Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Investigation of Ductile-to-Brittle Transition of RPV Materials by using the Pre-cracked Charpy Impact Data

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

1. Introduction

Much recent work in the field of elastic-plastic fracture mechanics has been directed to developing a mechanics-based relationship between the onset of cleavage fracture in structural components and that of Charpy V-notch specimens. The assessing processes of the cracks located in the reactor pressure vessel (RPV) is described in the ASME code Sec. III, App. G and Sec. XI, App. A. The RT_{NDT} obtained from the impact test using standard Charpy V-notch (CVN) specimens is used as a reference temperature to assess the integrity of RPV materials [1].

The initial RT_{NDT}, for the Linde 80 weld, was determined by the 67.8J Charpy impact energy instead of drop weight test. Generally, Linde 80 weld has low upper-shelf energy. The initial RT_{NDT} obtained from the Charpy impact energy curve has been considered overly conservative.

Recently, master curve method has been investigated to assess the integrity of RPV materials directly. The initial RT_{T0} obtained from the master curve method is considered more realistic than the initial RT_{NDT} obtained from impact test for low upper-shelf fracture toughness RPV materials [2].

In this research, the correlation of transition regions between the master curves and the Charpy impact energy curves was investigated using the dynamic fracture toughness curve and the impact energy curve obtained from the impact test of pre-cracked Charpy (PCC) specimens. For the low toughness RPV material the ductile-to-brittle transition corresponding to the static master curve was anticipated using the invested correlation.

2. Master Curves

The basis of the master curve method is a Weibull model to define the relationship between K_{Jc} and the cumulative probability for failure in materials. The $K_{Jc(med)}$ curve, which is the fracture toughness for 50 % cumulative probability for failure, is used to calculate the reference temperature of T_0 at $K_{Jc(med)}$ of 100 MPa-m$^{1/2}$ by Eq (1) [1].

$$K_{Jc(med)} = 30 + 70\exp(0.019(T - T_o)) \qquad (1)$$

The instrumented impact test using PCC specimens is considered more effective than using the CVN specimens in fracture mechanics. From that test, the dynamic fracture toughness and the impact energy curve can be obtained simultaneously. The dynamic fracture toughness K_{PCI} can be calculated using measured data obtained from the instrumented test facilities. The K_{PCI} can be calculated by Eq (2) using the impact energy to the maximum load point [3];

$$K_{PCI} = [\frac{2EE_M}{B(1-\nu^2)(W-a)}]^{1/2} \qquad (2)$$

where E_m is the energy to maximum load, E the Young's modulus, B the thickness, W the width, S the span, P_Q the maximum load, and υ the Poisson's ratio of the specimen. The K_{PCI} has been reported as a proper tool to describe the dynamic fracture toughness in the non-linear fracture mechanics. If the K_{PCI} values are assumed to satisfy the Weibull probability function, the $K_{PCI(med)}$ also can be defined as the same process of $K_{Jc(med)}$ in master curve method.

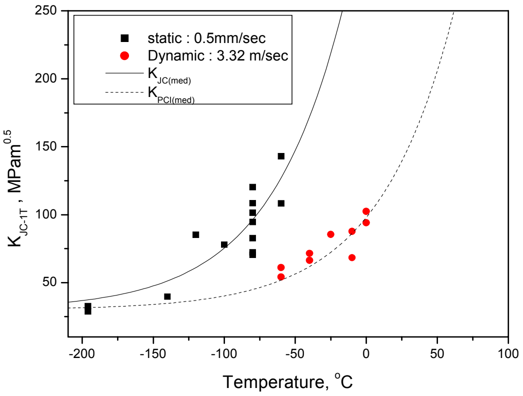

Figure 1. The master curves plotted using K_{Jc} data and K_{PCI} data obtained from SA508-3 steel [3].

The shift of T_0 of the master curve by rapid loading rate can be calculated as Eq (3) [2];

$$T_{0d,R2} = T_{0,R1} + 5.33\ln(R2/R1) \qquad (3)$$

where T_{0d} is the T_0 of the dynamic master curve, R2 the dynamic loading rate, and R1 the static loading rate. The shift of reference temperature T_0 seen in Fig.1 can be explained by Eq (3).

3. Impact Energy Curves

Figure 2 shows the impact energy curves obtained from the impact test of the CVN and the PCC specimens. The two impact energy curves are fit by the hyperbolic tangent functions, respectively.

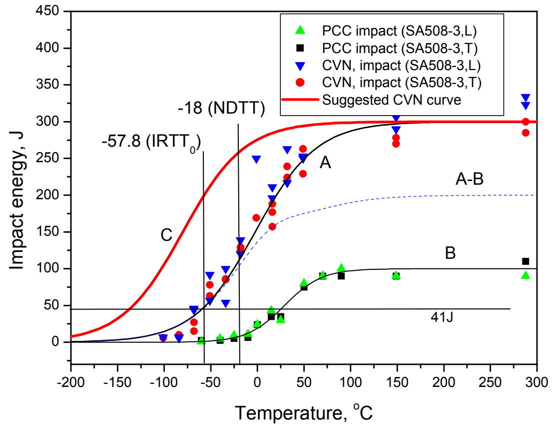

Figure 2. Charpy impact energy curves of standard V-notch specimens and pre-cracked specimens for SA508 Steel.

The curve *A* is the impact energy curve of the CVN specimens, and the curve *B* is that of PCC specimens. When considering the threshold points of upper-shelf energy in Fig. 2, the transition regions of the curve *A* and *B* are thought to be similar. The impact energy curves obtained from the CVN specimens and the PCC specimens may imply the same dynamic transition properties.

The transition region of the dynamic fracture toughness master curve of $K_{PCI(med)}$ can be thought to be corresponding to that of the impact energy curve of PCC specimens, because two kinds of values are obtained from the same rapid loading rates and same shapes of specimens.

Although the shift value of ΔT_0 in the master curve is reported almost same with ΔT_{41J} in the impact energy curve, the transition region of the static fracture toughness is, of course, not same as that of the impact energy curve [2]. The virtual impact energy curve *C*, which is corresponding to the transition of the static fracture toughness master curve, can be anticipated by shifting the *A* curve by T_{0d}-T_0 at the reference of T_{41J}.

The curve *A* in Fig. 3 shows the impact energy curve which is obtained from generic Linde 80 weld material. Using the above suggested method, the impact energy curve *B* corresponding to the master curve for the Linde 80 materials is anticipated as shown in Fig. 3 by shifting the curve *A* by T_{0d}-T_0, 69 °C, which is calculated by Eq (3).

The generic initial RT_{T0} and initial RT_{NDT} of Linde 80 weld materials are -59.8 °C and -20.6 °C, respectively [2]. As shown on Fig. 3, the energy value at the temperature of initial RT_{NDT} is the value on the region of the upper-shelf energy level of the anticipated curve *B*. We may expect that the initial RT_{NDT} obtained from CVN impact test is overly conservative. This phenomenon is due to the low upper-shelf energy level as shown in Fig. 3. Due to the overly conservative initial RT_{NDT}, some RPV having the Linde 80 weld may not have satisfied the screening value of RT_{PTS}.

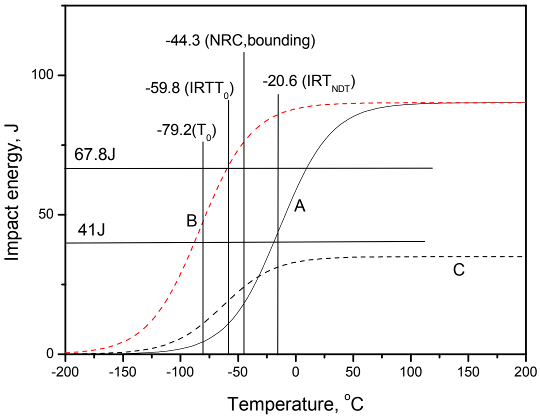

Figure 3. Charpy impact energy curves of standard V-notch specimens and pre-cracked specimens for generic Linde 80 weld materials.

4. Conclusion

The impact energy curves of the SA508 steel obtained from the CVN specimens and the PCC specimens are considered to have implied the dynamic same transition properties. The virtual impact energy curve, which is corresponding to the transition of the static fracture toughness master curve, is anticipated by shifting the CVN energy curve by T_{0d}-T_0. When using the suggested method, the initial RT_{NDT} of the generic Linde 80 weld material obtained from the CVN impact energy curve may be expected overly conservative.

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-TRS429, (2005)
[2] Initial RTNDT of Linde 80 Weld Materials, BAW-2308, Revision1, B&W Owner Group, (2003)
[3] Pre-irradiation Baseline Material Characteristics of Yong Gwang Unit 6 Reactor Pressure Vessel, Korea Heavy Industry &Construction Co.,(2000)