICROMECHANICS MODEL OF PARTICLE-REINFORCED COMPOSITES TAKING ACCOUNT OF DEBONDING DAMAGE AND PARTICLE SIZE EFFECT

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ABSTRACT

This paper deals with a micromechanics model of particle-reinforced composites which can describe debonding damage of particles from the matrix, matrix plasticity and particle size effect. Tohgo-Chou [1] and Tohgo-Weng [2] developed an incremental damage theory of particle-reinforced composites based on the Eshelby's equivalent inclusion method and Mori-Tanaka's mean field concept which can describe plastic deformation of the matrix and progressive debonding damage of the particle-matrix interface. Tohgo-Chou-Weng's theory has been extended to consider the particle size effect by using Nan-Clarke's simple method [3]. The particle size effect on deformation of the matrix is realized by introducing the dislocation plasticity for stress-strain relation of in-situ matrix in composites. The stress-strain relation is given by Ramburg-Osgood relation as follows:

$$\varepsilon^0{}_{\mathrm{e}} = \frac{\sigma^0{}_{\mathrm{e}}}{E_0} + \lambda \frac{\sigma^0{}_0}{E_0} \left(\frac{\sigma^0{}_{\mathrm{e}}}{\sigma^0{}_0} \right)^{1/n} \tag{1}$$

where, $\sigma^0{}_{\mathrm{e}}$ and $\varepsilon^0{}_{\mathrm{e}}$ are the equivalent stress and strain, E_0, $\sigma^0{}_0$ and n are Young's modulus, yield stress and work-hardening ratio, respectively, and λ is material constant. Nan-clarke[3] assumed that $\sigma^0{}_0$ is affected by particles in composites, and then modified as follows:

$$\sigma^0{}_0 = \left(\sigma^0{}_0\right)_{\mathrm{Bulk}} + \Delta\sigma^0{}_0 \tag{2}$$

where, $(\sigma^0{}_0)_{\mathrm{Bulk}}$ is the yield stress for a bulk of the matrix material. $\Delta\sigma^0{}_0$ is given by the dislocation plasticity as follows:

$$\begin{aligned}\left(\Delta\sigma^0{}_0\right)^2 &= \left(\Delta\sigma^0{}_{\mathrm{OR}} + \Delta\sigma^0{}_{\mathrm{KIN}}\right)^2 + \left(\Delta\sigma^0{}_{\mathrm{ISO}}\right)^2 + \left(\Delta\sigma^0{}_{\mathrm{CTE}}\right)^2 \\ &= \left(\xi\,\mu_0 b\sqrt{\frac{4 f_{\mathrm{p}}}{\pi d^2}} + \zeta\,\mu_0 f_{\mathrm{p}}\sqrt{\frac{\varepsilon^{0\mathrm{p}}_{\mathrm{e}}\, b}{d}}\right)^2 + \left(\eta\,\mu_0\sqrt{\frac{f_{\mathrm{p}}\varepsilon^{0\mathrm{p}}_{\mathrm{e}}\, b}{d}}\right)^2 + \left(\gamma\,\mu_0 b\sqrt{\frac{6\Delta T\,\Delta\theta\, f_{\mathrm{p}}}{b\, d\left(1-f_{\mathrm{p}}\right)}}\right)^2\end{aligned} \tag{3}$$

where, μ_0, b, $\varepsilon^{0\mathrm{p}}{}_{\mathrm{e}}$ are the shear modulus, Burgers vector and equivalent plastic strain of the matrix, and d is the particle diameter. ξ, η, ζ and γ are constants. $\Delta\sigma^0{}_{\mathrm{OR}}$ is the

Orowan stress, $\Delta\sigma^{0}_{ISO}$ and $\Delta\sigma^{0}_{KIN}$ are isotropic and kinematic contributions due to the effect of strain gradient plasticity, and $\Delta\sigma^{0}_{CTE}$ is a contribution of the dislocation stored in fabrication due to thermal expansion mismatch $\Delta\theta$ and temperature change ΔT. The particle size effect on damage is described by the strain energy release rate criterion for particle-matrix interfacial debonding. The critical particle stress for debonding damage is approximately given as $\sigma^{p}_{cr} = K_C/\sqrt{d}$, where K_C is the fracture toughness for interfacial debonding between the particle and matrix.

Numerical analyses are carried out on a SiC particle reinforced aluminum alloy composite (SiC/A356-T4) under uniaxial tension. Fig. 1 shows the particle size effect on stress-strain relations of the composites and comparison between the present theory and Nan-Clarke's theory. The present model predicts almost the same stress-strain relations as Nam-clarke's model. Fig. 2 shows the particle size effect on stress-strain relation of the composites with debonding damage. On the composites containing the same size particles, the debonding damage simultaneously occurs on all particles, and then the composite stress suddenly decreases. After the debonding damage, the composites behave as porous materials. Furthermore, a method to analyze composites containing particles with size distribution is developed. It is shown that the experimental stress-strain relation of the SiC/A356-T4 can be described by the present model taking account of the particle size effect, particle size distribution and debonding damage.

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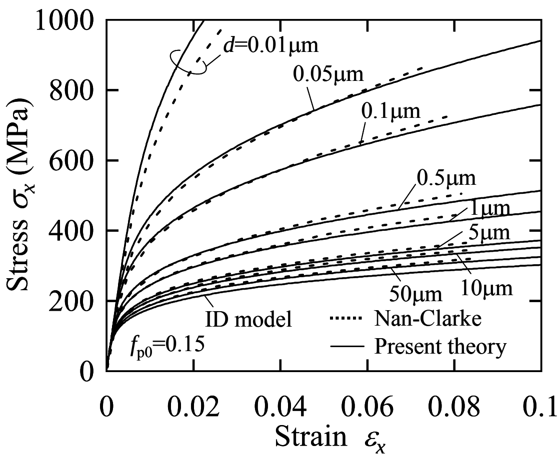

Fig. 1 Particle size effect on stress-strain relations of the composites and comparison between the present theory and Nan-Clarke's theory. ID model shows Tohgo-Chou-Weng's model.

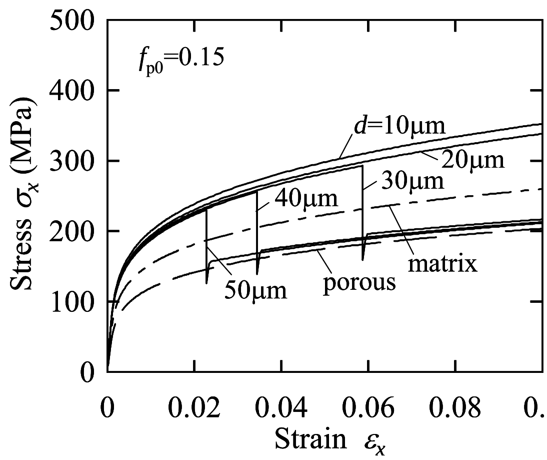

Fig. 2 Particle size effect on stress-strain relation of the composites with debonding damage.