Development of the PARA-ID Program to Simulate a Unified Viscoplasticity Behaviour

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1. Introduction

The PARA-ID code is a general purpose computer simulation program for a nonlinear cyclic material behavior with and without viscous effects, which can simulate various constitutive models such as

- Prager Model
- Armstrong and Frederick Model
- Chaboche 3-decomposed rule Model
- Chaboche 4-decomposed rule Model
- Ohno and Wang Model
- Unified Chaboche Viscoplastic Model

In this paper, the unified Chaboche viscoplasticity model[1,2] is investigated with some examples of application for a cyclic hardening material of 316L.

2. Theory of Unified Chaboche Model

In general, most materials have time-dependent characteristics due to viscous effects. We call this kind of material behavior as viscoplasticity. For example of the stainless steels, it is well-known that the viscous effects, which invoke stress relaxation as well as strain rate dependency, can occur even in room temperature. Actually, the time-independent plasticity is a particular limiting case of viscoplasticity.

In the unified theory which can simulate both a cyclic loading and viscous behaviors, the total inelastic strain is described with the unified plastic and viscous strain term as follows;

$$\boldsymbol{\varepsilon}^{in} = \boldsymbol{\varepsilon}^{p} + \boldsymbol{\varepsilon}^{v} = \boldsymbol{\varepsilon}^{vp} \tag{1}$$

The unified Chaboche viscoplasticity model has a form combined with the nonlinear kinematic and isotropic hardening rules as follows;

$$\dot{\boldsymbol{\varepsilon}}^{vp} = \left\langle \frac{|\boldsymbol{\sigma}-\boldsymbol{\alpha}| - R - \boldsymbol{\sigma}_{yo}}{K} \right\rangle^{n} \operatorname{sgn}(\boldsymbol{\sigma}-\boldsymbol{\alpha}) \tag{2}$$

$$\dot{\boldsymbol{\alpha}} = \sum_{k=1}^{m} \left(\frac{2}{3} C_k \dot{\boldsymbol{\varepsilon}}^{vp} - \gamma_k \boldsymbol{\alpha}_k \left| \dot{\boldsymbol{\varepsilon}}^{vp} \right| \right) \tag{3}$$

$$\dot{R} = b(Q - R)\left| \dot{\boldsymbol{\varepsilon}}^{vp} \right| \tag{4}$$

where [K, n, C_1, C_2, C_3, $C_{...}$, C_k, γ_1 γ_2, γ_3, $\gamma_{...}$, γ_k, b, Q, σ_{yo}] are material parameters and < > is the Macauley bracket. Total number of the material parameters identified for this model is actually dependent on the material types. The typically required experimental data to identify the material parameters contained in the unified viscoplastic constitutive equations are the Monotonic Tensile/Compression Tests, Cyclic Load Tests each with $\varepsilon(0) = 0$, and Stress Relaxation Tests [3].

3. Examples of Application

The material in this study is 316L used in Chaboche 1989. The material parameters for the constitutive equations through Eq.(1) to (4) are as follows (Chaboche, 1989);

C_1 = 162400 MPa
C_2 = 6750 MPa
γ_1 = 2800
γ_2 = 25
Q = 60 MPa
b = 8
E = 185 GPa
σ_{yo} = 82 MPa
K = 151 MPa
n = 24

All the initial conditions are assumed to be zero in this study. Among the viscous effects such as stress relaxation, creep strain increment, and strain rate dependency, first, the stress relaxation behavior is investigated with the strain-controlled simulations. Fig. 1 shows the strain-controlled hysteresis loop and Fig. 2 shows the stress-time history in case of the strain rate, $1.25\text{x}10^{-6}$ %/sec when there is no hold time. As shown in figures, we can see that the yield surface steadily increase during the initial cycles due to the isotropic hardening but there are no specific viscous behaviors something like the stress relaxation. Fig. 3 show the simulation results with same conditions but when there is a hold time during each cycle. In figures, we can see the evident viscous behavior of the stress relaxation at each cycle.

To investigate the behavior of the creep strain increment, the stress-controlled simulations are carried out. Fig. 4 shows the result of a stress-controlled hysteresis loop in case of no hold time. As shown in figure, the creep strain increment slightly occurs in ends of loading and unloading cycles. However, in case of with hold time, the significant creep strain increment occurs as shown in Fig. 5.

Finally, Fig. 6 shows the strain rate effects on the monotonic tensile stress. As shown in figure, we can see that the strain rate significantly affects the material behavior and when the strain rate increases, more hardening behavior occurs in the material.

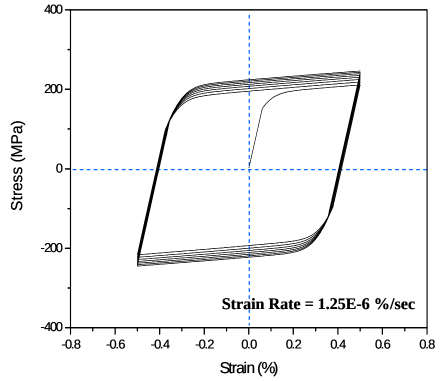

Fig. 1 Strain-Controlled Hysteresis Loop w/o Hold Time

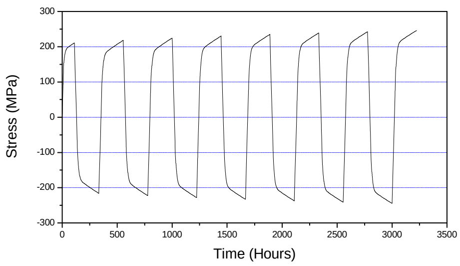

Fig. 2 Stress-Time History w/o Hold Time

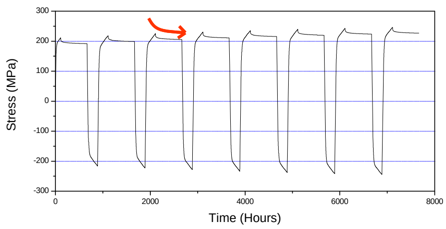

Fig. 3 Stress-Time History with Hold Time

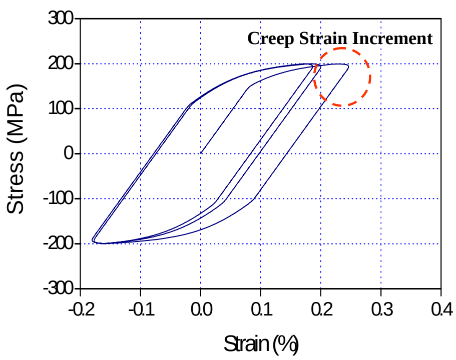

Fig. 4 Stress-Controlled Hysteresis Loop w/o Hold Time

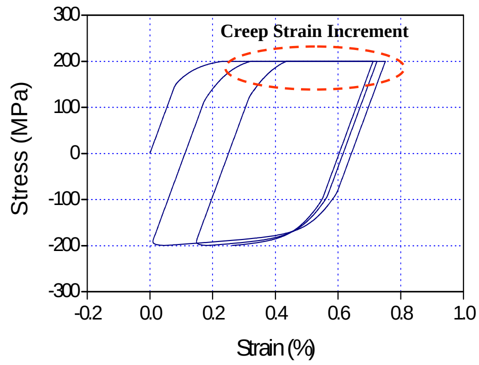

Fig. 5 Stress-Controlled Hysteresis Loop with Hold Time

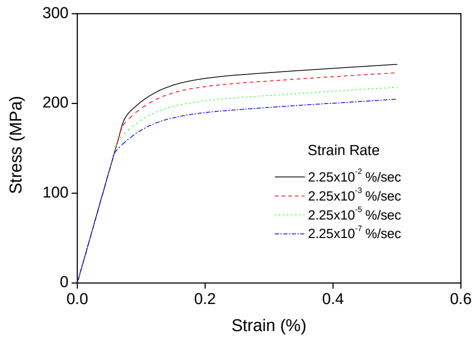

Fig. 6 Strain Rate Effect on Monotonic Hardening Behavior

3. Conclusions

From the examples of an application, it is verified that the developed PARA-ID program can simulate the viscoplasticity behavior of metal and be used for material constant identifications.

ACKNOWLEDGMENTS

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