Study on the Relationship between Transition Temperature Shift and Yield Strength Increment of Reactor Pressure Vessel Materials in Surveillance tests of Korea

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1. Introduction

The embrittlement of the reactor pressure vessel (RPV) is one of the key factors in determining the lifetime of a nuclear power plant, which is caused by fast neutron irradiation during operation [1]. A surveillance test program assesses the structural integrity of the RPV steel for the safety issues. In this work, we analyzed the surveillance test results of Korean LWRs in order to derive an empirical relationship between the embrittlement and strengthening of irradiated RPV steels, and the results were compared with US data [2]. The relationship is useful to determine that non-hardening embrittlement occurs or not. Additionally, it can be used to predict a TTS behavior roughly from evaluating the yield strength change.

2. Methods and Results

2.1 Data base

The surveillance test reports are listed in Table 1; Kori 1-4, Yonggwang 1-4, Ulchin 1-4. The report was prepared following the 10CFR part 50.61 [3], USNRC Regulatory Guide DG-1053 and corresponding Korea Regulatory guide.

2.2 TTS vs. yield strength change

Table I: RPV materials of Korean PWR

Plant ID	Plant design	Test #	Materials	Product
KR 1	Westinghouse	5	SA508 Gr2 Cl1	forging
KR 2	Westinghouse	5	SA533 Type B	plate
KR 3	Westinghouse	5	SA533 Type B	plate
KR4	Westinghouse	5	SA533 Type B	plate
YG 1	Westinghouse	5	SA533 Type B	plate
YG 2	Westinghouse	5	SA533 Type B	plate
YG 3	System 80	1	SA508 Gr3 Cl1	forging
YG 4	System 80	1	SA508 Gr3 Cl1	forging
UC 1	Framatome	4	SA508 Gr3 Cl1	forging
UC 2	Framatome	4	SA508 Gr3 Cl1	forging
UC 3	OPR1000	1	SA508 Gr3 Cl1	forging
UC 4	OPR1000	1	SA508 Gr3 Cl1	forging

Fig. 1 shows the ΔYS with neutron fluence for the base metals and weld metals. In the case of the base metals, we can observe that ΔYS increases with neutron irradiation. Some samples show a decrease in the yield strength in a low fluence region, which is thought to be a deviation of the test samples. In contrast, the weld data do not show a clear correlation between the neutron fluence and ΔYS. The variety of preparation process conditions seems to have caused the significant deviation in the weld data.

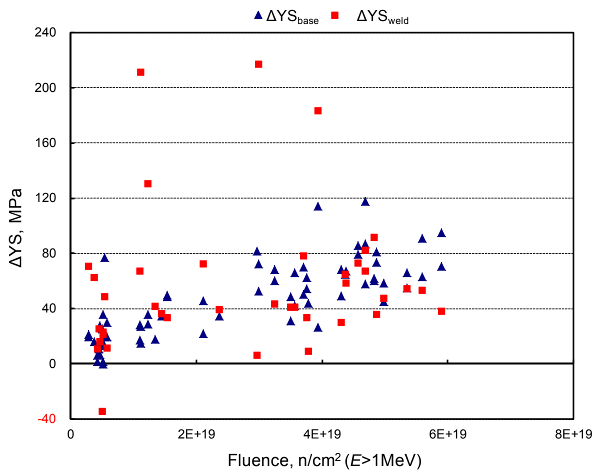

Fig. 1. Changes in yield strength of base metal and weld metal of Korean surveillance data with neutron irradiation

Fig. 2 shows the plot between the ΔYS and TTS, including all of the LWR data in Korea. We assumed the relationship between the ΔYS and TTS as a linear function through the origin for simplicity. As shown in Fig. 2(a), the proportional coefficient of ΔYS with TTS is 0.49, and the coefficient of determination, R^2, was 0.81 in the case of ΔYS. Fig. 2(b) shows the data for the welds, and the trend is rather different. The points with large ΔYS over 100 MPa are originated from Kori-1 unit, which had a higher ΔYS and TTS because of the higher Cu content of about 0.22 wt% in Linde 80. We determined the proportional coefficients from the ΔYS for the data, which were 0.58.

2.2 Change in upper shelf energy

It has been reported that the fractional decrease in USE due to irradiation is related to ΔYS [2]. We checked the relationship between ΔYS and a fractional decrease in USE using the Korean surveillance data.

Fig. 3 shows a plot of the base metals and weld metals between ΔYS and a fractional decrease in USE. There are many negative data points, and a significant scatter can be seen in the plot. It seems that the correlation is a non-linear function. In order to make a comparison with the US results, the data are superimposed on the US results. The trend of positive data points is roughly similar in spite of some scatter. It is suggested that we may use the US formula to predict the fractional decrease in USE alternatively.

By using the analyzed relationship between the yield strength change and related Charpy results, it is possible to predict the embrittlement of RPV materials [4]. Further work including multiscale modeling will be taken into account in the future.

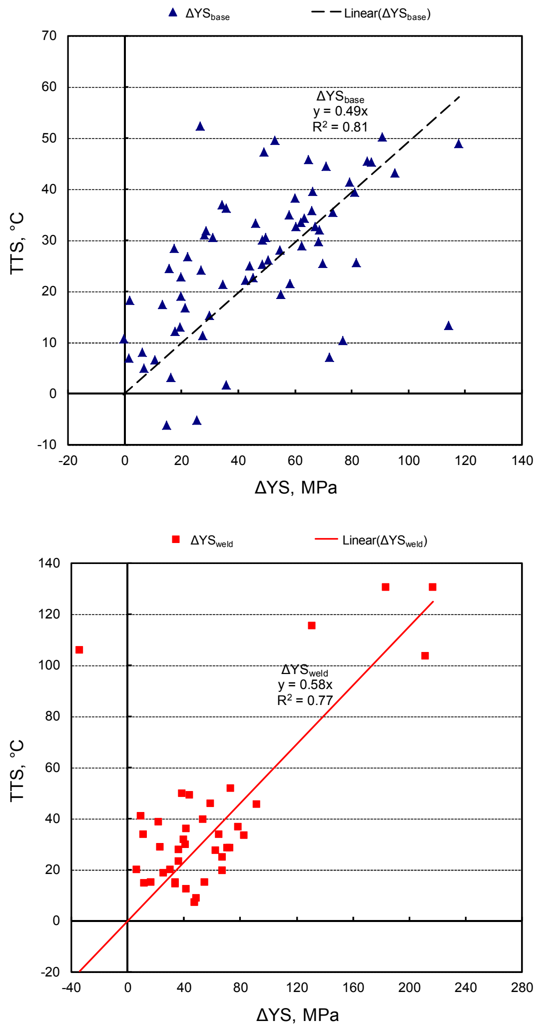

Fig. 2. Plots of ΔYS versus TTS: (a) base metal and (b) weld metal. Kori-1 data points are included.

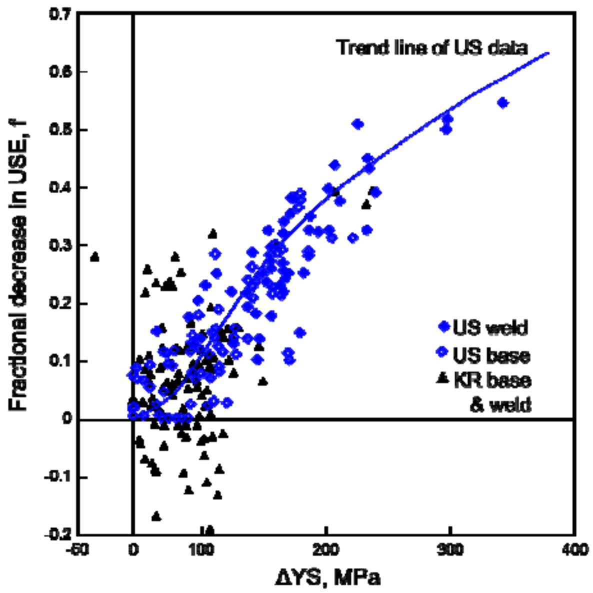

Fig. 3. Plots of ΔYS versus fractional decrease in USE. Korean surveillance result and US result are superimposed.

3. Summaries

The relevance of the Charpy-V notch impact test results and tensile strengths of Korean RPV steels in surveillance tests were summarized. The yield strength change caused by irradiation showed a rough linear relationship with the transition temperature shift change in base metals (plate/forgings). The proportional coefficient was determined to be about 0.5°C/MPa. The base metals indicated an apparent trend, however the weld metals did not show a clear relation between ΔYS and TTS. The upper shelf energy decrease ratio was non-linearly proportional to ΔYS, and the data lay roughly along the trend curve of the US results.

REFERENCES

[1] IAEA, "Integrity of Reactor Pressure Vessels in Nuclear Power Plants: Assessment of Irradiation Embrittlement Effects in Reactor Pressure Vessel Steels," IAEA Nuclear Energy Series No. NP-T-3.11, International Atomic Energy Agency (2009).

[2] G. R. Odette, P. M. Lombrozo, and R. A. Wullaert, Relationship Between Irradiation Hardening and Embrittlement of Pressure Vessel Steels, ASTM Committee E-10 on Nuclear Technology and Applications, p. 840, 1985.

[3] KAERI, "Final report for the 5th surveillance test of the reactor pressure vessel material of Kori nuclear power plant unit 1", KAERI/CR-93/20002000.

[4] J. Kwon, G.-G. Lee, and C. Shin, "Multiscale Modeling of Radiation Effects on Materials: Pressure Vessel Embrittlement," Nucl. Eng. Technol., vol. 41, pp.1-20, (2009).