Viscoplastic Stress Parameters for 316L Using a Relaxation Test

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1. Introduction

The inelastic behavior and creep-fatigue damage of the LMFBR structure under elevated temperature service needs to be evaluated properly for its structural integrity. For the inelastic analysis accounting for both the time independent plasticity and time dependent creep behaviors, a Chaboche's viscoplasticity constitutive model[1] was implemented into a general purpose finite element code ABAQUS as a subroutine NONSTA[2,3]. There are several ways of determining the material parameters which influences the analysis results to a large extent. Kim[4,5] proposed a way to obtain a set of material parameters and compared the temperature dependent elastoplastic characteristics of 15% cold worked 316L and solution annealed 316L. In this study, the determination method of viscoplastic stress parameters for simulating a creep and relaxation behavior by using relaxation test data is presented and reviewed.

2. Viscoplastic Parameters

The stress-strain relationship in the constitutive equations used in this study is shown in Equation (1).

$$\dot{\boldsymbol{\sigma}} = \mathrm{E}(\dot{\boldsymbol{\varepsilon}} - \dot{\boldsymbol{\varepsilon}}_p) = \mathrm{E}\left\{\dot{\boldsymbol{\varepsilon}} - \frac{3}{2}\left\langle\frac{J(\mathbf{s}-\boldsymbol{X}) - (R+\kappa)}{K}\right\rangle^n \frac{\mathbf{s}-\boldsymbol{X}}{J(\mathbf{s}-\boldsymbol{X})}\right\} \quad (1)$$

The viscoplastic strain rate($\dot{\boldsymbol{\varepsilon}}_p$) and the accumulated plastic strain rate($\dot{p}$) are

$$\dot{\boldsymbol{\varepsilon}}_p = \dot{p}\mathbf{n}, \quad \dot{p} = \left\langle\frac{J(\mathbf{s}-\boldsymbol{X}) - (R+\kappa)}{K}\right\rangle^n, \quad \mathbf{n} = \frac{3}{2}\frac{\mathbf{s}-\boldsymbol{X}}{J(\mathbf{s}-\boldsymbol{X})} \quad (2)$$

The hardening evolutions are defined as

$$\dot{X} = \frac{2}{3}C\dot{\boldsymbol{\varepsilon}}_p - \gamma\boldsymbol{X}\,\dot{p} = \left(\frac{2}{3}C\mathbf{n} - \gamma\boldsymbol{X}\right)\dot{p} \quad (3)$$

$$\dot{R} = b(Q-R)\dot{p} \quad (4)$$

where C, γ, Q, b, and κ are the material parameters. X is the back stress, R is the drag stress, p is the accumulated plastic strain, and function <x> is defined as: <x>=x if x ≥ o, <x>=0 if x < 0.

The kinematic hardening variables C and γ in Equation (3) and the cyclic hardening variables Q and b in Equation (4) are determined following the procedure of Reference [5].

The general equations are easily specialized to the tension-compression and the flow law may be inverted to yield

$$\sigma = X + R + \kappa + K(\dot{\varepsilon}_p)^{1/n} \quad (5)$$

The last term in Equation (5) is called as viscoplastic stress (Equation 6) to simulate the rate dependent plasticity including creep behaviors.

$$\sigma_V = K(\dot{\varepsilon}_p)^{1/n} \quad (6)$$

A procedure to evaluate the viscoplastic stress parameters K and n by making use of two tensile data with different strain rates was explained in Reference [5] but cannot be used for the case of a negative strain rate sensitivity. Annealed 316SS showed a negative strain rate sensitivity at 600°C; that is, the hardening decreased as the strain rate increased. Therefore, another method to determine parameters by utilizing stress relaxation test data is presented in this study.

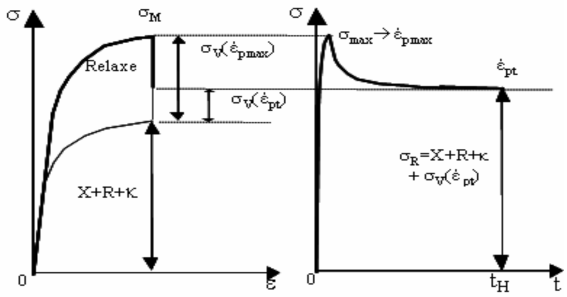


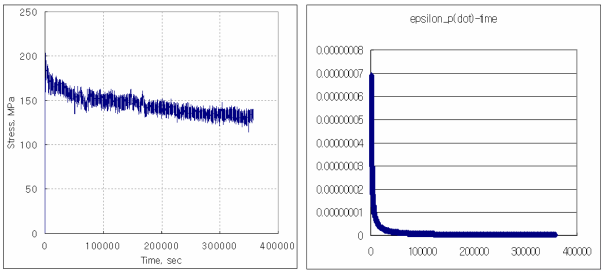
Fig. 1 Stress Decomposition into Internal and Viscous Parts during Relaxation

The schematic of a stress decomposition into nonviscous internal stresses and a viscopoastic stress during a relaxation test are illustrated in Fig.1. The starting value of the maximum stress (σ_M) contains both time independent elastic and plastic internal stresses (X, R, κ) and a time dependent viscoplastic stress (σ_V). This viscoplastic stress relaxes to a certain amount during a strain hold period. Here, it is noteworthy that the viscoplastic stress affects the initial behavior to reach σ_M while an elastoplastic analysis yields σ_M equal to the sum of X, R, and κ. This causes difficulties for the identification of the material parameters of a viscoplasticity constitutive equation.

During a relaxation test, a strain is maintained and the viscoplastic strain rate can be obtained as

$$\varepsilon = \varepsilon_{el} + \varepsilon_p = 0 \;\rightarrow\; \dot{\varepsilon}_p = -\dot{\sigma}/E \quad (7)$$

Fig.2(a) shows the relaxation test result of Annealed 316SS for 100 hours at 600°C and a strain was held as 2%. By differentiating a relaxation curve (σ-t), a relaxation stress rate ($\dot{\sigma}-t$) was obtained. Then, a relation between the viscoplastic strain rate and time ($\dot{\varepsilon}_p - t$) was obtained by following Equation (7) and it is shown in Fig. 2(b). Fig. 3 shows the rearranged relationship between the stress (σ) and the viscoplastic strain rate ($\dot{\varepsilon}_p$). Using a least square method or curve fitting, the parameters K and n in Equation (6) can be determined.



(a) Relaxation Test (σ-t) (b) $\dot{\varepsilon}_p - t$ relationship

Fig. 2 Stress Relaxation of 316L at 600°C (2%)

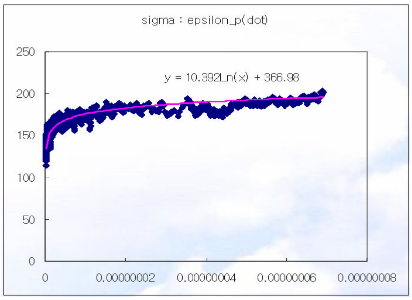


Fig. 3 Stress versus Viscoplastic Strain Rate during Relaxation

3. Inelastic Behavior of Annealed 316L

A set of material parameters obtained in this study is shown in Table 1. The values of K and n depend upon the reliability of the relaxation data and the concerned range of the viscoplastic strain rate. As shown in Equation (1), stress depends on the value of the viscoplastic strain rate. Before a relaxation starts, the viscoplastic strain rate reaches a maximum and the stress reaches its maximum value, too. The amounts of a starting value of relaxation and a final value after 100 hours were numerically investigated with changing values of K and n. With increasing K and n, the amount of relaxation increases and the hardening also increases. Therefore, it should be emphasized to consider the hardening behavior properly in determining the viscoplastic stress parameters K and n. The comparison of an inelastic analysis result by using the parameters of Table 1 with that of the test data shows a good agreement as shown in Fig. 4.

Table 1. Viscoplastic Material Parameters(316L, 600°C)

E(GPa)	ν	C(MPa)	γ	b
150	0.3	11700	130	5.9
Q(MPa)	κ(MPa)	K(Mpa)	n	
148	5	300	10	

In Fig. 4, it is noted that the initial behavior up to 1000 seconds showed an excellent agreement between the analysis and the test result. The analysis predicted the amount of relaxation excessively at the beginning of the relaxation while the overall behavior agrees well. The cyclic relaxation behavior for the compression hold following a tension hold was examined and the results are shown in Fig. 5. The cyclic hardening behavior of 316L and the relaxations during both a tensile hold and a compressive hold were expressed satisfactorily.

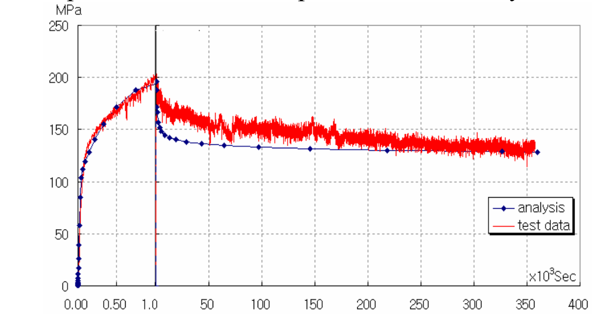


Fig. 4 Comparison of Analysis Result and Test Data

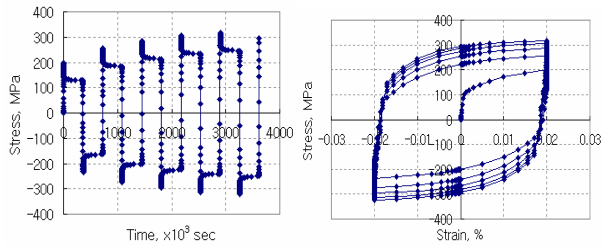


Fig. 5 Simulation of Cyclic Relaxation

4. Conclusion

A method to determine the viscoplastic stress parameters is presented and the parameters for an Annealed 316SS are obtained. The results of the inelastic analysis by using the obtained values showed a good agreement with the test results.

ACKNOWLEDGMENT

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