§21. Effect of Post-weld Heat Treatment on Irradiation Hardening of the Weld Metal of Low Activation Vanadium Alloys

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Low activation vanadium alloys are attractive blanket structural materials for fusion reactors because of their low induced activation characteristics, high temperature strength and high thermal stress factors. [1,2] Welding is an essential technology for the low activation vanadium alloys for application to fusion blankets. However, the weld metal can be more brittle than the base metal by neutron irradiation which induced nuclear fusion. Post-weld heat treatment (PWHT) is known to improve the brittle characteristic of the weld joint. The purpose of this study is to estimate PWHT effects on hardness, microstructure and impact properties of the weld after irradiations.

Bead-on-plate welds were made on the reference V-4Cr-4Ti alloy, NIFS-HEAT-2[3], by electron beam welding. PWHT was conducted at 673-1273K for 1h. The samples were irradiated in the Fixed Field Alternating Gradient (FFAG) accelerator in KURRI at 573K. The proton fluence was 2.2×10^{20} protons / m^2 (5.1×10^{-4} dpa). Hardness around the weld bead was measured by Vickers hardness tests and nano-indentation tests. Charpy impact tests were conducted at 77-283K. Microstructural observations were carried out with transmission electron microscope (TEM).

Figure 1 shows the effect of PWHT on irradiation hardening. The weld metal was harder than the base metal under any PWHT temperatures condition. Hardness of the base metal was increased slightly but reduced to the level similar to those before welding after PWHT at 673K and higher. On the contrary, the weld metal exhibited additional hardening by PWHT at 873K. Hardness of the weld metal was recovered to the level before welding after PWHT at 1273K. The hardness of the base metal and the weld metal after PWHT at 673 K after the irradiation was 155Hv and 190Hv, respectively. The irradiation hardening of the weld metal was 20Hv. The TEM analysis clarified that the Ti-CON precipitates were dissolved during the welding. Therefore, interstitial impurities were expected to cause solid solution hardening by the welding. The hardening by PWHT at 873K might be due to formation of submicroscopic precipitations. The precipitates were inhomogeneous and formed islands after PWHT at and above 1073K. Orowan's equation describing the relationship between precipitations and hardening ΔH is given by

$$\Delta H = \alpha \mu b (N d)^{1/2} \qquad (1)$$

α: barrier strength, μ: shear modulus, b: Buger's vector, N: number density of Ti-CON precipitations, d: diameter of Ti-CON precipitations. After PWHT above 1073K, hardening decreased due to N becoming low.

Figure 2 shows the results of Charpy impact tests. Absorbed energy is normalized by the function of ligament size. The base metal (BM) and the weld metal (WM) with PWHT temperature at 673-1073K maintained good ductility. Upper shelf energy was estimated as 0.51 Jm^{-3}. After PWHT at 1273 K, upper shelf energy of the weld metal was around 0.4 - 0.15 J m^{-3}. The fracture surface at 77K was observed by the scanning electron microscope. The base metal indicates ductile fracture. On the contrary, weld metal indicates brittle fracture. It was seemed that large Ti-con precipitations induce brittle fracture of the weld metal after PWHT at 1273K.

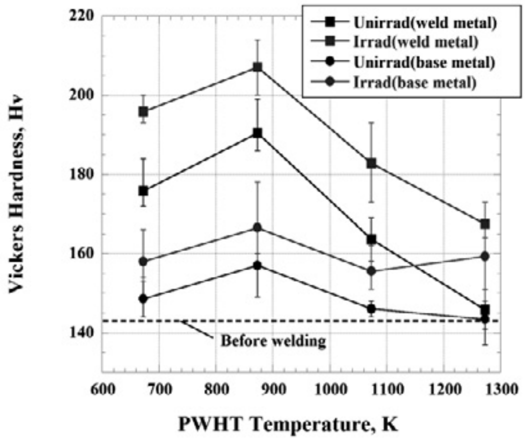

Fig. 1. Effect of PWHT on Vickers hardness of the base metal and weld metal before and after the irradiation up to 2.2×10^{20} protons / m^2 at 563K.

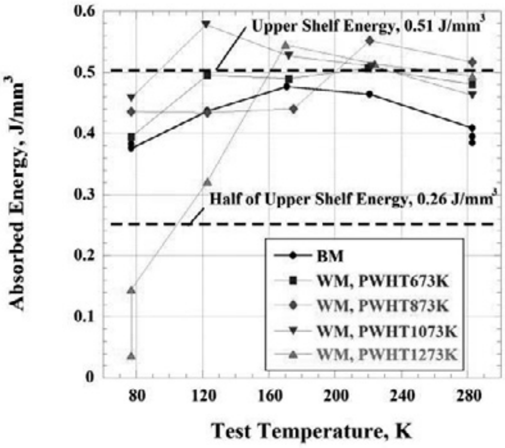

Fig. 2. Test temperature dependence of absorbed energy at Charpy impact tests before irradiation

1) Nagasaka, T. et al.: Fusion Technol. **39** (2001) 664-668.
2) Nagasaka, T. et al.: Fusion Eng. Design **61-62** (2002) 757-762.
3) Nagasaka, T. et al.: J. Nucl. Master. **329-333** (2004) 1539-1543.