EFFECTS OF LOW TEMPERATURE NEUTRON IRRADIATION ON DEFORMATION BEHAVIOR OF AUSTENITIC STAINLESS STEELS--J. E. Pawel, A. F. Rowcliffe, D. J. Alexander, M. L. Grossbeck (Oak Ridge National Laboratory), and K. Shiba (Japan Atomic Energy Research Institute)

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Extended Abstract

An austenitic stainless steel, designated 316LN-IG, has been chosen for the first wall/shield (FW/S) structure for the International Thermonuclear Experimental Reactor (ITER). The proposed operational temperature range for the structure (100 to 250°C) is below the temperature regimes for void swelling (400-600°C) and for helium embrittlement (500-700°C). However, the proposed neutron dose is such that large changes in yield strength, deformation mode, and strain hardening capacity could be encountered which could significantly affect fracture properties. Definition of the irradiation regimes in which this phenomenon occurs is essential to the establishment of design rules to protect against various modes of failure [1].

Two experiments have been conducted to quantify the effects of neutron irradiation on the deformation and fracture behavior of solution annealed austenitic stainless steels irradiated to doses ranging from 3 to 19 dpa at temperatures from 60 to 400°C. In both experiments the thermal to fast neutron flux ratio was such that the helium generation rate was within the range expected for the ITER first wall and shield, about 10-20 appm He/dpa. Alloys in the study included the European Reference Heat (ERH) which meets the specification for 316LN-IG, J316 and 316F, both Japanese grades of 316 steel, and JPCA, which is a titanium-stabilized austenitic steel.

Large changes in yield strength, deformation mode, strain to failure, and strain hardening capacity were seen in the irradiation experiments described here. For all alloys, yield strength increases rapidly with dose in the 60-300°C regime. For the same dose, a maximum increase in yield strength in the 60-400°C temperature regime is seen after irradiation to 330°C.

Radiation hardening is accompanied by changes in the flow properties with the appearance of an initial yield drop and a significant reduction in strain hardening capacity. The magnitude of the changes is dependent upon both neutron dose and irradiation temperature. Following irradiation at 60 to 90°C, the yield strength is greatly increased and the smooth yielding behavior of the unirradiated material is replaced by the appearance of a small yield drop; subsequently, the irradiated material work hardens at a much lower rate than in the unirradiated condition. The total elongation is progressively reduced with increasing dose. In the range 200 to 250°C, the work hardening rate is decreased still further. Following the yield drop, the work hardening rate is not sufficient to raise the engineering stress above the yield point. Total elongation remains high at 15 to 20%. At around 330°C, a significantly different mode of deformation is observed. Following the yield drop, the J316 stainless steel does not undergo strain hardening and the applied load falls rapidly with failure occurring after only 3 to 4% total elongation.

Each of these stainless steels in the annealed condition had very high values of toughness ($K_J > 300$ MPa$\sqrt{m}$). Irradiation of ERH at ~90°C to 3 dpa produced a small reduction in K_J. Although irradiation at ~250°C produced a significantly larger decrease, toughness values remained high, in the range 220-280 MPa$\sqrt{m}$. In all tests conducted on the irradiated ERH, the tearing modulus, T_M, which characterizes resistance to crack growth, remained high. The other two steels (J316 and JPCA) also exhibited high values of fracture toughness, a greater reduction in K_J following irradiation at 250°C as compared to 90°C, and a tendency for K_J to decrease with increasing test temperature.

1. G. E. Lucas, M. C. Billone, J. E. Pawel, and M. L. Hamilton, to be published in J. Nucl. Mater.