§13. Cyclically Induced Softening in Reduced Activation Ferritic/martensitic Steelbefore and after Neutron Irradiation

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The RAF/M steel, F82H IEA heat has particularly excellent mechanical properties with adequate ductility. Most of this performance is based on high dislocation densities and a fine, well dispersed precipitate distribution. F82H IEA heat, however, has an inclination to softening during cyclic loading. Cyclic straining processes can lead to microstructural changes causing cyclic softening of the material. This effect could become a significant engineering problem affecting (creep-) fatigue, swelling and segregation phenomena during irradiation. It has been previously reported that alternating strain destroys the lath structure and induces polygonization, and crack initiation occurs as the final phase of polygonization. And also, irradiation hardening causes a decrease in the strain range, and a size reduction of polygonized regions. The main purpose of this report is to evaluate the low-cycle fatigue life and the cyclic stress response of normalized and tempered F82H-IEA heat at room temperature. The influence of neutron irradiation on the fatigue life and the cyclic stress response was also evaluated.

The material used was Japanese RAF/M steel, F82H-IEA heat, which was normalized at 1313 K for 38-40 min followed by aircooling (AC) and tempered at 1023 K for 60 min followed by AC.

Neutron irradiations up to a fluence of 3×10^{19} N/cm^2 (E > 1.0 MeV; about 0.02 dpa) at temperatures around 423 K and 573 K were carried out on SF-1 miniaturized hourglass-shaped fatigue specimens in the Japan materials testing reactor (JMTR) at Japan Atomic Energy Agency (JAEA).

A detailed analysis of the flow stress, as originally suggested by Cottrell and employed by Kuhlmann - Wilsdorf and Laird as well as Handfield and Dickson, was used to determine the mechanisms responsible for the cyclic softening behavior. Upon this method, the flow stress obtained from the hysteresis loops is the result of two kinds of resistance to plastic deformation: the ‘friction stress’, σ_f, and the ‘back stress’, σ_b. The friction stress corresponds to the resistance which the dislocations have to overcome to keep moving in the lattice. The back stress is associated with piled-up dislocations that were created after overcoming the friction stress.

At the peak stress, the applied stress σ_P is the sum of the friction stress and the back stress. On lowering the applied stress, the friction stress will oppose the backward motion of dislocations. Reversed plasticity will be obtained when the applied stress, yield stress σ_y, aided by the back stress, can overcome the friction stress. The friction stress and the back stress are simply determined as follows:

$$\sigma_P = \sigma_f + \sigma_b \quad (1)$$
$$\sigma_y = \sigma_f - \sigma_b \quad (2)$$

The variation of the normalized friction and back stresses with the normalized number of cycles for the unirradiated and irradiated samples is shown in Fig. 1. Due to the inaccuracy of the method, these values of stresses exhibit a scatter band which was represented by 5% of error bars in the diagram. Despite this inaccuracy, the trends of the curves are clearly defined. Remarkable difference of the friction stresses and the back stress behavior between unirradiated and irradiated samples is observed as cycling proceeds.

The difference of the friction stress curves could be rationalized thinking that the friction stress is difference in each cycle to the yield stress in a monotonic tensile test. It will defend on the obstacles that the initial internal structure of the metal imposes to the dislocation movement. These obstacles can be the lattice friction, precipitated particles, other dislocations and foreign atoms. As the initial structure between unirradiated and irradiated samples is considered to be very different, the yield stress for the first cycle (friction stress) should be different each other. In the case of neutron irradiated samples, the irradiation defects and/or defect clusters are a typical example of these obstacles which lead to polygonization in the early stage of fatigue, where the size of the polygons become smaller than those of unirradiated sample. These results should produce a larger decrease rate in the friction stress; hence, remarkable increase in cyclic softening rate occurred in the irradiated sample during LCF test.

The back stress depends on the density of long-range impenetrable obstacles that are created by the dislocations movement such as pile-ups. Therefore, the smaller the polygons produced by the irradiation defects and/or defect clusters, the larger the density of these obstacles. As a result of this effect, the back stress will be also larger. The observed increase following this initial hardening, the back stress of irradiated sample in Fig. 1, could be attributed to the increased amount of dislocations produced during cycling.

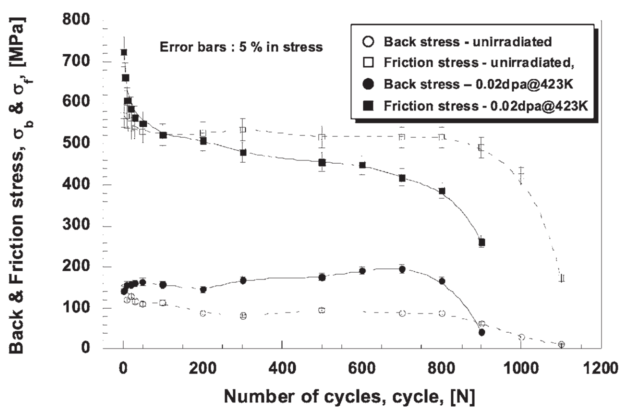

Fig. 1 Back and friction stresses with number of cycles for F82H IEA heat before and after irradiation.