Characterizing Fracture Toughness using Reconstituted Specimens

Ho-Jin Lee, Soon-Dong Park, Ki-Baik Kim, Bong-Sang Lee, and Jun-Hwa Hong
Korea Atomic Energy Research Institute, 150 Deogjin-dong, Yuseong-gu, Daejeon, hjlee1@kaeri.re.kr

1. Introduction

Material for reactor pressure vessel (RPV) is embrittled by neutron irradiation during its whole life. Because the fracture toughness and ductility decreases by the irradiation, the surveillance program is needed to assess the integrity of RPV. The process of assessing the integrity of structure is described in ASME code section XI, Appendix G. The indexed reference fracture toughness curve, which is shifted by RT_{NDT} from the reference fracture toughness curve, is used to expect the fracture toughness of the pressure boundary materials[1].

The Charpy impact test using V-notch specimens is used to obtain initial RT_{NDT}, Δ RT_{NDT}, and upper self energy. These data are available to assess the integrity of RPV and to anticipate the life time. The Charpy V-notch specimens are installed around the reactor core before operation, and these irradiated specimens are tested for surveillance program of the RPV materials during the operation.

Recently, the precise and quantitative assessment of integrity has been performed with advanced fracture mechanics theory. Because the prepared specimens for surveillance program had been already tested, it is hard to get new specimens for advanced assessment. The investigation of the fracture toughness using the reconstituted specimens is considered a good method to overcome the lack of prepared specimens. In this paper, the optimal fabrication process of the reconstituted specimens was investigated. The fracture toughness and impact energy obtained from the reconstituted specimens were compared with those obtained using original specimens.

2. Reconstituted Specimens

The reconstituted specimen is composed of one insert and two end tabs as shown in Fig.1. The insert is prepared by cutting out the tested original specimen, and the end stud is made of the similar materials to the specimen insert. The interesting material is the insert, and the end tabs have a role to keep the insert as if it is the original specimen. The insert and end tabs are stud-welded to make them as one piece. The welded reconstituted specimen is also seen in Fig. 1[2]. The robust specimens could be obtained when welding current is 1200 A, duration is 0.06 sec, and loading pressure is 6 atm. The material for both of the insert and the end tabs is a SA508-3 RPV steel[3,4].

Since the reconstituted specimen has welded zone, the mechanical behavior may be different from the original specimens. As shown in Fig. 2 the welded zone has high hardness. However, the width of hardened zone is relatively narrow.

Figure 1. Specimens before welding and after welding. (insert : 10mm x 10mm x 14mm,end tab :10.5mm x 10.5mm x 22 mm)

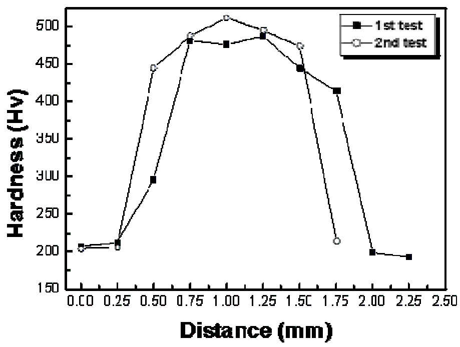

Figure 2. Micro-hardness values near the welded zone.

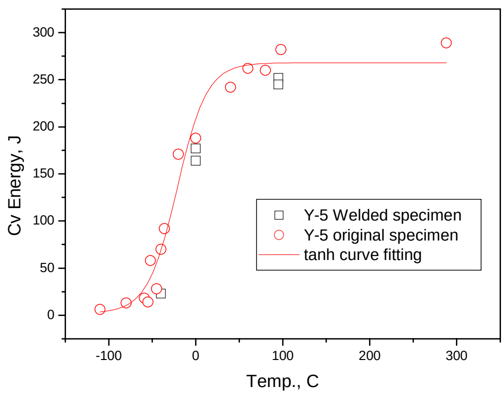

Figure 3. Comparison of the impact energy values between the original specimens and the reconstituted specimens.

2. Charpy Impact Test

The Charpy impact energy values of the reconstituted specimens and the original specimens were compared. The reconstituted specimens were machined as the same size with the original specimens after stud welding. The measured impact energy values obtained from reconstituted specimens are considered to have slightly lower tendency compared with the original specimens.

The differences of impact energy values are more detectable in the region of the high energy level than of the low energy level as shown in Fig. 3. This trend also can be seen in the referred report[3]. In the high energy level, the deformation of specimen and the impact loading may be considered higher. This means that the effects of welded zone and end tabs can occur prominently in the region of the high energy level during the impact test using dull V-notch specimens.

3. Master Curve using the Reconstituted Specimens

The basis of the master curve method is a Weibull model to define the relationship between K_{Jc} and the cumulative probability for failure. The K_{Jc}, cleavage fracture toughness value, is obtained from the J-integral at the onset of cleavage fracture of J_c by using Eq (1);

$$K_{Jc} = \sqrt{J_c \frac{E}{1-\nu^2}} \qquad (1)$$

where, E is the Young's modulus, and γ the Poisson's ratio for steel. The $K_{Jc(med)}$, the fracture toughness for 50 % cumulative probability for failure, determined for the data set at test temperature is used to calculate the reference temperature, T_o, at $K_{Jc(med)}$ of 100 MPa-m$^{1/2}$ by Eq (2)[1].

$$K_{Jc(med)} = 30 + 70\exp(0.019(T - T_o)) \qquad (2)$$

The reconstituted specimens for fracture toughness test were machined on just one surface after stud welding for specimen alignment with testing equipment. The machining process should be made simple, because the machining is performed in the hot cell. Due to the sharp and long pre-cracks in the specimens, the effects of the welded zone and the end tabs are negligible in the fracture toughness test.

As shown in Fig. 4 the calculated T_o of the master curve obtained from the reconstituted specimen was rather lower than the original specimens. The scattering of data was larger in the case of reconstituted specimens. If the data which are pointed in the Fig. 4 are removed, the T_o increases and almost agrees with that of the original specimens. This means that the effects of the welded zone and end tabs of the reconstituted specimens are negligible in the static fracture toughness test. But, the precise machining of the specimens is necessary to decrease the data scattering. The misalignment of the specimen with testing equipment may be considered the cause of the large scattering of data.

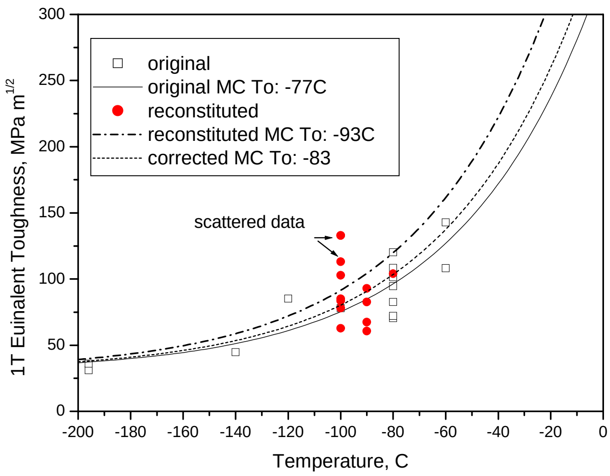

Figure 4. Comparison of master curves between the original specimens and the reconstituted specimens.

4. Conclusion

Optimal welding conditions for the robust reconstituted specimens were obtained. The measured impact energy values obtained from reconstituted specimens were slightly low compared with the original specimens especially in the region of high energy level. T_o of the master curve was almost identical to that of the original specimens, if the scatted data could be effectively removed.

ACKNOWLEDGMENT

This research was supported by the Nuclear R&D Program funded by MOST in Korea.

REFERENCES

[1] Guidelines for Application of the Master Curve Approach to Reactor Pressure Vessel Integrity in Nuclear Power Plants, IAEA-TRS (draft), (2004).

[2] Standard Guide for Reconstitution of Irradiated Charpy-sized Specimens, ASTM E1253-99

[3] Nuclear Material Technology Developments / Reactor Pressure Boundary Materials, KAER/RR-2225/2001, Korea Atomic Energy Research Institute, (2002).

[4] Evaluation of Neutron Irradiation Embrittlement of the Korean Reactor Pressure Vessel Steels, KAERI/CR-116/2001, Korea Atomic Energy Research Institute, (2001)