Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Characteristics of Domestic Reactor Pressure Vessel Steel After High-dose Neutron Irradiation

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1. Introduction

The continued utilization of nuclear energy systems for worldwide baseload electricity offers a number of materials research challenges [1,2]. One of the major degradation issues for reactor pressure vessel (RPV) steels is embrittlement associated with hardening from radiation induced solute–defect clusters [3]. However, the effects of high dose, long operation lifetimes and irradiation flux on hardening and embrittlement of RPV steel are not well-known worldwide. Therefore, it is needed to obtain data from domestic RPV steel after high-dose neutron irradiation for the potential extension of reactor operating licenses of nuclear power plants beyond their initial term [3].

2. Experimental

The archival SA508-Gr. 3 RPV steel of Hanul Unit 3 was used for this study. The specimens for tension, fracture toughness and Charpy impact testing were encapsulated in 13M-02K instrumented capsule and irradiated at fluence up to 5.51×10^{19}(n/cm^2) (E > 1.0 MeV) as shown in Fig. 1. The irradiation temperature was controlled at 290±10^{o}C. The irradiated specimens were tested in IMEF (Irradiated Material Examination Facility) as shown in Fig. 2. The tension testing were conducted in a temperature range 25-371^{o}C with a strain rate of 5.6 x 10^{-4}/s. The reference T_0 temperature obtained as a result of K_{Jc} fracture toughness tests. The loading rate of the fracture toughness test was 0.15 mm/min that corresponds to 1 MPa√m/s.

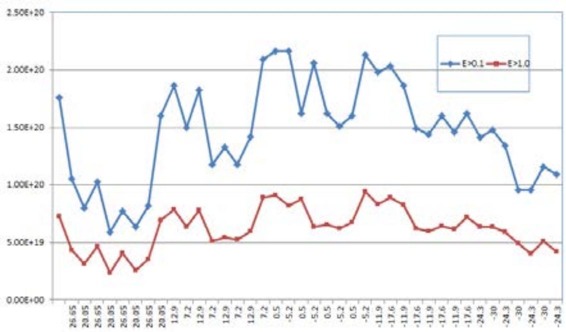

Fig. 1. Fast neutron fluence profile in 13M-02K capsule (E > 0.1, 1.0 MeV).

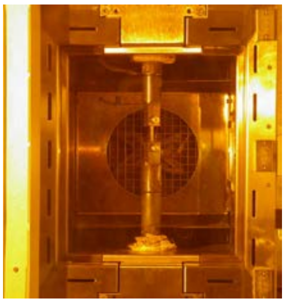

Fig. 2. Tension testing rig with specimen loaded.

3. Results and Discussion

The strength changes of RPV steels of Hanul Unit 3 after neutron irradiation are shown in Fig. 3. The yield strengths were increased after irradiation at all temperatures. The yield strength increment at the elevated temperature was reduced, comparing to that at ambient temperature, due to recovery of radiation damages at the elevated temperature.

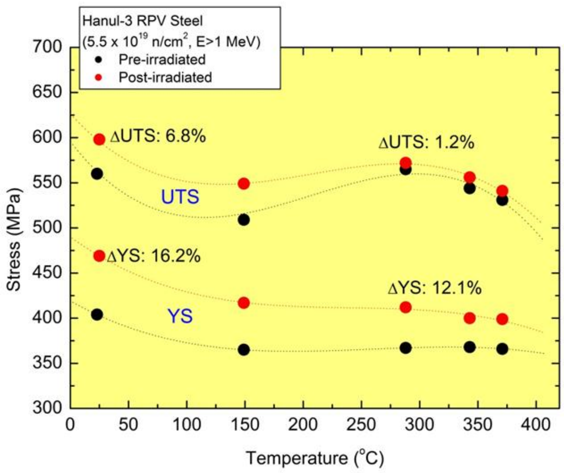

Fig. 3. Tensile strength changes at various temperatures after irradiation of Hanul-3 RPV steel.

T_{41J} temperature and T_{68J} temperature for the irradiated Hanul-3 RPV steel shifted to the higher temperatures by 29.8^{o}C and 33.4^{o}C, respectively as shown in Fig. 4 showing the results of Charpy impact testing. The upper shelf energy was dropped by 47.2 J.

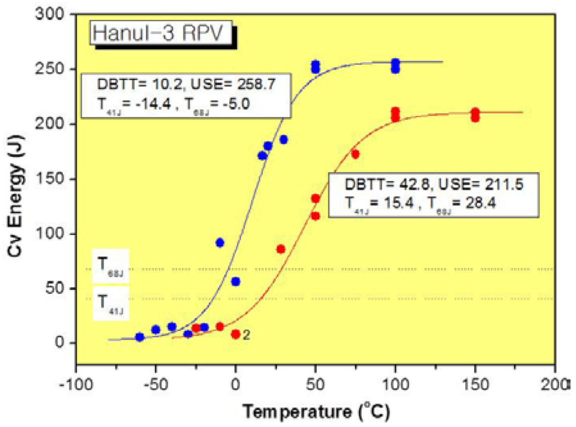

Fig. 4. Charpy impact curves for pre-irradiated and post-irradiated Hanul-3 RPV steel.

The T_0 reference temperature for the RPV steel of Hanul Unit 3 were shifted to the higher temperature by 49°C after irradiation as shown in Fig. 5.

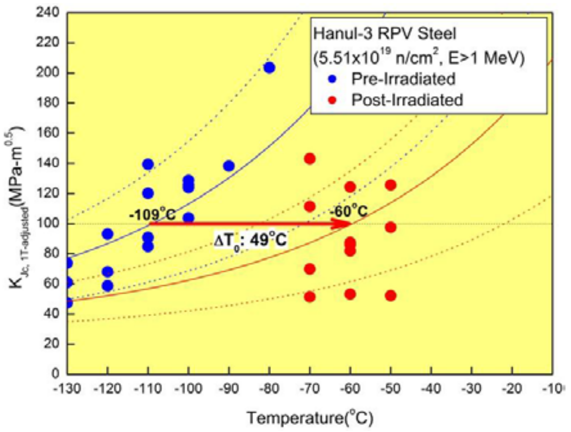

Fig. 5. Master Curve test results for pre-irradiated and post-irradiated Hanul-3 RPV steel.

4. Conclusions

The Charpy impact, tensile and Master Curve fracture toughness properties for domestic reactor pressure vessel steel of after irradiation with neutron dose corresponding to > 40 years. The post-irradiation behaviors, which were founded in the results for Charpy impact testing and tension testing, matched well with the embrittlement models. The analysis result of pressurized thermal shock (PTS) for the irradiated domestic RPV steel showed that the integrity of RPV would surpass the regulation criteria.

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