DATA REQUIREMENTS TO MODEL CREEP IN 9CR-1MO-V STEEL *

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Models for creep behavior are helpful in predicting response of components experiencing stress redistributions due to cyclic loads, and often the analyst would like information that correlates strain rate with history assuming simple hardening rules such as those based on time or strain. On the other hand, much progress has been made in the development of unified constitutive equations that include both hardening and softening through the introduction of state variables whose evolutions are history dependent. Although it is difficult to estimate specific data requirements for general application, there are several simple measurements that can be made in the course of creep testing and results reported in data bases. The issue is whether or not such data could be helpful in developing unified equations, and, if so, how should such data be reported. Data produced on a martensitic 9Cr-1Mo-V-Nb steel were examined with these issues in mind.

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Approximately 40 creep tests were performed on the steel in the temperature range 475 to 650 C and for times to beyond 10,000 h. The initial creep rate, time to 0.2% creep strain, and minimum creep rate data were taken and used to examine two types of creep models. In the first model, strain hardening was assumed and the 0.2% creep data used to estimate the parameters for a simple Norton-Bailey power law creep equation. In the second model, the initial and minimum creep rate data were used to estimate the evolution of a kinematic state variable that reduces the effective stress included in a simple power law creep equation. In addition to the above data, more than 100 creep rate data from stress and temperature change tests were obtained and examined in connection with the expectations of the two deformation models.

An example of the creep response to changing stresses in a test lasting 13,000 h is shown in Fig. 1. Here the stresses ranged from 0 to 241 MPa at 500 C, and creep response included both softening and hardening features. Analysis of these and other data are shown in Fig. 2 which compares the creep rates from constant and variable stress-temperature conditions with the rates calculated from a simple strain hardening rule and creep law. Data and calculations agree within reasonable bounds, although there is some tendency for the rates to be greater than expected. These comparisons do not include results from short-time transients. In such situations the strain hardening model was found to underestimate creep rates for stress increases and overestimate creep rates for stress decreases.

In the unified equation, the creep rate was assumed to be proportional to the function $(S-\alpha)^n$, where α may be a kinematic state variable (called the "back stress"), as many other investigators have postulated. The choice of 4 for the stress exponent is quite common in the literature, and the proportionality factor may be written as A(T)/D, where A(T) is some function of temperature and D is either constant or slowly changing as a result of the metallurgical aging produced by time-temperature-strain exposure. Assuming that α is initially 0 and that D does not change permits the use of the initial creep rate data to calculate α for any condition where the instantaneous creep rate is known. Fig. 3 shows a comparison of the calculated α against the applied stress for the minimum creep rate condition. The calculated values are proportional to stress at low stresses but approach a maximum that depends on the testing temperature. Calculations of the hardening and recovery parameters in the Orowan-Bailey growth law for α requires more data, however. Here the rate of change in α is given by the difference $H\dot{e}-R\alpha$, where H is a hardening term, $\dot{e}$ is creep rate, and R is the recovery term. Examples of H and R obtained from the creep tests are shown in Figs. 4 and 5.

Stress change data at various stages of creep are needed to determine whether or not it is necessary to evaluate changes in D. If the α calculated from the initial creep rate and the minimum creep rate does not agree with the α determined from a recovery creep experiment, then either the model is totally wrong or D is changing. The latter situation seems to be the case for the 9Cr-1Mo-V-Nb steel. Either way, the data base needed to fully develop unified equations from creep tests is fairly substantial. It may be easier to least squares fit entire data sets together rather than to correlate parameters from individual tests and restructure a model from the these elements.

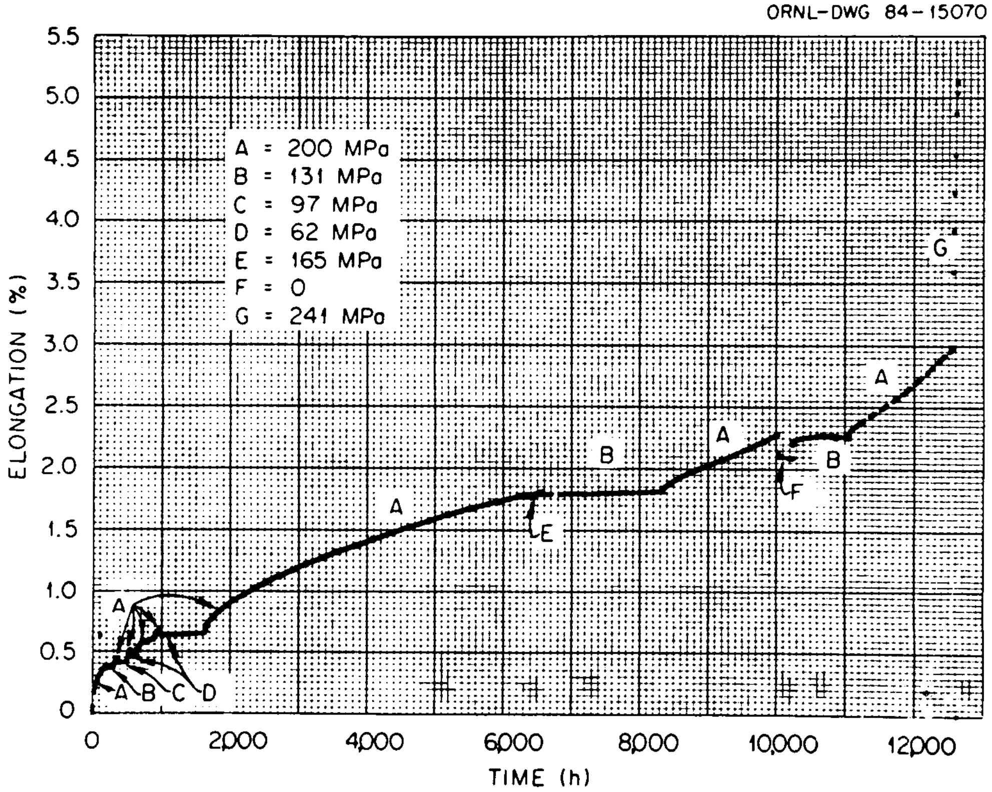

Fig. 1. Creep response of 9Cr-1Mo-V-Nb steel during stress changes at 550 C.

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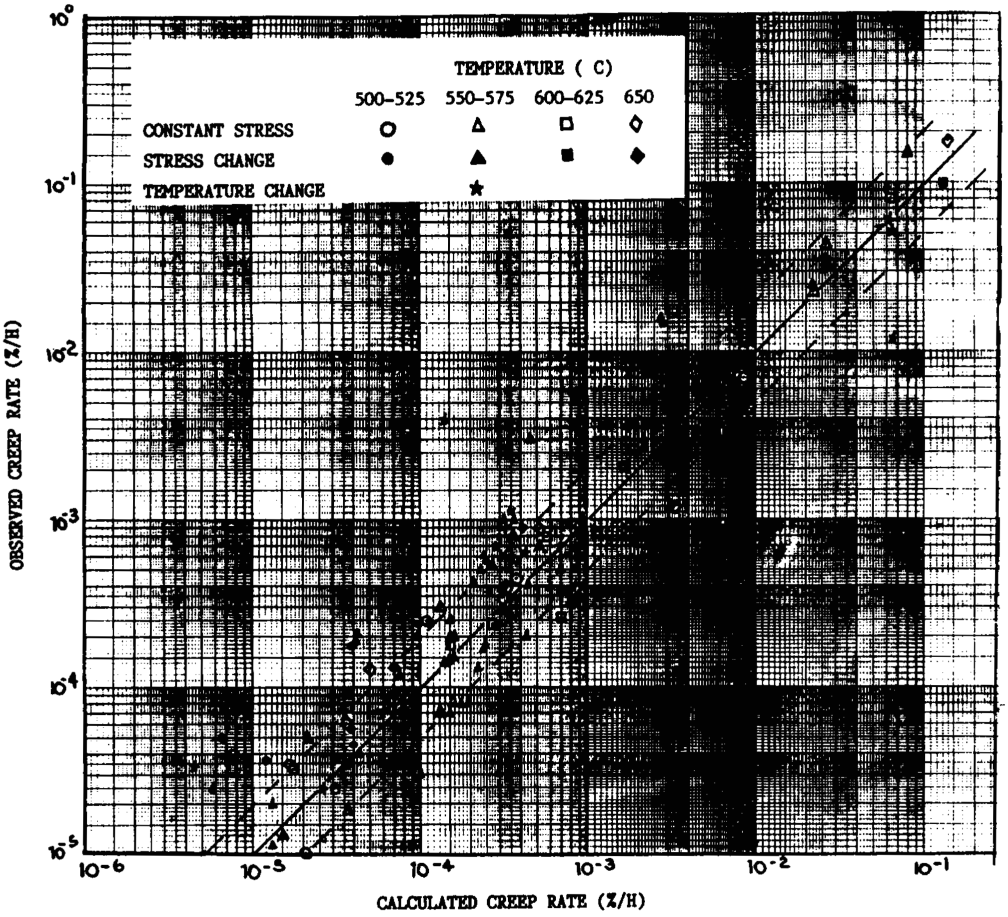

Fig. 2. Comparison of calculated and observed creep rate data produced from constant, variable stress, and variable temperature testing.

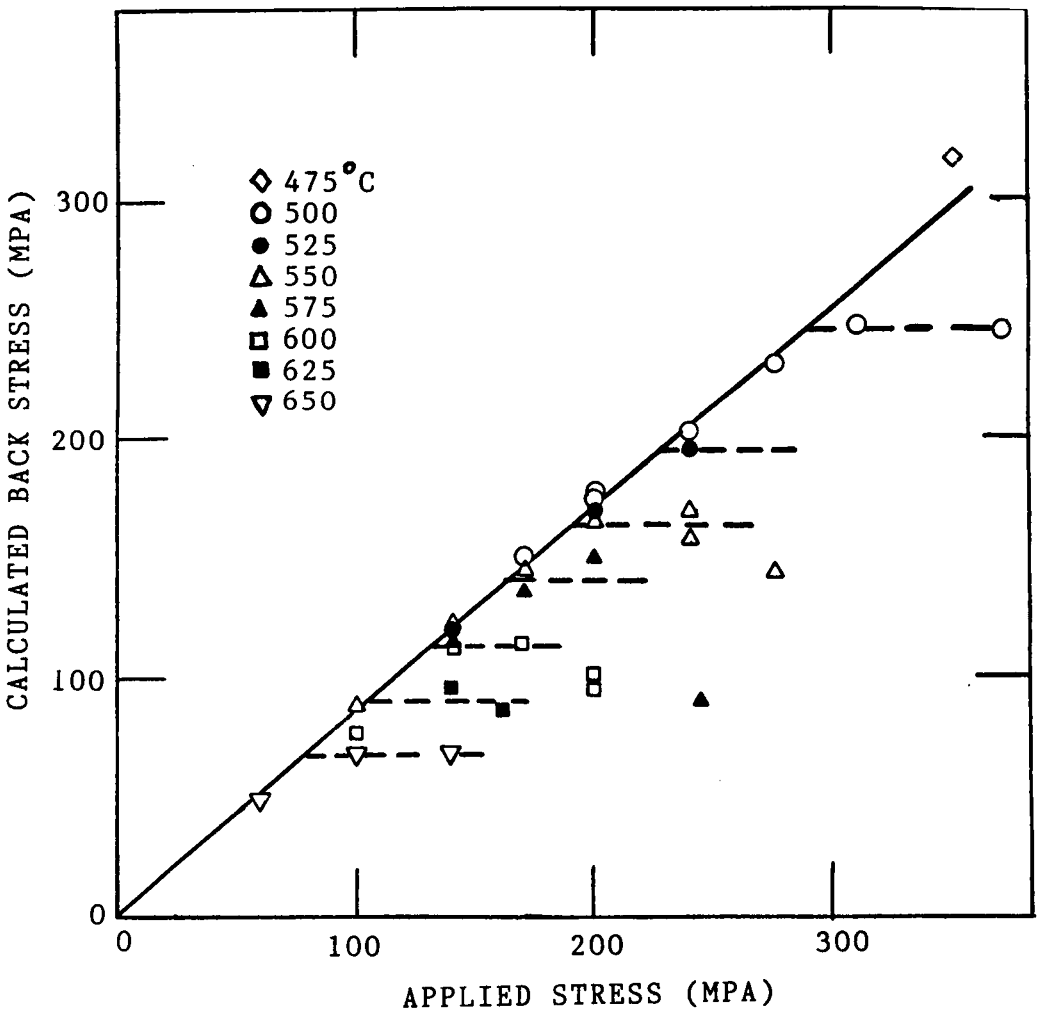

Fig. 3. Calculated back stress versus applied stress.

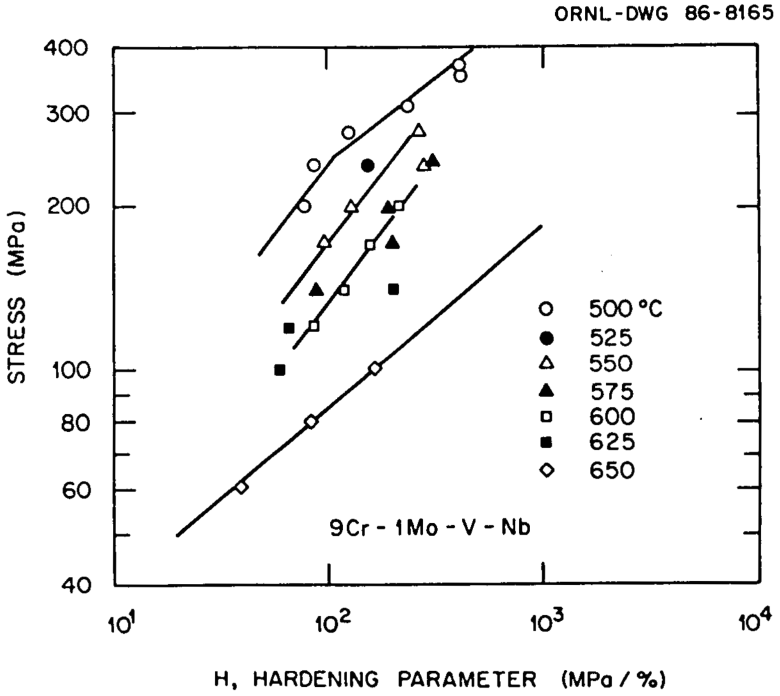

Fig. 4. Log stress versus log of the calculated hardening parameter of the Orowan-Bailey equation.

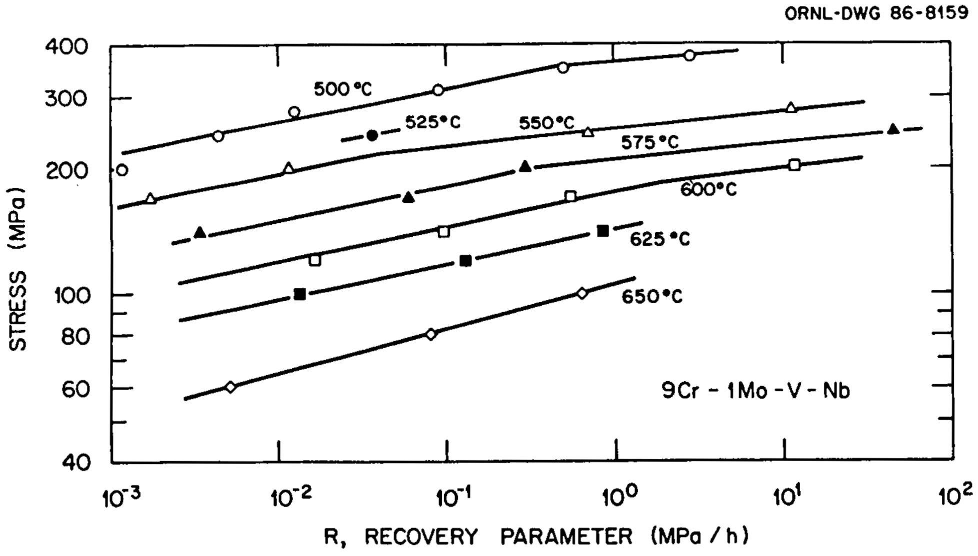

Fig. 5. Log stress versus the log of the calculated recovery parameter of the Orowan-Bailey equation.