THERMOMECHANICAL DEFORMATION IN THE PRESENCE OF METALLURGICAL CHANGES*

D.N. Robinson
University of Akron
Akron, Ohio 44325

Cyclic hardening of some common structural alloys within their temperature range of interest is believed to be influenced by the phenomenon of dynamic strain aging.[1] Strain aging occurs in solid solutions where solute atoms (e.g., carbon, nitrogen, etc.) are particularly free to diffuse through the parent lattice. It is energetically preferable for these solute atoms to occupy sites in the neighborhood of mobile dislocations where their presence immobilizes the dislocations or at least makes their movement difficult, thus causing strengthening.

Isothermal cycling at temperatures where such metallurgical changes occur might therefore be expected to show abnormal hardening, i.e., higher hardening rates and greater saturation strengths than at temperatures both lower and higher. Macroscopic evidence of strain aging in three common alloys (i.e., Hastelloy X and types 304 and 316 stainless steel) is shown in Figures 1 through 3. In each case the hardening rate and the stress range at "saturation" are maximal at an intermediate temperature in the range. This hardening peak is interpreted as a manifestation of dynamic strain aging. At lower temperatures the mobility of solute atoms is far less and strain aging cannot occur; at higher temperatures normal recovery precesses, e.g., climb of edge dislocations, take over.

In the aging process described dislocations can, under some circumstances, break away from their Cottrell solute atmospheres becoming mobile again. Although temporarily freed, dislocations can again be immobilized as solute atoms gradually diffuse back to them. As the thermally activated process of diffusion is involved

*This work was performed under NASA Grant NAG-3-379.

and solute atoms are migrating to dislocations which themselves are moving under the applied stress, it is expected that the ensuing inelastic deformation (cyclic hardening in particular) has a complex dependence on thermomechanical history.

Phenomenological evidence of themomechanical path dependence under cyclic conditions is seen in the results of the simple nonisothermal tests reported in Figures 1 and 2 (dotted curves). In these tests cycling is initiated at one temperature and after some cycling the temperature is changed and cycling resumed.

Figure 1 shows the results of two nonisothermal tests on Hastelloy X cycled over a strain range at constant strain rate. In one, the specimen is cycled at 800F for five cycles; the temperature is them changed to 1000F and cycling is continued to virtual saturation, at about one hundred cycles. In the second, this history is repeated up to thirty cycles where the specimen is then brought back to 800F and cycling continued. Results of a similar test on type 304 stainless steel are shown in Figure 2 (dotted line).

The features of these test results that reflect thermomechanical history dependence are: 1) The change in strength (stress range) with temperature at a fixed number of cycles is always negative, i.e., an increase in temperature always produces a decrease in strength and vice versa, contrary to the implication of the isothemal data; 2) The current strength, in particular the "saturation" strength, depends on the temperature-strain history. Evidently, the information contained in the isothermal data is not sufficient for a complete nonisothermal description of the cyclic deformation in the temperature range of interest. In fact, the data suggests that, with accompanying metallurgical changes, the materials retain a full memory of their themomechanical history to cyclic saturation.

In the present work a discussion is given of nonisothermal testing that can be used as a basis of a nonisothermal representation. Related tests were discussed in Ref. 2 with regard to metallurgical changes that occur in other high temperature structural alloys.

In spite of the sparseness of nonisothermal data, a visco-plastic constitutive model capable of qualitatively representing the behavioral features observed in Figures 1 through 3 has been formulated. This model is used here to begin to assess the differences in ultimate life prediction in some typical noniso-thermal structural problems when the constitutive model does or does not account for metallurgically induced thermomechanical history dependence.

REFERENCES

1. J.D. Baird, "Dynamic Strain Aging", The Inhomogeneity of Plastic Deformation, ASM, Metals Park, Ohio (1973).

2. G. Cailletaud and J.-L. Chaboche, Macroscopic Description of The Microstructural Changes Induced by Varying Tempera-ture: Example of IN 100 Cyclic Behavior, ICM, 3, Vol. 2 (1979)

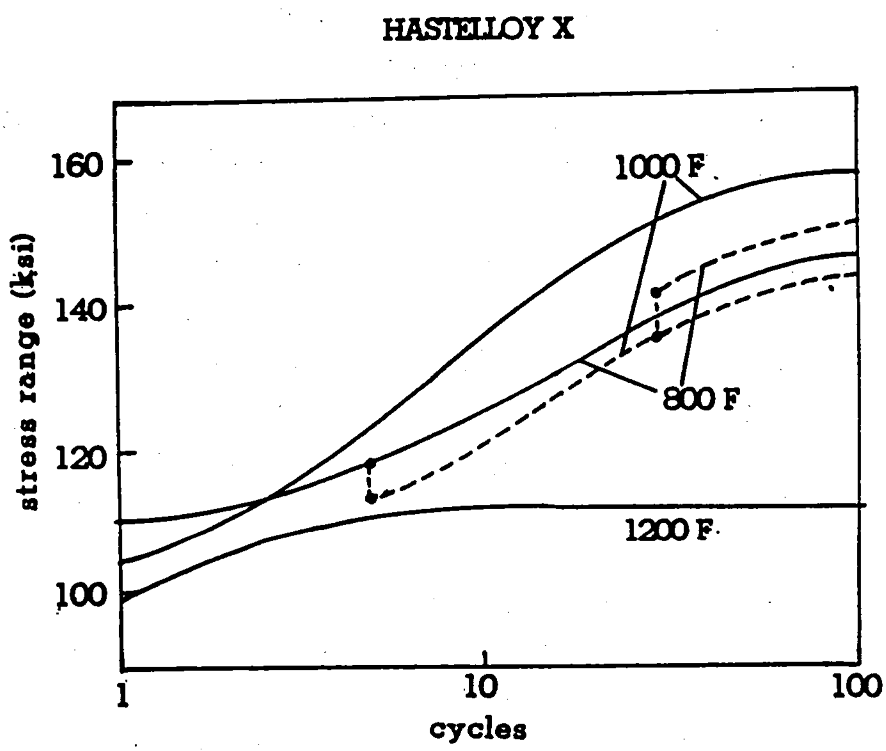

Fig. 1 Isothermal (solid) and nonisothermal (dotted) cyclic hardening curves for Hastelloy X.

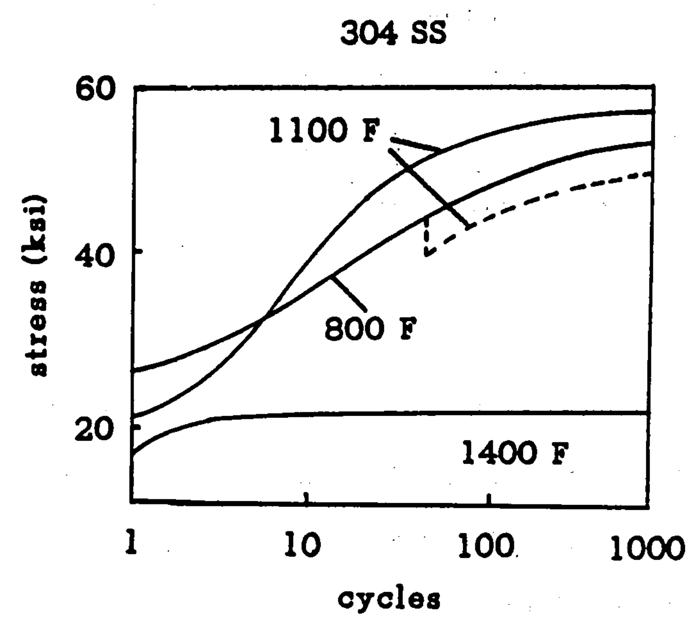

Fig.2 Isothermal (solid) and nonisothermal (dotted) cyclic hardening curves for type 304 stainless steel.

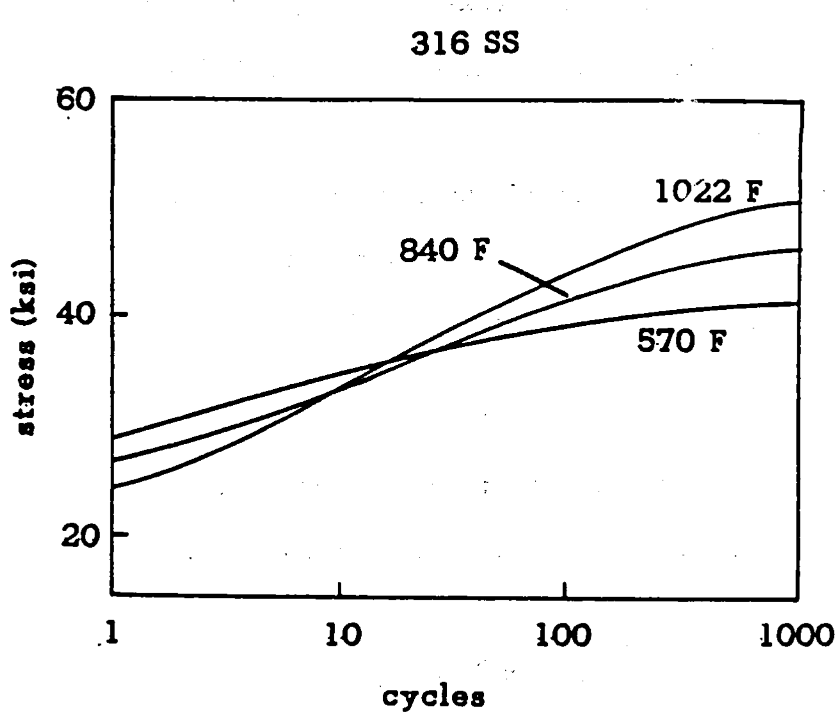

Fig.3 Isothermal cyclic hardening curves for type 316 stainless steel.