§9. The Effect of Final Heat Treatment Temperature on Radiation Response of V-4Cr-4Ti

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The manufacturing technology for low activation V-4Cr-4Ti has made significant progress in recent years. Of particular importance for obtaining high ductility of V-4Cr-4Ti is the final heat treatment condition. For V-4Cr-4Ti, 1173-1223K for 1-2 hr(s) were chosen as the optimum heat treatment conditions because, with these conditions, formation of thin Ti-C-O precipitates was maximized and, as the result, the level of O and C impurities in the matrix was minimized, which can lead to optimizing the ductility of the alloy.

In these studies, however, radiation effects were not taken into account, which can change the precipitate stability and the level of impurities in the matrix. Of particular importance is the effect of radiation at relatively low temperatures where the increase in the impurity level in the matrix by the radiation-induced precipitate dissolution can cause hardening and embrittlement.

In this study, neutron irradiation was carried out at 673K to ~0.11 dpa on V-4Cr-4Ti (NIFS-HEAT-2) with the standard fabrication procedure except different final heat treatment temperatures from 1073 to 1373K for 1 h were used. The hardness, Charpy impact properties and TEM microstructure were compared before and after irradiation for the purpose of optimizing the heat treatment conditions considering the effect of neutron irradiation.

The alloy used was V-4Cr-4Ti (NIFS-HEAT-2). From the ingot, the alloy was hot forged, hot rolled and cold rolled. The alloy was heat treated at 1073K, 1173K, 1223K, 1273K and 1373K for 1hr. Miniature impact specimens (1.5x1.5x20mm) with V-notch of 0.3 mm in depth without any pre-crack and TEM discs (3mm-diameter x 0.2mm-thickness) were machined from the alloy.

Neutron irradiation was carried out in the JMTR (Japan Materials Test Reactor) in the 05M-15US irradiation capsule, at an irradiation temperature of 673K and to a neutron fluence of 6.3x1023 n/m2 (>1 MeV) which corresponds to ~0.11 dpa for vanadium alloys. After irradiation, Charpy impact tests, Hardness tests and TEM observations were carried out at International Research Center for Nuclear Materials Science (Oarai Center) of Institute of Materials Research, Tohoku University. The results were compared with those before the irradiation, some of which were already published in previous papers. TEM observations of some unirradiated samples were carried out at Research Institute for Applied Mechanics, Kyushu University.

The results of the Vickers Hardness tests are shown in Figure 1. The results before the irradiation are also shown for comparison. Before irradiation, the hardness had a sharp minimum at 1173K and then increases with the annealing temperature. After irradiation, however, the hardness had weak temperature dependence at 1073 to

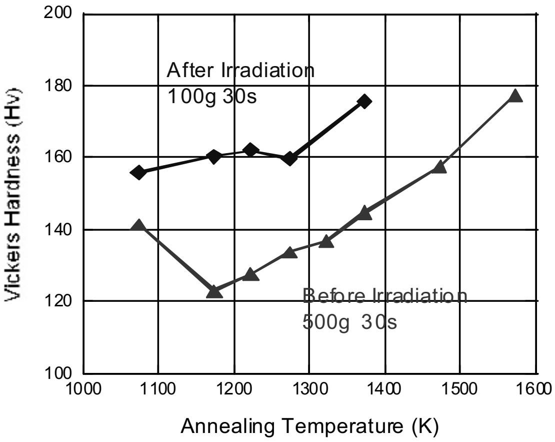

Fig. 1. Vickers Hardness as a function of the final annealing temperature before and after irradiation. Note that the applied load is different in the two cases.

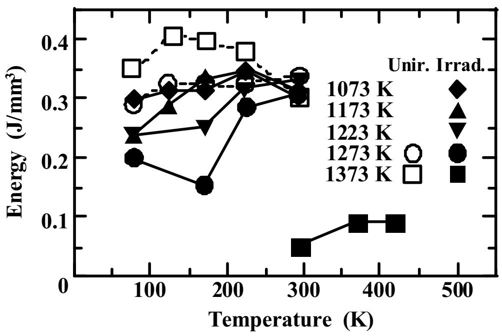

Fig. 2. Absorbed energy in the Charpy impact tests as a function of the test temperature before and after irradiation for various cases of the final annealing temperature.

1272K. At 1373K, remarkable hardening took place. It should be noted that the applied load was different before and after the irradiation. Lower load tests were performed after irradiation, which may exaggerate the hardening by irradiation.

Figure 2 shows absorbed energy obtained by the Charpy impact tests. The data before irradiation are also shown for 1273 and 1373K for comparison. Relative to 1073K, the absorbed energy decreased with the increase in the annealing temperature. However, at 1273K, the Ductile Brittle Transition Temperature (DBTT), defined as the temperature where the absorbed energy is half the upper-shelf energy, is still well below room temperature. Drastic embrittlement by irradiation occurred at 1373K, where the DBTT seems to be above room temperature.

The optimum final heat treatment temperature of V-4Cr-4Ti with respect to the ductility of the alloy is in a narrow region around 1173K, where the precipitation of Ti-C-O precipitates are maximized and the level of C and O in solution is minimized. On the other hand, the mechanical properties do not change significantly with the annealing temperature from 1073 to1273K after irradiation at 673K and 0.11 dpa. The reason of the weak dependence on the temperature after irradiation seems that radiation induced dissolution of small Ti-C-O precipitates weakened the effects of precipitate control by the prior heat treatment.