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Predictability of Tensile Properties of RPV Steels in KSNP using Draft Standard Small Punch Test Method

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1. Introduction

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 [1]. Many organizations in Europe participates in standardization and international round-robin test are now in progress as ASTM work item WK61832 (continum of WK47431) and interlaboratory study (ILS1408) [2]. In ASTM WK61832, test procedures such as sample preparation, shape of test rig, test conditions, and collecting SP parameters from the load-displacement (deflection) curve, etc are defined. However, the way of estimating mechanical properties from SP test is mention in Appendix as nonmandatory information. To apply SP test for testing the domestic RPV materials, verification of standardization SP test methods should be performed and development of improved mechanical property derivation method is needed. In this study, SP test of KSNPP RPV materials was performed and tensile properties are derived by standardization SP test methods.

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.

SP test method according to the ILS1408 (WK47431) use disc shaped specimen (8ϕ x 0.5 mm) and Punch/ball (dia. 2.5 mm and hardness > 55 HRC). Test rig have 4 mm receiving die bore and chamfer edge (0.2mm l, 45 degree). Test rig have chamfer edge in ASTM WK47431, but it changed to round edge in ASTM WK61832 because round edge shape showed better reproducibility and repeatability in result of ILS1408. Using FEM simulation, effects of edge shape (round and chamfer) on Load displacement behavior were analyzed.

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.

3. Results

3.1. Effects of rig edge shape.

Figure 1 shows load-displacement curves from FEM SP simulation with different test rig edge shape conditions. Two FEM simulation load-displacement curves are almost same at the beginning, but round edge simulation result is slightly higher than chamfer edge result at the maximum point. At the peak load, load value of round edge is 1591N and load value of chamfer edge is 1564N. The difference between the two values is less than 1.7%. Those difference are not large.

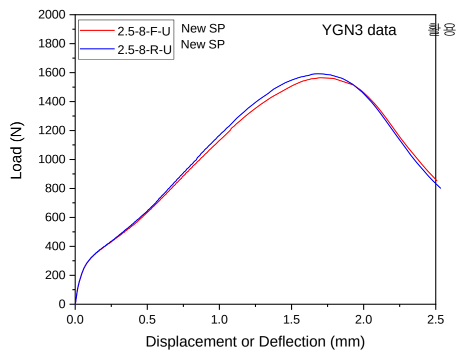

Fig.1 Load-displacement curves obtained from FEM SP simulation with different test rig edge shape condition.

3.2. Derivation of tensile properties

In previous SP test, load-displacement curve were distinguished 4 stages; I: elastic bending region, II: plastic bending region, III: plastic membrane stretching region, and IV: plastic instability region [3-4]. In previous SP test, the elastic-plastic transition force, F_e, was determined by offset method and tangent line intersection method [3-4]. Such method is ambiguous to determine the correct slope elastic bending region and plastic bending region. However, ASTM method use bilinear function to determine the elastic-plastic transition force, F_e. The following procedure describes how to determine F_e [2].

$$\mathrm{f(u)} = \frac{f_A}{u_A} \quad for\ 0 \le u < u_A$$
$$= \frac{f_B - f_A}{u_B - u_A}(u - u_A) + f_A \quad for\ u_A \le u < u_B$$

Minimization of the error:

$$\mathrm{err} = \int_0^{u_B} [F(u) - f(u)]^2\, du$$

Then, the yield displacement $u_e = u_A$, $F_e = F(u_A)$. u_B is free parameter but it is recommended to choose u_b=h_0

In ASTM WK61832 appendices, derivations of tensile properties are described as follows [5]:

Tensile Properties:

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

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

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

YS_SP and UTS_SP of KSNPP RPV steels were derived by SP test and compared with YS and UTS obtained by standard tensile test. Those results are shown in Figure 2 and 3.

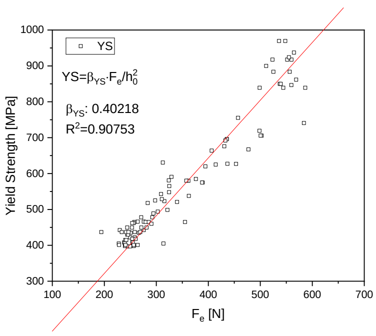

Fig. 2 The relationship between yield strength(σ_0) and yield load(F_e)

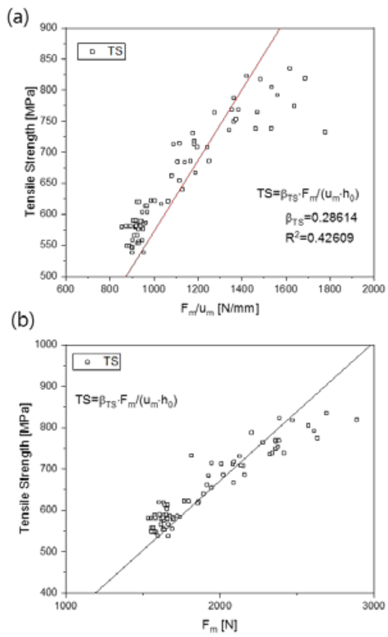

Figure 3. The relationship between tensile strength (σ_{UTS}) and maximum load parameters (a)F_m/u_m, (b) F_m

Yield strengths and Fe values show linear correlation. When the relationship of YS and Fe value are fitted with WK61832 methods, coefficient of determination, R-square value, is 0.90753. The relationship of YS and Fe values is well represented by the ASTM equation. Tensile strength and F_m values also show linear correlation. However, when the relationship of TS and F_m/u_m value are fitted with WK61832 methods, coefficient of determination, R-square value, is 0.42609. It means that the relationship TS and F_m values is not well represented by the equation.

4. Conclusions

In this study, derivation of tensile properties using SP test was conducted according to the ASTM WK61832 method. F_e and F_m values showed linear correlation with YS and UTS. YS was well predicted by the ASTM methods, but UTS was not. As predictive equations are nonmandatory conditions, it requires further study for better prediction of mechanical properties.

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