§3. Impact Properties of NIFS-HEAT-2 (V-4Cr-4Ti) after YAG Laser Welding and Neutron Irradiation at 563 K

Nagasaka, T., Heo, N.J., Muroga, T., Nishimura, A.
Watanabe, H. (RIAM, Kyushu Univ.)
Narui, M. (IMR Oarai, Tohoku Univ.)
Shinozaki, K. (Hiroshima Univ.)

Welded high purity low activation vanadium alloys, such as NIFS-HEATs, have demonstrated good mechanical properties at as-welded condition. In this study, welded NIFS-HEAT-2 were irradiated at a low temperature to investigate the effect of irradiation hardening on impact properties, and to understand the characteristics of radiation defects in welded vanadium alloys.

The weld materials were 4 mm-thick plates of NIFS-HEAT-2 (V-4Cr-4Ti) annealed at 1273 K for 2 hr. The samples were made by bead-on-plate welding with a 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. Table 1 shows concentration of H/C/N/O before and after welding. No significant contamination by welding was observed. V-notch impact specimens (1.5 X 1.5 X 20 mm) were machined from the weld metal and the base metal of the welded plate. The notch depth (d) was 0.3 mm. In order to investigate the effect of post weld heat treatment (PWHT), specimens for hardness investigation were prepared and annealed for 1 hr at 673 K, 873 K and 1223 K. The samples were irradiated in JMTR (Japan Materials Testing Reactor) at 563 K. The neutron fluence was 4.5 X 10^{23} n m^{-2} (0.08 dpa).

Figure 1 shows results of Charpy impact test. Absorbed energy is normalized by the function of the specimen size at the V-notch, where specimen width (B) is 1.5 mm, and ligament (b = B - d) is 1.2 mm. Before irradiation, both the base metal (BM) and the weld metal (WM) maintained good ductility at all tested temperatures. Upper shelf energy, E_U, was estimated as 0.4 J m^{-3}. After irradiation, upper shelf energy of the base metal and weld metal was around 0.35 J m^{-3}, which was 10-15 % lower than that before irradiation. In addition, absorbed energy of the weld metal after irradiation showed a remarkable drop at 77 K. Ductile-brittle transition temperature (DBTT) of the weld metal after irradiation was estimated as 113 K, where absorbed energy was expected to be half the upper shelf energy before irradiation. DBTTs determined from the other curves were less than 77 K.

Figure 2 shows hardness distribution around the weld bead. From microstructural observations, the width of the weld metal was 1 mm as indicated in the figure. Base metal regions were determined as 4 mm or farther from the bead center, where the hardness before irradiation was the same as that before welding. Irradiation hardening was estimated as the difference between the average hardness in each region. Irradiation hardening of the weld metal, 64 Hv, was 40 % larger than that of the base metal, 46 Hv.

The weld metal became brittle at 77 K after irradiation as shown in Fig. 1. It is recognized that the large hardening shown in Fig. 2 is responsible for the embrittlement of the weld metal at 77 K. Yield stress is increased due to irradiation hardening, and higher than the stress for cleavage fracture.

Table 1 Impurity levels of the welded NIFS-HEAT-2

Material	Cr	Ti	H	C	N	O
Base metal	4.00	4.02	29	51	123	139
Weld metal			35	49	129	158

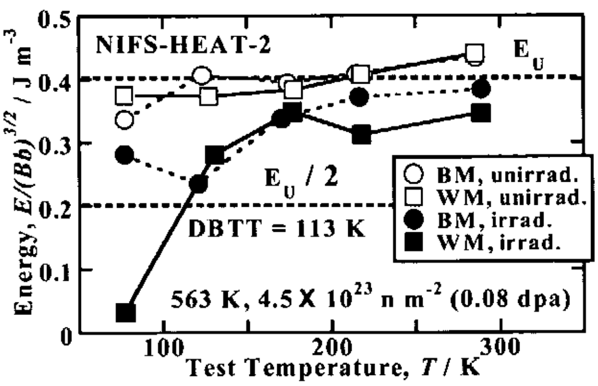

Fig. 1. Test temperature dependence of absorbed energy at Charpy impact test before and after the neutron irradiation.

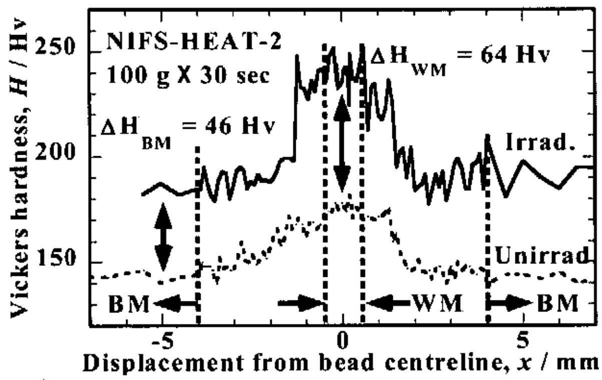

Fig. 2. Hardness distribution around the weld bead. The vertical dashed lines indicate regions of the weld metal and the base metal. Irradiation hardening, ΔH, is the difference of the average hardness of the regions.

Microstructural analyses on the weld metal showed decomposition and re-solution of Ti-(C, N, O) precipitates, which means release of C, N and O impurities into the alloy matrix. Since the interstitial impurities stabilize radiation defects, the released impurities is considered to enhance irradiation hardening and irradiation embrittlement. Suppression of the interstitial impurities by re-precipitation of Ti-(C, N, O) precipitates will be effective to avoid the irradiation hardening. It was found that PWHT above 673 K produced Ti-(C, N, O) precipitates and reduced irradiation hardening of the weld metal.

According to the tests before irradiation, precipitation hardening at 673 K and precipitate coarsening at 1223 K induced degradation of impact property. On the contrary, the weld metal after PWHT at 1073 K indicated small precipitation hardening and good impact properties. The future irradiation test will be focused on the welded samples after PWHT at 1073 K.