A UNIFIED CONSTITUTIVE RELATIONSHIP FOR THE TIME-DEPENDENT BEHAVIOR OF FAST BREEDER ALLOYS*

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EXTENDED ABSTRACT

Constitutive equations based on classical concepts of creep and plasticity generally rest on the assumption that the inelastic strain can be decomposed into two distinct and additive contributions, one time-dependent (creep) and the other time-independent (plastic). Experimental data collected on structural alloys at high temperature (500 to 600°C), however, suggest that an improved approach is to adopt a unified representation in which creep and plasticity are characterized as occurring simultaneously and interactively and time is an essential ingredient throughout.

Examples of the inherent time dependency exhibited by some fast breeder alloys (particularly 2-1/4 Cr—1 Mo steel) at elevated temperature are rate-dependency under monotonic and cyclic straining, thermal recovery (Fig. 1), and strong creep-plasticity interaction. One manifestation of the latter is illustrated in Fig. 2 which shows the strong influence of the recent history of plastic straining on stress relaxation. Account of such behavior is important in structural problems related to the design of fast breeder components.

A creep-plasticity-recovery constitutive model has been under development at Oak Ridge National Laboratory (ORNL) in recent years[1,2,3] that allows for some of the more important nonclassical features observed in the behavior of fast breeder alloys. The ORNL model is based on the Bailey-Orowan theory of competing hardening and recovery mechanisms and incorporates some aspects of the work of several authors, e.g., Rice,[4] Ponter and Leckie,[5] and Lagneborg.[6] A notable distinction between this constitutive model and the related state-variable theories of Krieg[7] and Miller[8] lies in an accompanying set of inequalities that, in effect, delineate analytically different regions of the "state space." This approach in so structuring the state space follows the work of Onat[9]

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and Larrson and Stöakers[10] and admits a representation of analytically discontinuous response such as that observed before and after reductions or reversals of stress and exemplified in Figs. 1 and 2.

Figures 3 through 6 provide a qualitative demonstration of the ability of the ORNL unified model to represent key features of high temperature uniaxial response. Figure 3 illustrates creep behavior (in arbitrary nondimensional units) under constant stress conditions, indicating saturation of the state variable α at steady state creep. Figure 4 shows the predicted response in an interrupted creep test and is characterized by the occurrence of state recovery with zero creep strain recovery (cf. Fig. 1). The state variable α is seen, in this case, to decrease during the period at zero stress. Figure 5 illustrates the capability of the model, coupled with linear elasticity, to represent rate-dependent plasticity. Shown are several monotonic stress strain curves corresponding to different strain rates. Finally, Fig. 6 demonstrates the ability of the unified equations to model the complex behavior depicted in Fig. 2. A saturated hysteresis loop predicted on the basis of the ORNL unified equations is shown in Fig. 6a, the numbers indicating points from which the stress is relaxed. The corresponding predictions of stress relaxation are given in Fig. 6b. Figure 6c depicts the limit cycle in state space corresponding to the saturated hysteresis loop of Fig. 6a and shows the trajectories followed by the state points during stress relaxation. The relaxation behavior is seen to be strongly dependent on the initial inelastic state even for points of equal starting stress.

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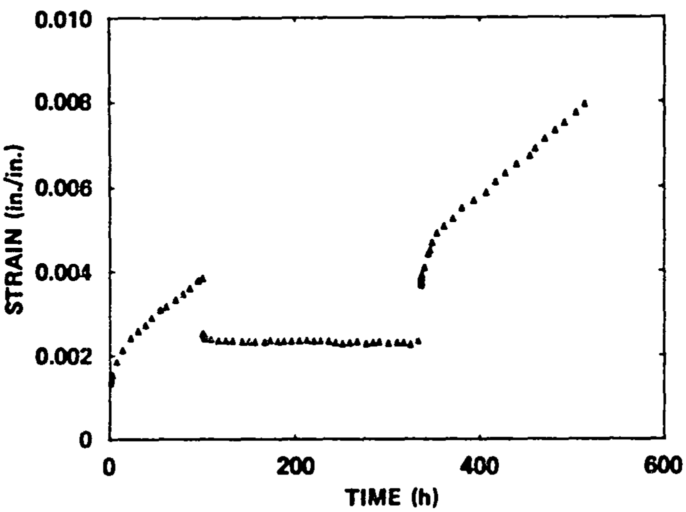

Fig. 1. Response of 2-1/4 Cr-1 Mo steel at 538°C in interrupted creep test. Stress alternates as 124 MPa, 0 MPa, 124 MPa.

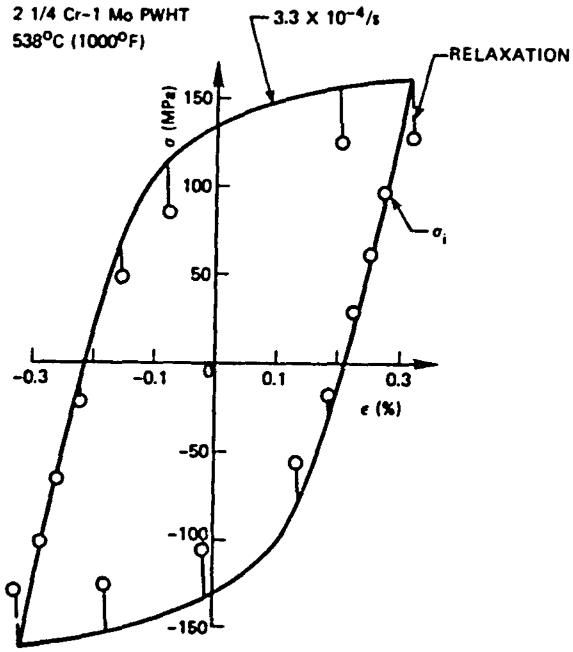

Fig. 2. Stress relaxation in one hour from various points around a saturated hysteresis loop.

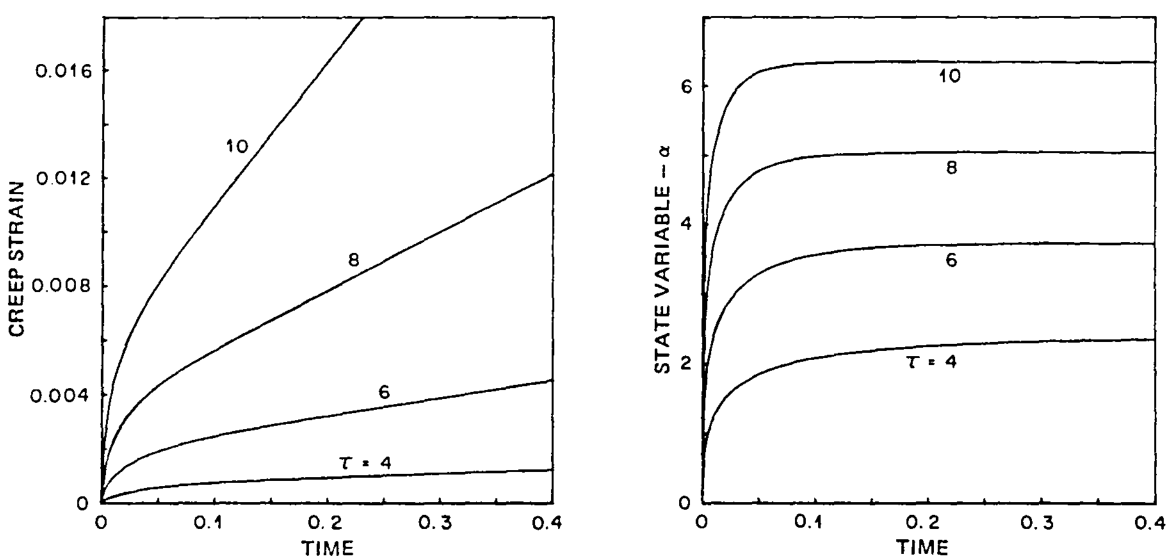

Fig. 3. Prediction of creep strain vs time and state variable α vs time under constant stress (τ = const.) conditions. Units are arbitrary and nondimensional.

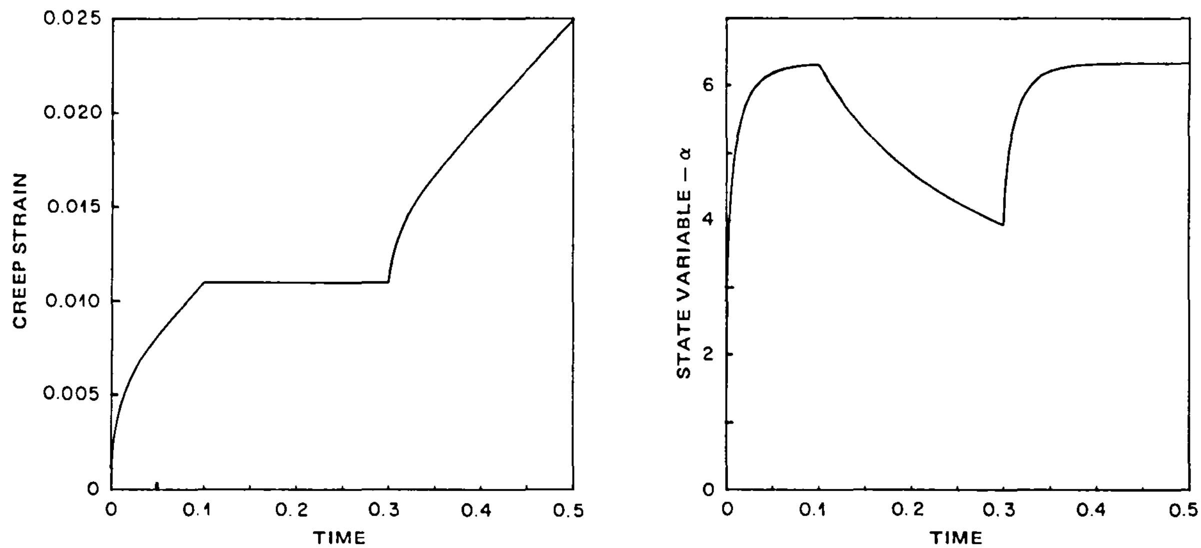

Fig. 4. Prediction of response in interrupted creep test. Creep strain vs time and state variable α vs time (cf. Fig. 1). Arbitrary, nondimensional units.

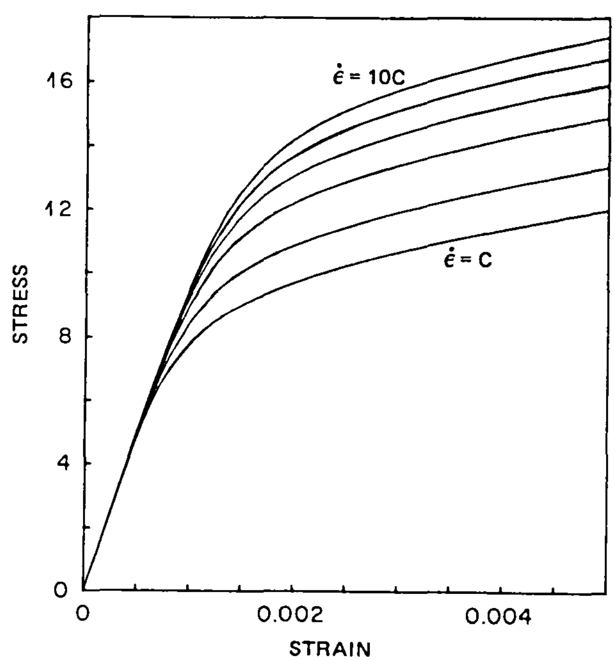

Fig. 5. Prediction illustrating rate sensitive plasticity. Stress vs strain under constant strain rate. Variation in strain rate is one decade. Arbitrary, nondimensional units.

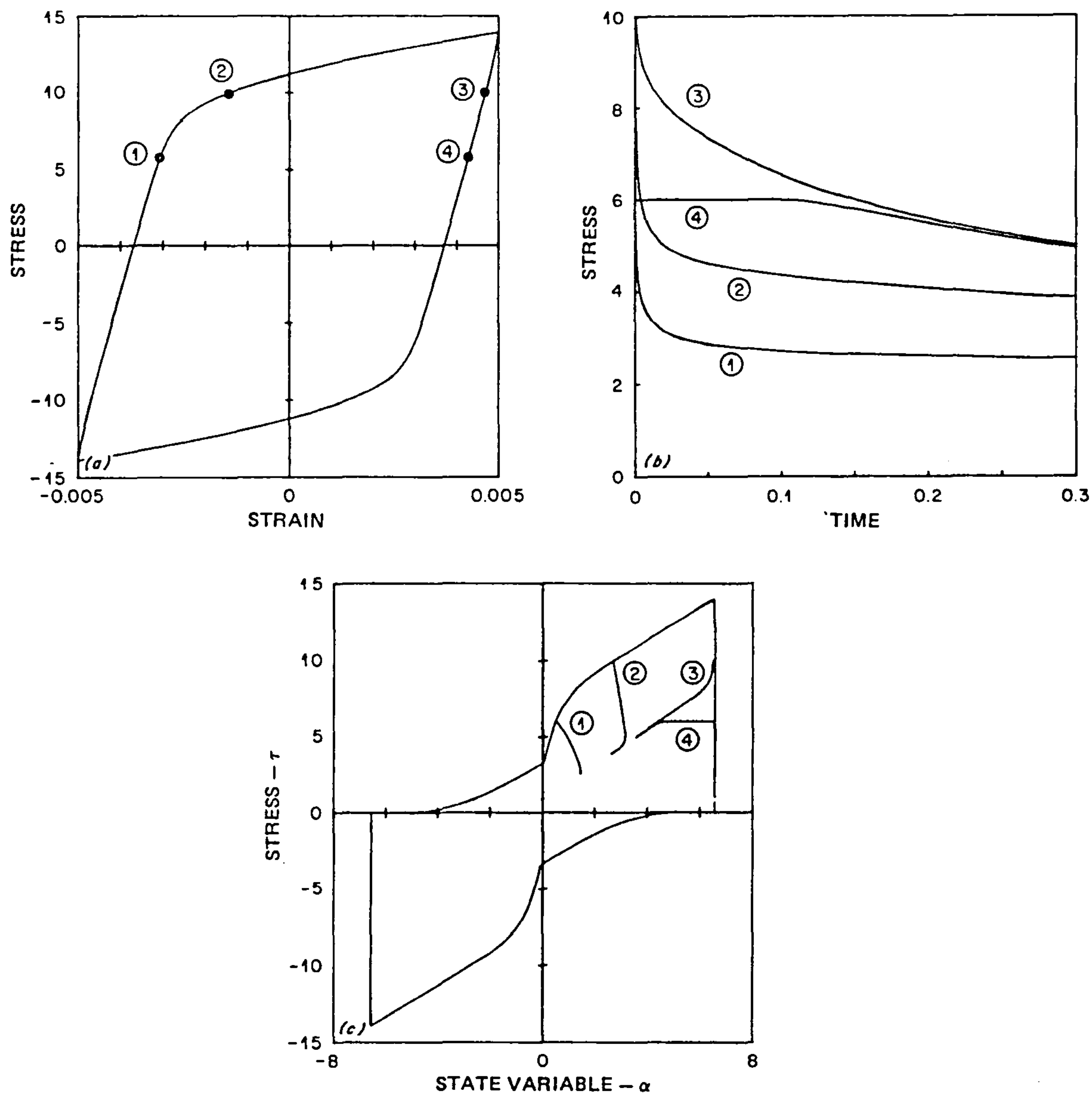

Fig. 6. (a) A saturated hysteresis loop at constant strain rate. Numbers indicate points from which stress is relaxed. (b) Stress relaxation curves corresponding to points in (a). (c) Saturated limit cycle in state space τ vs α showing trajectories followed during stress relaxation. Units are arbitrary and nondimensional.