APPLICATION OF AN UNCOUPLED ELASTIC-PLASTIC-CREEP CONSTITUTIVE MODEL TO METALS AT HIGH TEMPERATURE

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Abstract

A uniaxial, uncoupled constitutive model for predicting the response of thermal and rate dependent elastic-plastic material behavior is presented. The model is based on an incremental classical plasticity theory extended to account for thermal, creep, and transient temperature conditions. Revisions to the combined hardening rule of the theory allow for better representation of cyclic phenomenon including the high rate of strain hardening upon cyclic reyield and cyclic saturation. Also, an alternative approach is taken to model the rate dependent inelastic deformation which utilizes hysteresis loops and stress relaxation test data at various temperatures. Evaluation of the model is performed by comparison with experiments involving various thermal and mechanical load histories on 5086 aluminum alloy, 304 stainless steel and Hastelloy-X.

The uncoupled model assumes that there is a temperature below which the total strain consists essentially of elastic and rate independent inelastic strains only. Above this temperature, the rate dependent inelastic strain (creep) dominates. Experimentally, Bradley has shown for Hastelloy-X that such an uncoupling appears feasible.

The rate independent inelastic strain component is modelled in an incremental form with a yield function, flow rule and hardening law. However, the model is able to predict kinematic-isotropic hardening behavior, cyclic saturation, asymmetric stress-strain response upon stress reversal, and variable Bauschinger effect. The rate dependent inelastic strain component is modelled using a rate equation in terms of back stress, drag stress and exponent n as functions of temperature and strain. A sequence of hysteresis loops and relaxation tests are utilized to define the rate dependent inelastic strain rate (see Bradley).

Numerical testing of the constitutive model against experiment has thus far centered primarily at the low temperature range where the rate dependent component is negligible. Figure 1 presents results for 5086 Aluminum subjected to a cyclic thermomechanical loading. Numerical results are in excellent agreement with experiment. Figure 2 shows the cyclic response of 304 stainless to strain-controlled cycling at 1000°F. The model uses a variable hardening ratio and accounts for the asymmetry in tension-compression response exhibited by the experimental data. Figures 3 and 4 show the room temperature experimental and model results, respectively, for Hastelloy-X during strain-controlled cycling at several strain rates. Cyclic saturation is modelled reasonably well as shown in Figure 4. Numerical comparison of model predictions and experiment at elevated temperature where rate dependent inelastic strain is significant are currently being obtained.

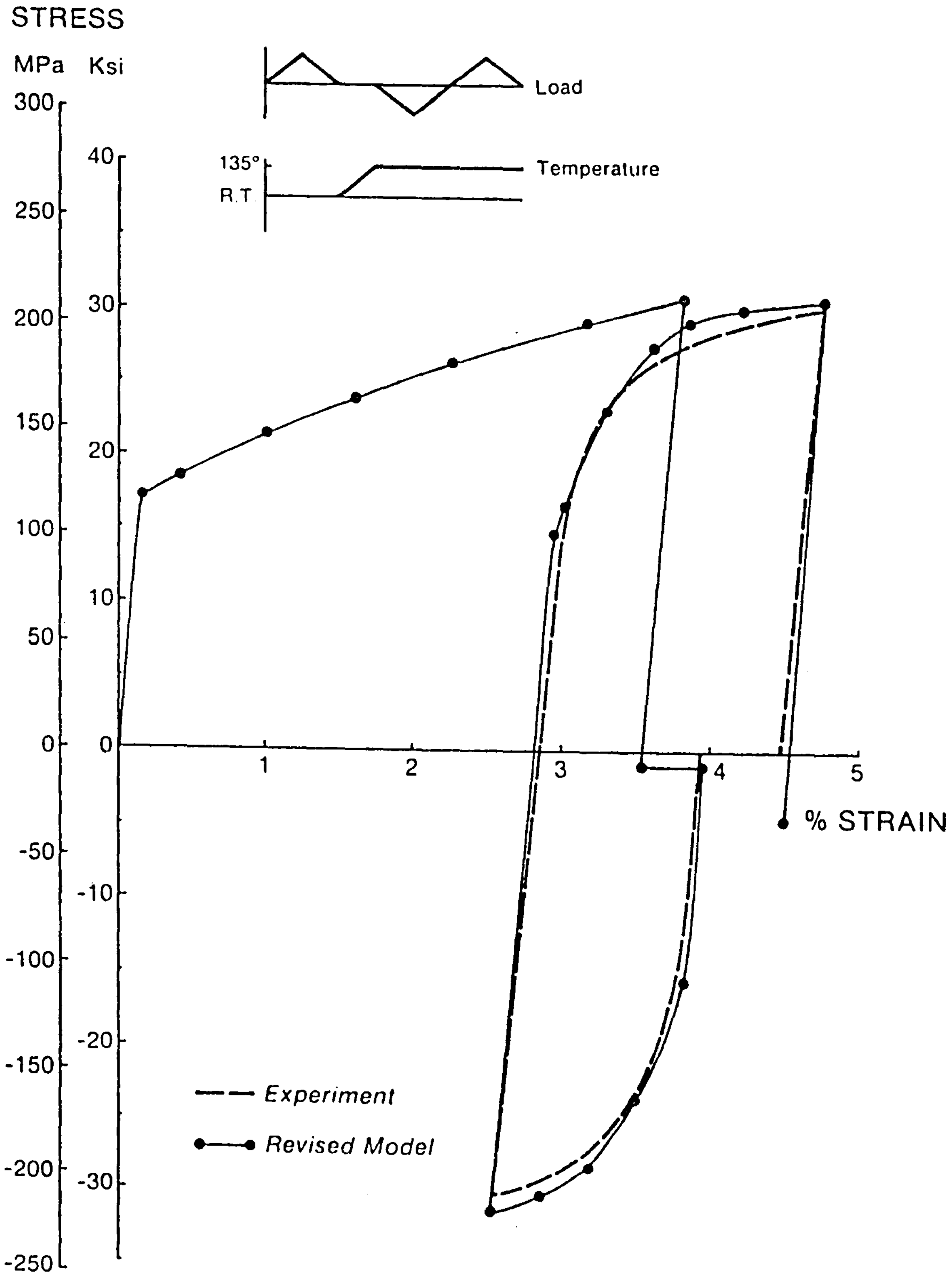

Fig. 1 Comparison of revised model to experiment for aluminum cyclic load test

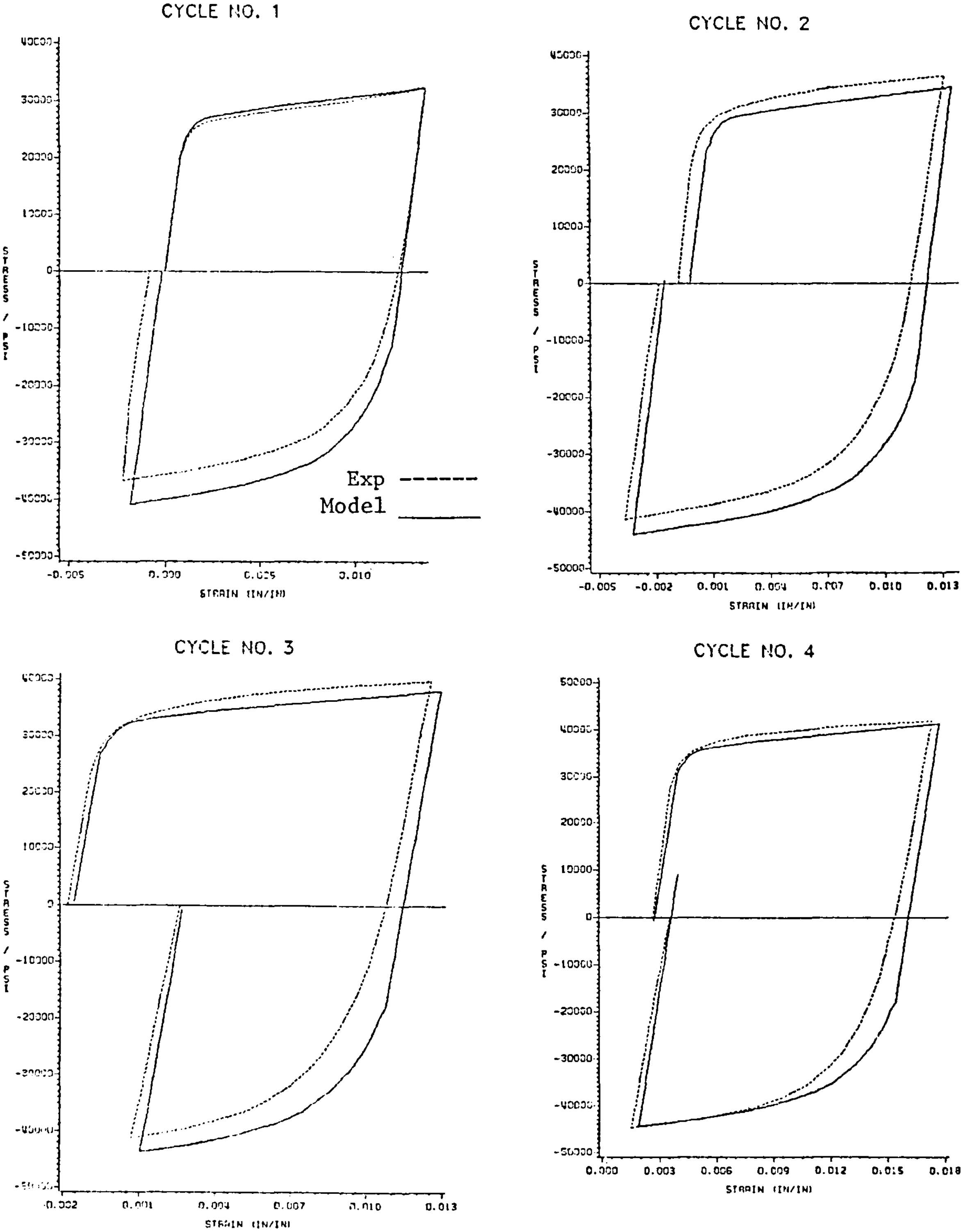

Fig. 2 Comparison of model and experiment for 304 stainless steel at 1000°F using first cycle data as input. A hardening ratio of 0.2 in tension and 0.35 in compression was used

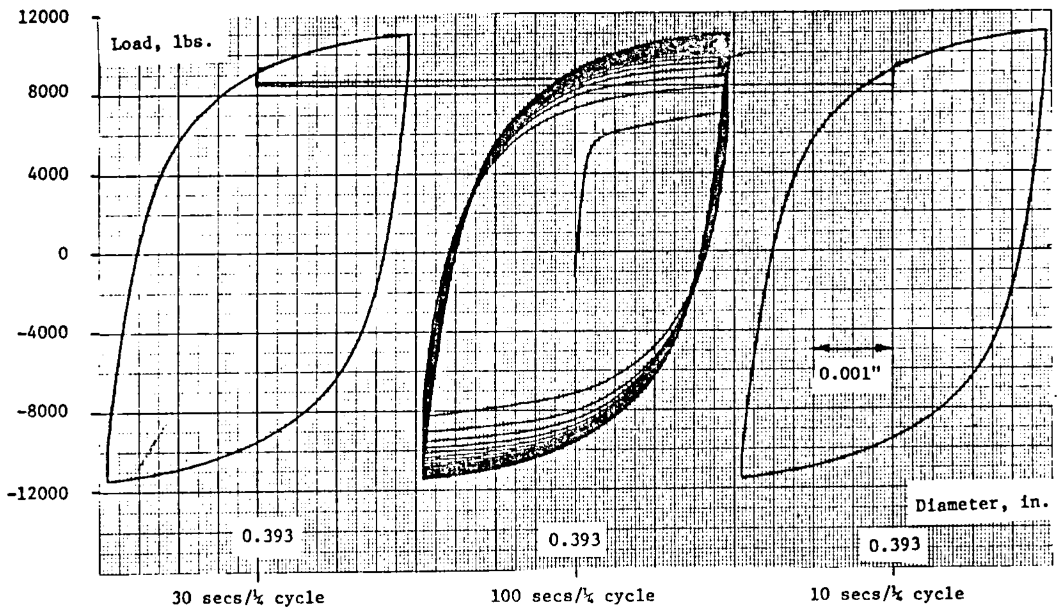

Fig. 3 Experimental hysteresis loops for hastelloy-X at room temperature

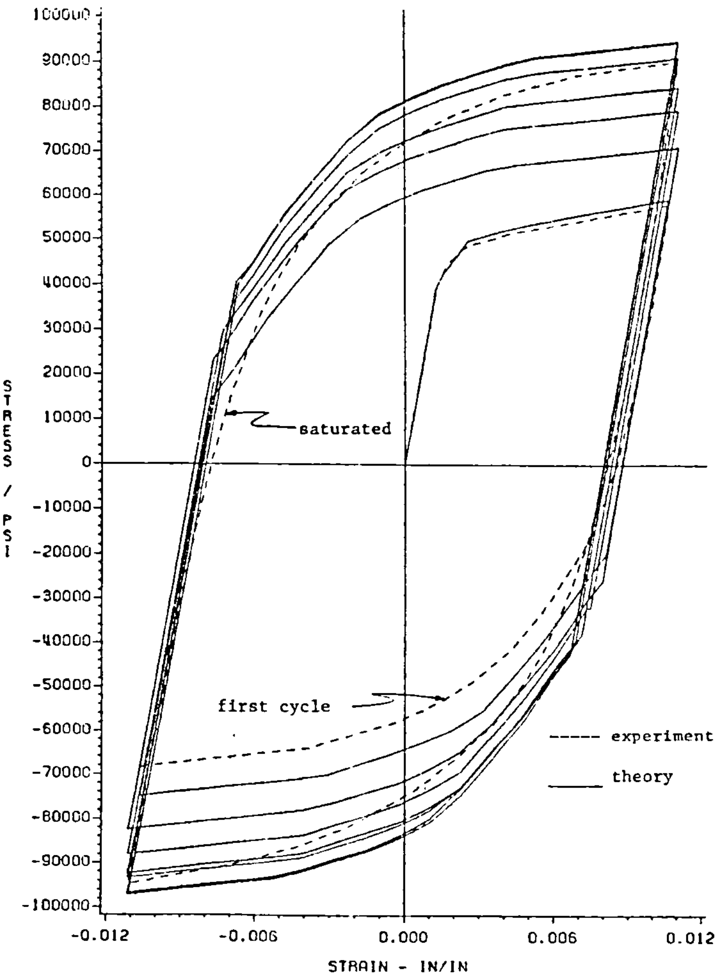

Fig. 4 Cyclic saturation of hastelloy-X at room temperature