§3. Impact Properties of Low Activation Vanadium Alloy after Laser Welding and Neutron Irradiation

Nagasaka, T., Muroga, T.,
Miyazawa, T. (Grad. Univ. Advanced Studies),
Watanabe, H. (RIAM, Kyushu Univ.),
Yamazaki, M. (IMR, Tohoku Univ.),
Shinozaki, K. (Hiroshima Univ.)

Vanadium alloys are very attractive for structural materials for DEMO and commercial fusion reactors. In this study, weld samples of the reference vanadiuma alloy, NIFS-HEAT-2, were irradiated up to the neutron fluence level of 10^{25} to 10^{26} n m^{-2} (over 1 dpa) at the temperature range (e.g., 670 and 720 K) assumed as the lower limit for operation temperature for fusion blanket. Impact properties and microstuructural evolutions were evaluated to discuss the capability of the weld joints to the fusion blanket, and mechanisms of the irradiation embrittlement during the heavy neutron irradiations.

The weld material was 4 mm-thick plates of NIFS-HEAT-2 (V-4Cr-4Ti) annealed at 1273 K for 2 h. Grain size for the annealed plate was 29 μm. The weld samples were made by bead-on-plate welding with 1.6 kW YAG laser in a high purity Ar. Input power and welding speed were 290 J/m and 0.33 m/min, respectively. The welded plate was machined into two kinds of miniature Charpy impact specimens which were 3.3 x 3.3 x 25.4 mm (1/3 size) and 1.5 x 1.5 x 20 mm (1.5 size). The specimens were irradiated in JOYO reactor in Japan for 117 effective full power days (EFPD) with experiment ID of JNC53 and JNC59. The neutron fluence and irradiation temperature was 1.5 x 10^{25} n m^{-2} (E > 0.1 MeV) (1.2 dpa) at 670 K for JNC59 and 1.3 x 10^{26} n m^{-2} (5.3 dpa) at 720 K for JNC53, respectively. 1/3-size Charpy specimens were irradiated only under the latter irradiation condition due to the limitation of the irradiation volume. Impact tests were conducted after the irradiation and after a post-irradiation annealing at 873 K for 1 h.

Figure 1 plots the results of Charpy impact tests. Absorbed energy is normalized by the function of ligament size, which is B x b = 0.33 x 0.264 cm^2 and $(B \times b)^{3/2} = (1.5 \times 1.2)^{3/2}$ mm^3 for 1/3-size and 1.5-size specimens, respectively. In the present paper, ductile-to-brittle transition temperature (DBTT) is defined as the temperature where absorbed energy is expected to be half the upper-shelf energy (E_U) before irradiation, which is determined as 120 J cm^{-2} for 1/3-size and 0.4 J mm^{-3} for 1.5-size specimens. Before irradiation, both the base metal (BM) and the weld metal (WM) maintained low DBTT as 122 K and 103 K, respectively, for 1/3-size specimens (Fig. 1 (a)). After the 5.3 dpa irradiation at 720 K, upper-shelf energy for 1/3-size specimens decreased by 33% into 82 J cm^{-2}; however, DBTT was still 189 K, which is much lower than room temperature (RT). On the other hand, absorbed energy for the weld metal scattered too much to determine DBTT. The two data point at higher temperature are connected with a line to estimate a possible DBTT, and provided 334 K in DBTT. For 1.5-size specimens, DBTT before irradiation was below 77 K for both the base metal and the weld metal

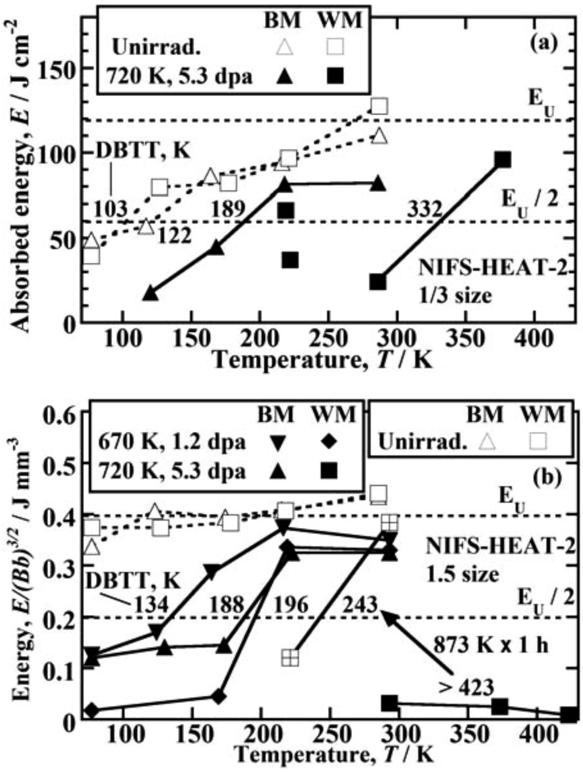

Fig. 1 Test temperature dependence of absorbed energy at Charpy impact test before and after the neutron irradiation. Recovery of DBTT by a post-irradiation annealing is indicated by an arrow.

(Fig. 1 (b)). DBTT for the base metal was 134 K and 188 K after the irradiation at 670 K to 1.2 dpa and at 720 K to 5.3 dpa, respectively, while DBTT for the weld metal was 196 K and above 423 K for the same irradiation conditions. The weld metal was annealed at 873 K for 1 h after the irradiation at 720 K to 5.3 dpa, and exhibited recovery of DBTT into 243 K, which is lower than RT.

It is indicated that DBTT increases with increasing hardness after the irradiation, and that the post-irradiation annealing at 873 K for 1 h recovered hardness and DBTT as shown by the arrow in the figure. The enhancement of the irradiation embrittlement is understood by the larger hardness in the weld metal than that of the base metal. The additional hardening for the weld metal is attributed to solid solution hardening by the interstitial impurities introduced by decomposition of Ti-CNO precipitates during welding before irradiation, and decoration and stabilization of radiation defects (i.e., dislocation loops) with the released interstitial impurities. The irradiation hardening and impact property of the weld metal was effectively recovered by a post-irradiation annealing at 873 K for 1 h, mainly due to the recovery of the dislocation network introduced by the irradiation. Maintenance as periodic annealing at 873 K is effective to control the irradiation hardening of the weld joints in the blanket. In order to avoid the maintenance, revision of the position of the weld joints in the blanket or post-welding heat treatment for the weld metal will be required.

This study was supported by the budget NIFS10UFFF005 and NIFS11UFFF024.