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Derivation of Yield and Tensile Strength of RPV Steels in KSNP using Small Punch Test

Seokmin Hong [a], Jongmin Kim [a], Tae-Kyung Lee [a], Min-Chul Kim [a*]

[a]*Nuclear Materials Research Division, Korea Atomic Energy Research Institute, Deokjin dong, Daejeon, Korea.*

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

1. Introduction

Integrity of materials was usually tested by bulk-size destructive test methods such as tensile, impact, and fracture toughness tests. In response to the structural integrity test for nuclear components, where the amount of material available for destructive testing is limited, much effort has been performed to estimate material properties using miniature testing techniques [1-3]. Small punch (SP) test is one of the miniature test techniques. It has been developed for nuclear applications, but SP test for metallic materials is not yet standardized. The European Committee for Iron and Steel Standardization (ECISS) has tried to standardize SP test method [4]. Many organizations in Europe participates in standardization and international round-robin test are now in progress as ASTM work item WK47341 and interlaboratory study (ILS1408) [5]. Korea Atomic Energy Research Institute (KAERI) tried to derive material properties using SP test in early 2000s. Recently, KAERI participated in ILS1408 [6-7]. Previous SP test performed in KAERI was slightly different from SP test in ASTM WK47341 and ILS 1408. In this study, two SP test methods were compared using Finite Element Method (FEM) simulation. Utilizing both newly performed SP test and already performed SP test results, yield strength(YS) and tensile strength (TS) were derived according to the ASTM WK 47341 method, and compared with YS/TS obtained from standard tensile test.

2. Experiments

The SP test materials were mainly SA508 Gr.3 Cl.1 steels used in Korea Standard Nuclear Power Plants (KSNPPs). For the standard tests, tensile test were performed at -196°C ~ RT. Round bar-type tensile specimens (gauge length 16 mm, diameter 2.5 mm) were prepared in the transverse direction and were tested using a universal testing machine (model MTS 810, MTS, USA) with a 10-ton capacity under a strain rate of 5.2×10-4, according to ASTM E8M [8]. The 0.2% offset stress method was used to determine the yield strength from the engineering stress-strain curves.

Previously performed SP tests in KAERI (K-SP) used rectangular shape specimen (10x10x0.5mm) and punch ball (diameter 2.4 mm and hardness 62~67 HRC). K-SP test rig had 4 mm receiving die bore and round edge (0.2 mm R). Test velocity was 1 mm/min. New SP test method (S-SP) according to the ILS1408 use disc shaped specimen (8ϕ x 0.5 mm) and Punch/ball (dia. 2.5 mm and hardness > 55 HRC). S-SP test rig have 4 mm receiving die bore and chamfer edge (0.2mm l, 45 degree). Detailed comparison of K-SP method and S-SP method are described in Table 1. K-SP and S-SP method results are compared using FEM simulation.

Through the SP test, force-punch displacement or/and force-specimen deflection data can be obtained. This data contains information about the elastic-plastic deformation and material properties. Through the load-displacement/deflection curves, material characteristic such as F_m, F_e, u_m, u_f, and E^{sp} can be determined and those values are used to derive material properties as shown in figure 2.

Table 1. Comparison of two SP test conditions.

	K-SP (performed in KAERI in early 2000s)	S-SP (SP test according to ILS1408 test methods)
Specimen Shape	Rectangular (10 x 10 x 0.5 mm)	Disc (8ϕ x 0.5 mm)
Punch	Ball (dia. 2.4mm, Hardness 62~67HRC)	Ball (dia=2.5mm, hardness: 62~65HRC)
Test Rig Edge	Round (0.2mm R)	Chamfer Edge (0.2mm l, 45 degree)
Test Velocity (Punch v.)	1 mm/min	0.5 mm/min
Sample Preparation	EDM Cutting	EDM cutting (0.65mm) and grinding to final thickness(0.5mm) using abrasive paper (P320~P1200)
Clamping force	Not Recorded.	10 Nm
Data Measurement	Force-Punch displacement	Force-Punch displacement and/or force-deflection

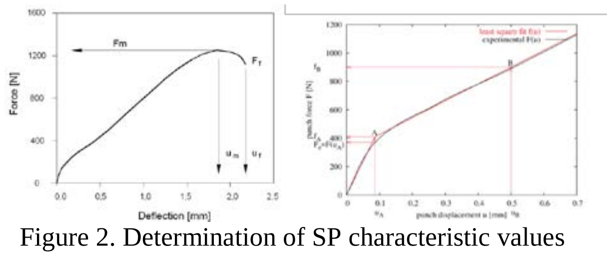

Figure 2. Determination of SP characteristic values such as F_e, F_m, u_m, F_f, and u_f from the load-displacement curve.

3. Results

Load-displacement curves obtained FEM simulation and experimental data are shown in figure 3. In FEM simulation result, initial load-displacement curves of K-SP and S-SP are same. Load of S-SP is larger after displacement of 1.0. Experimental results also shows similar behavior. Even though the test results are not same exactly, both test methods and test results are quiet similar. Thus, in this research, both test result is used to deviate YS/TS according to the ASTM WK47341 data analysis methods.

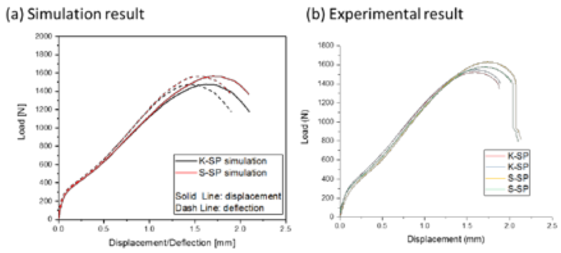

Figure 3. Comparison of Load-displacement curves of K-SP and S-SP test; (a) FEM simulation and (b) experimental results

In ASTM WK47341, Derivations of YS and TS using SP test result are expressed as below.

Tensile Properties:

$$\text{YS} = \beta_{\text{YS}} \cdot F_e/h_0^2$$

$$\text{UTS} = \beta_{\text{UTS}} \cdot F_m/(h_0 \cdot u_m)$$

Where β_{YS} and β_{UT} are empirical constants.

In figure 4, Fe and Fm obtained from SP tests are compared with YS and TS obtained from standard tensile test. The elastic-plastic transition force, F_e, and yield strength show linear correlation. F_m, and tensile strength also show linear correlation. Though some data points are out of $\pm 1\sigma$ deviation line, almost data point are exist in the $\pm 1\sigma$ deviation line. From the test results, empirical constants β_{YS} and β_{UT} can be express as 0.403 and 0.29, respectively.

4. Conclusions

In this study, derivation of tensile properties using SP test was conducted. Previously performed KAERI SP test (K-SP) were slightly differed from new SP test methods preparing standardization (S-SP). Using FEM simulation, K-SP and S-SP Load-displacement behaviors were analyzed. Initial load-displacement behavior of two SP methods was similar, but after the large displacement deformation over 1 mm the load of S-SP was higher because of larger ball size. F_e and F_m determined by S-SP method show linear correlation with YS and TS. Yield strength and tensile strength can be derived by following equations:

$$\text{YS} = \beta_{\text{YS}} \cdot F_e/h_0^2$$

$$\text{UTS} = \beta_{\text{UTS}} \cdot F_m/(h_0 \cdot u_m)$$

Where empirical constant β_{YS} = 0.403 and β_{UTS} =0.29

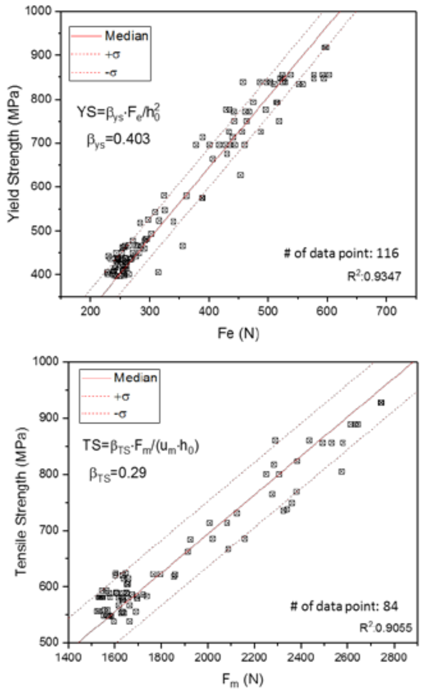

Figure 4. The relationship between yield strength & F_e and tensile strength(σ_{UTS}) & maximum load(F_m)

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