Study of Irradiation Effects on the Fracture Properties of A533-Series Ferritic Steels

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1. Introduction

Since the Kori nuclear power plant unit 3 (Kori-3) was founded in 1986, the surveillance tests have been conducted five times. One of the primary objectives of the surveillance test is to determine the effects of irradiation on reactor pressure vessel (RPV) steel embrittlement. The RPV is made out of ferritic steels such as SA533 type B class 1, which were used for early nuclear power plants industry including Kori-2, 3, 4 and Yonggwang-1, 2 units in Korea.

The Westinghouse supplied Kori-3 with the RPV steels ASTM A533 grade B class 1, which is equivalent to SA533 type B class 1. The irradiation effects on tensile properties in ASTM A533 grade B class 1 steel had been studied by Steichen and Williams [1]. They experimentally determined the effect of strain rate and temperature on the tensile properties of unirradiated and irradiated A533 grade B steel 1.

The effects of neutron irradiation on ferritic steels could be determined from tensile properties, as well as the fracture strength and toughness measurements.

Hunter and Williams [2] have reported that the strength and ductility for unirradiated material at a low strain rate increase with decreasing test temperature. Also, neutron irradiation increases strength and decreases ductility. Crosley and Ripling [3] revealed that the yield strength of unirradiated material rapidly increases with the strain rate. Therefore, yield strength for unirradiated and irradiated materials should be determined by test parameters along with strain rate and temperature.

In this study we compare ASTM A533 grad B class 1 steel obtained from several papers [1,2] with SA533 type B class 1 steel taken from the surveillance data [4] of Kori-3 unit, whose mechanical property of unirradiated and irradiated materials was correlated with the rate-temperature parameter.

2. Methods and Results

2.1 Yield strength – Temperature and Strain effect

From low to room temperature in Fig. 1, ultimate and yield strength for ASTM A533 grade B class 1 steels decrease with increasing temperature. From room temperatures to 288 °C, little change is observed. The yield strength value of SA533 type B class 1 steel is slightly higher than that of ASTM A533 grade B class 1 steel.

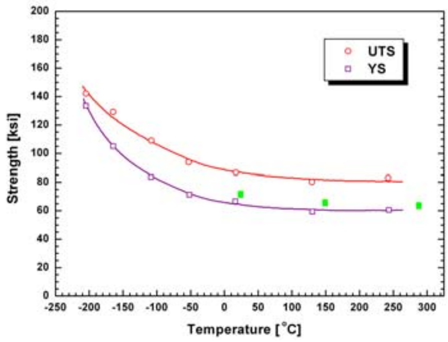

Fig. 1. Temperature dependence of the tensile properties of unirradiated ASTM A533 grade B class 1 steel and SA533 type B class 1 steel used for Kori-3 unit .

In Fig. 2 mechanical properties show the yield strength significantly increases with increasing strain rate for the test at -157 °C. However, at room temperature (22 °C) and 260 °C the material is less rate-sensitive and the strength only slightly increases over the same range of strain rate. The yield strength of SA533 type B class 1 steels made with asterisks is over the ASTM A533 grade B class 1 steel.

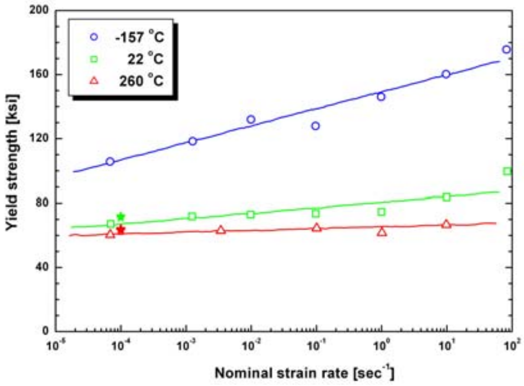

Fig. 2. Effect of strain rate on the tensile properties of unirradiated ASTM A533 grade B class 1 steel and SA533 type B class 1 steel used for Kori-3 unit .

2.2 Yield strength – Strain rate-Temperature parameter of unirradiated steels

The yield strength could be correlated with rate-temperature parameter ($T \ln A/\dot{\varepsilon}$) which consists of test temperature and strain rate (Fig. 3). Where T is absolute temperature (K), A is a constant (10^8) and $\dot{\varepsilon}$ is strain rate (sec^{-1}). The correlation allows prediction of yield strength for any temperature or strain rate. The yield strength of SA533 type B class 1 steels tested at 0.0001 sec^{-1} are also represented on the graph with asterisks. It was on the correlation line fitted by ASTM A533 grade B class 1 steels.

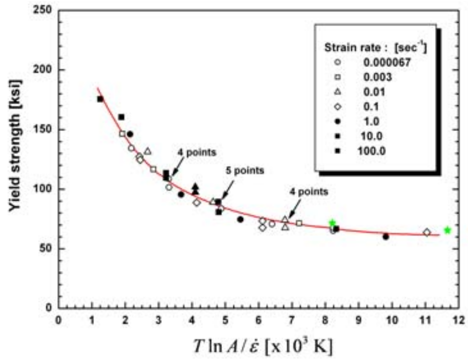

Fig. 3. Rate-temperature parameter representation of the yield strength of ASTM A533 grade B class 1 steel and SA533 type B class 1 steel used for Kori-3 unit .

2.5 Yield strength – Strain rate-Temperature parameter of irradiated steels.

Behavior of irradiated material parallels that of unirradiated material for rate-temperature parameter levels over 4440 K (Fig. 5). In lower parameter levels (higher test rates or lower temperatures) closed symbols denote the test conditions (temperature, strain rate and fluence) where cleavage fractures occurred. Irradiation to the lowest fluence (~0.5 x 10^{19} n/cm^2) provided enough triaxial constraint to produce cleavage fracture. However, in the unirradiated material it produced ductile fractures at the same test conditions. The apparent effective cleavage stress for irradiated material is approximately 150 ksi. It is significant that cleavage fractures did not occur in unirradiated material for all test conditions even though the yield stress was elevated up to 177 ksi. Although SA533 type B class 1 steels were irradiated up to 5.9 x 10^{19} n/cm^2, the value of its yield strength is similar to that of ASTM A533 grade B class 1 steel irradiated up to 0.5 x 10^{19} n/cm^2.

2.6 Strain rate-temperature parameter - Fluence

As fluence increases, the rate-temperature parameter value at which cleavage fracture occur increases. In Fig. 5 cleavage fractures were observed at random stress levels from slightly less than 140 ksi to a high of 178 ksi; therefore, the nominal stress level of 150 ksi was chosen as the effective cleavage stress. Fig. 6 shows the intersection value of this stress level with the lines representing the yield strength for the various fluences.

The rate-temperature parameter value for Charpy V-notch test was calculated where the strain rate is about 644 sec^{-1} because the velocity at the moment of impact is about 5.15 m/sec and the temperature is obtained from DBTT (ductile-brittle transition temperature). It is shown in Fig. 6 that the value of irradiated SA533 type B class 1 steel increases as fluence increases. As observed the slope of SA533 type B class 1 steel was less rate-sensitive than that of ASTM A533 grade B class 1 steel.

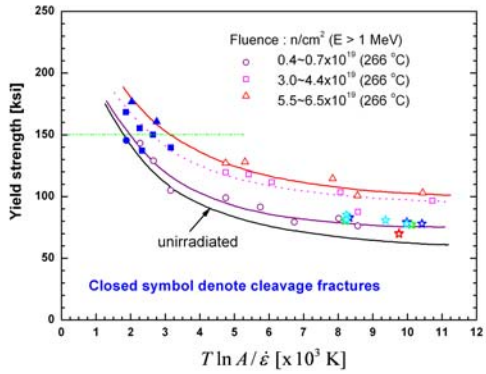

Fig. 4. Rate-temperature parameter representation of the yield strength of irradiated ASTM A533 grade B class 1 steel and SA533 type B class 1 steel used for Kori-3 unit .

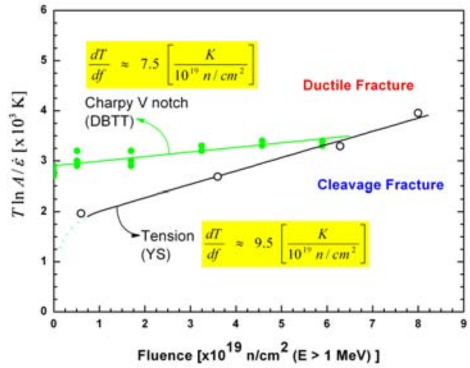

Fig. 5. Tensile fracture behavior of irradiated ASTM A533 grade b class 1 steel and DBTT behavior of irradiated SA533 type B class 1 steel used for Kori-3 unit.

3. Conclusions

We have compared ASTM A533 grad B class 1 steels with SA533 type B class 1 steels used for Kori-3 unit. In order to compare the mechanical property of unirradiated and irradiated materials, we have utilized the rate-temperature parameter. The value of parameter for neutron irradiated SA533 type B class 1 steel increases with fluence. The SA533 type B class 1 steel used for Kori-3 unit was less sensitive to fluence than ASTM A533 grade B class 1 steel.

REFERENCES

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