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Estimation of DBTT of RPV Steels in KSNPP using Standardization Small Punch Test

Tae-kyoung Lee [a,b], Seokmin Hong [a], Jongmin Kim [a], Min-Chul Kim [a] ,Jae-il Jang [b]

[a]*Nuclear Materials Research Division, Korea Atomic Energy Research Institute, Daejeon, Korea.*
[b]*Materials Science & Engineering, Hanyang University, Seoul, Korea.*

[*]*Corresponding author: mckim@kaeri.re.kr*

1. introduction

Small punch (SP) test is one of the miniature test techniques. In an SP test a small hemispherical punch is pushed through a disc-shaped specimen along its axis of symmetry. At this time a constant displacement rate is applied to the punch and the force is measured as function of time. The mechanical properties of the material are measured with the obtained function. [1-3]

The principal advantage of SP testing is in the small amounts of test material required, which in many cases allows for nearly non-destructive material sampling. At the same time, SP testing can be used to obtain mechanical property data from areas with limited dimensions. Moreover, small scale specimens offer advantages as regards post-irradiation testing of material from nuclear applications. There is an advantage that it can reduce the cost of materials testing. However SP test is not yet standardized. Therefore, the results of analysis of SP test differs for each researcher. Recently, many organizations in Europe participates in standardization and international round-robin test are now in progress as ASTM work item WK61832 [3] and interlaboratory study (ILS1408) [4]. In ASTM WK61832, test methods such as specimen size, test rig shape, specifications, test condition are specified. However, the way of estimating mechanical properties from SP test is mention in appendix as nonmandatory information.

In this study, the purpose is to evaluate the ductile to brittle transition temperature (DBTT) of RPV Steels in KSNPP by SP test according to ASTM WK61832 standardize methods. DBTT were evaluated using normalize fracture energy (E_n) presented in ASTM WK61832. When the En value was determined, the force -punch displacement curve and the force-specimen deflection curve were compared to analyze the appropriate evaluation criteria.

2. Experiments

The SP test materials were mainly SA508 Gr.3 Cl.1 steels used in Korea Standard Nuclear Power Plants (KSNPPs). SP test method according to the ASTM WK61832 use disc shaped specimen (8ϕ x 0.5 mm) and punch ball (dia. 2.5 mm and hardness > 55 HRC mm). Test rig have diameter 4 mm receiving die bore and chamfer edge (0.2mm, 45 degree). The specimen was placed in a rig and clamped with force of 10N. The test was performed from -196℃ to RT at a constant displacement rate of 0.5 mm / min. Through the SP test, force-punch displacement and force-specimen deflection data can be obtained. This data can be used to obtain specific parameters for measuring material properties such as maximum punch force (F_m), maximum punch force displacement (u_m), fracture punch force (F_f), fracture punch force displacement (u_f), SP fracture energy (E_{sp}). (Figure. 1)

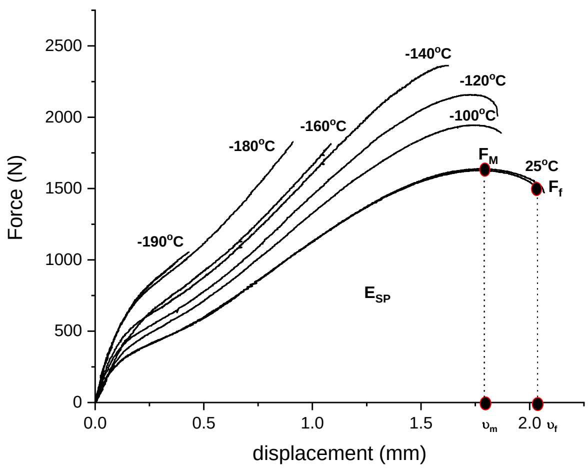

Figure 1. Determination of SP characteristic values such as F_m, u_m, F_f, and u_f from the force-displacement curve.

3. Results and discussion

To evaluate the DBTT of the material through the SP test, the SP fracture energy must first be evaluated. SP fracture energy (E_{nPD}) of force - punch displacement curve and SP fracture energy (E_{nDS}) of Force - specimen deflection curve were obtained using the equations (1) and (2). In ASTM WK61832 appendices, derivations of fracture energy are described as follows [5]:

SP fracture energy:

$$E_{SP} = \int_0^{u_f} F(u)du \quad (1)$$

SP Normalized fracture energy:

$$E_n = \frac{E_{SP}}{F_m} \quad (2)$$

The ductile-brittle curve (Fig. 2, Fig. 3) was obtained by the following equation (3) using the tanh function. [3,6]:

$$E_n(T) = \frac{E_{US}+E_{LS}}{2} + \frac{E_{US}-E_{LS}}{2} \cdot \tanh\left(\frac{T-T_{SP}}{C}\right) \quad (3)$$

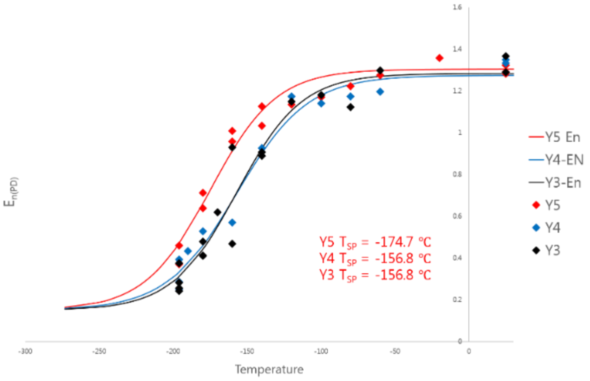

Figure 2. Normalize fracture energy (E_n) as function of temperature evaluated using the punch displacement

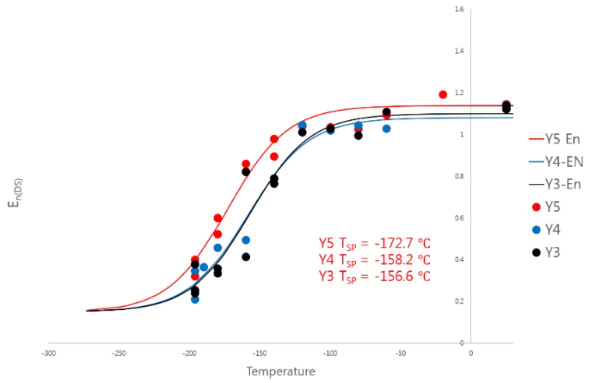

Figure 3. Normalize fracture energy (E_n) as function of temperature evaluated using the specimen deflection

It is difficult to obtain lower shelf energy through SP test. Therefore, it is difficult to define E_{LS} when using Eq. (3). The E_{LS} value used in this study is defined as a value showing a good standard deviation for the E_n value measured by the experiment. However, in addition to this method, it is a need to establish E_{US} and E_{LS} through more reliable and clear criteria. As a result of comparing the ductile – brittle curve of E_{nPD} and E_{nDS}, the fracture SP energy (E_{nDS}) obtained from the deflection specimen criteria is lower than the SP fracture energy (E_{nPD}) obtained from the punch displacement criteria. However for each SP DBTT T_{SP} determined by the mean of each shelf energy the difference was not significant.

Following Eq. (4) was used to obtain the correlation between the T_{SP} obtained from the experiment and the T_{CVN} obtained from the Charpy impact test. The correlation between T_{SP} and T_{CVN} can be explained as following equations [3]:

$$T_{SP}(K) = a \cdot T_{CVN}(K) \quad (4)$$

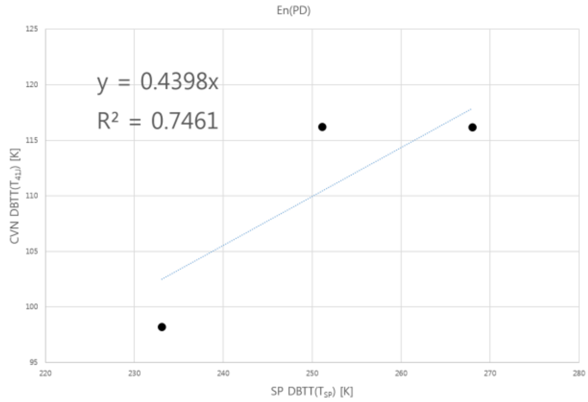

Figure 4. Correlation of CVN DBTT and SP DBTT based on punch displacement

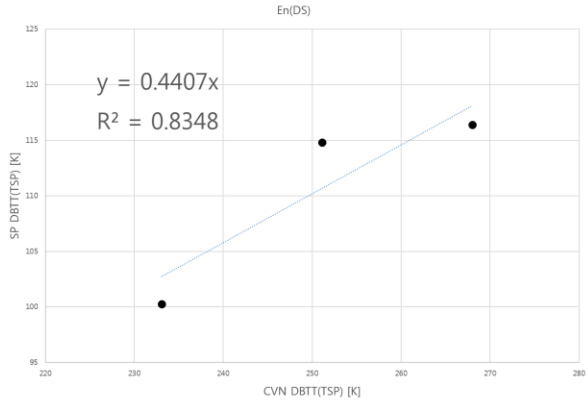

Figure 5. Correlation of CVN DBTT and SP DBTT based on specimen deflection

The curve in Fig.4, Fig.5 show the correlation of CVN DBTT and SP DBTT. The test results show a linear correlation between SP DBTT and CVN DBTT, which shows that there is a meaningful correlation experimentally. In the case of Fig.4, the empirical constant (α) = 0.4398, coefficient of determination (R^2) = 0.7461 was obtained when SP DBTT (T_{SP}) based on punch displacement. In the case of Fig. 5, the empirical constant (α) = 0.4407, coefficient of determination (R^2) = 0.8348 was obtained when SP DBTT (T_{SP}) based on specimen deflection. As a result of comparison between SP DBTT (T_{SP}) and CVN DBTT (T_{CVN}), there was no significant difference in a value between the two criteria. .

However, coefficient of determination (R^2) has a low value, a lot of data is needed to get a more accurate relationship. Therefore, research is underway to find out accurate relationship between T_{SP} and T_{CVN} and the difference between the punch displacement criteria and specimen deflection criteria by acquiring a lot of data by further testing other steel materials.

4. Conclusion

According to ASTM WK61832, the DBTT of the RPV Steels in KSNPP was evaluated and the following results were obtained. The SP transition temperature T_{SP} measured by normalize fracture energy (E_n) compared with T_{CVN} obtained from the Charpy impact test. The test results show that T_{SP} and T_{CVN} have a linear correlation. And the empirical constants α = 0.4407 which can be used to measure DBTT of RPV Steels in KSNPP was obtained by SP test. There was no significant difference between the method of measuring by specimen deflection criteria and the method of measuring by punch-displacement criteria. However, it is necessary to acquire more data through experiments in order to obtain an accurate relationship. Currently, experiments are underway for other steel materials.

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