CORRELATIONS BETWEEN METALLURGICAL CHARACTERIZATION STUDIES, EXPLORATORY MECHANICAL TESTS, AND CONTINUUM MECHANICS APPROACHES TO CONSTITUTIVE EQUATIONS*

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Austenitic stainless steels, such as types 316 and 304, are widely used as pressure vessel materials in the temperature range of 425 to 650°C. Depending on the loading rate, the deformation behavior may fall into categories classified in continuum mechanics as either time-dependent plasticity or time-dependent creep. Ad hoc rules are sometimes needed to accommodate interaction effects. Some of the rules for interaction effects can be better understood by taking into account the dynamic nature of the dislocation-dislocation and dislocation-precipitate substructure and how it responds to transient stress, strain, and temperature conditions. The variation in this structure includes changes in mobile dislocation density, dislocation link lengths, cell sizes and misorientation angles, and precipitate sizes and distributions.

Although somewhat limited in its use for understanding kinematic hardening behavior, microscopy is a valuable tool in the study of isotropic hardening, especially as it is affected by the Orowan-Bailey concept of strain hardening versus thermal recovery and acceleration of aging phenomena due to cyclic strain. Indeed, a better understanding of metallurgical phenomena needs to be developed in order to establish the useful range of accumulated strain as a state variable.

In considering type 304 stainless steel that exhibits a creep behavior characterized by a relatively high stress exponent of creep rate and the development of subgrains during creep deformation of recrystallized material,

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and for tests conducted under constant stress (σ), temperature (T), and environments (E), the creep rate, $\dot{\varepsilon}$, may be given as:

$$\dot{\varepsilon}(\sigma,T,E,S)_{\sigma,T,E} = \dot{\varepsilon}(S) \ .$$

Here S is a parameter that describes microstructure, which for dislocation creep is characterized by the following parameters:

$$S = S[\lambda,\rho,\theta,F(\theta),f(p)] \ ,$$

where λ is the subgrain size, ρ the dislocation density, θ is the average misorientation angle between subgrains, $F(\theta)$ is the distribution function of the misorientation angle, and $F(p)$ is some function of dislocation-second phase interactions.

Figures 1 through 3 show creep curves (strain-time) of some exploratory mechanical tests performed at temperatures 704, 650, and 593°C. Specimens were tested to rupture at two different stress levels σ_1 and σ_2 ($\sigma_1 > \sigma_2$) to establish the normal strain-time behavior. A subsequent test was performed in which the specimen was crept at the higher stress (σ_1) to the beginning of the secondary stage of creep, presumed to be the strain/time conditions at which a steady state microstructure is developed, and then the stress was reduced to the lower level (σ_2). In most of the conditions studied, it was observed that some incubation time period (Δt) would prevail at which the strain, other than elastic strain recovery, would show no measurable change. In some cases, such as a stress change to 48 or 33 percent of the initial stress for tests conducted at 650°C and an initial stress, σ_1, of 207 MPa, a negative strain would prevail for a period of time. As the test temperature is decreased, the incubation period is significantly increased such as the 160 hours observed at the 593°C with a stress drop of about 25%.

The associated microstructure, S, and significance of this microstructure on the creep strain-hardening model for variable uniaxial loads were assessed and found to be consistent with the use of creep-recovery models at high stresses and temperatures and strain-hardening models at low stresses and temperatures.

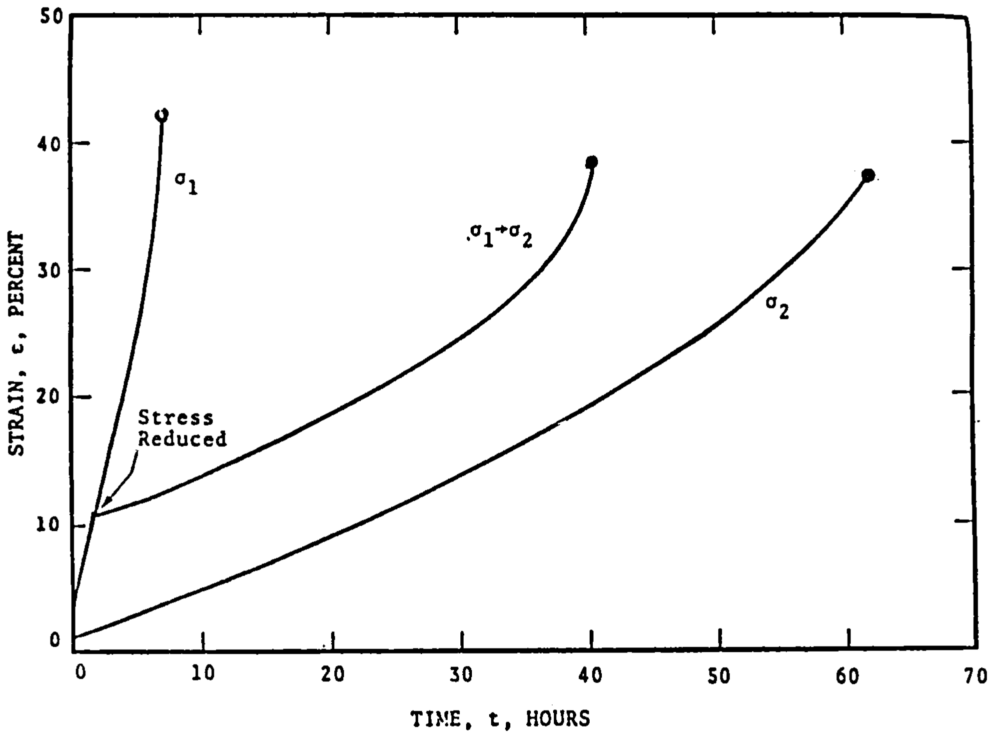

Fig. 1. Strain-time curves for 304 stainless steel tested at 704°C (σ_1 = 207 MPa, σ_2 = 151 MPa).

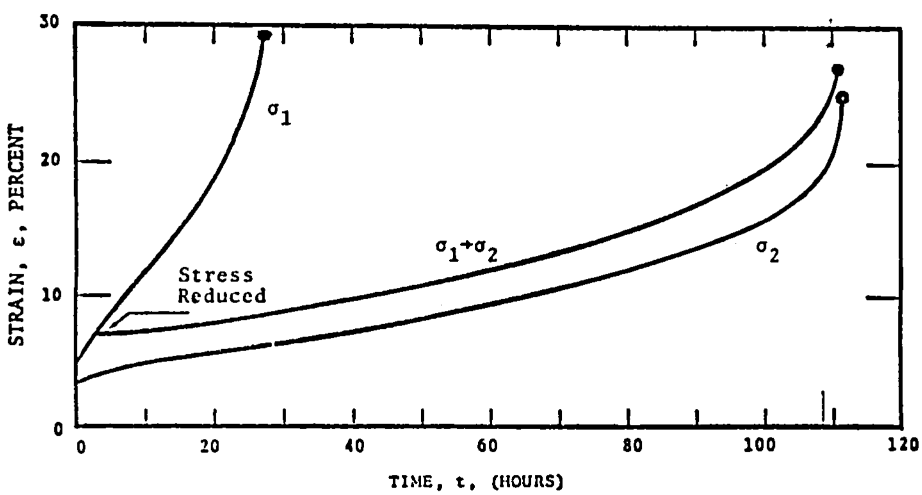

Fig. 2. Strain-time curves for 304 stainless steel tested at 650°C. (σ_1 = 172 MPa, σ_2 = 138 MPa)

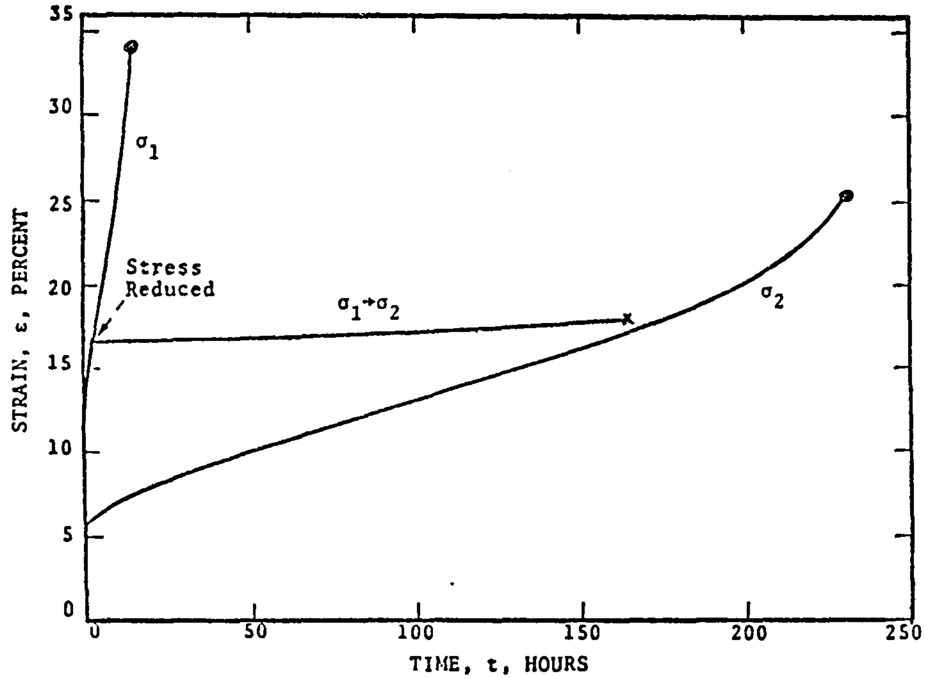

Fig. 3. Strain-time curves for 304 stainless steel tested at 593°C. (σ_1 = 276 MPa, σ_2 = 207 MPa)