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Evaluation of fracture toughness by notched small punch tests with Weibull stress method ☆

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ABSTRACT

The fracture toughness obtained by pre-notched (pre-cracked) small punch specimens is much higher than that obtained by conventional single edge notch bending (SENB) or by compact tension specimens. In this paper, an equivalent Weibull stress method has been introduced. The tests with 0.4 T SENB specimens and linear notched small punch specimens were carried out at 77 K. At this temperature (on lower shelf), the results of both test methods show scatter but not significant. The loads at fracture of both types of specimen were used to determine the Weibull stress parameter, *m*, and the Weibull stress, $\sigma_{w,}$ with finite element method. Base on the assumption that Weibull stress parameters are material constants, the *m* which could meet a condition that $\sigma_w^{0.4TSENB} = \sigma_w^{LNSP}$ was regarded as Weibull stress parameter, *m*. The critical *J* integral of 1 T SENB J_c^{1TSENB} at 77 K has been estimated with *m* and σ_w deduced by 0.4 T SENB and LNSP specimens.

1. Introduction

Small specimen technique was originally developed to overcome the limit of materials used for nuclear power reactors [1,2]. Among these small specimen techniques, the small punch (SP) test technique has been used to obtain the mechanical properties from smaller specimens than other methods [3]. Decreased consumption of materials makes the SP test very promising. Using the SP (or shear punch) test to estimate the fracture property was one of the research hotspots [4–9]. Recently several new types of specimens [3,10–16], which were pre-notched or pre-cracked were proposed to assess the fracture properties instead of the conventional SP specimen [4–8] because of the similarity of the structures between the new types of SP specimens and the compact tension (CT) specimens (or single edge notch bending (SENB) specimens). However, the fracture toughness values obtained by SP tests were very different from the values obtained by CT tests and SENB tests due to the size effect.

In this paper, two-parameter Weibull-distribution as described by Beremin [17] was used to obtain the fracture toughness of 1 T SENB specimen from 0.4 T SENB specimen and linear notched small punch (LNSP) specimen [14–16] (as shown in Fig 1), one of the new types of SP specimen [3,10–16]:

$$P_R = 1 - \exp\left(-\left(\frac{\sigma_w}{\sigma_u}\right)^m\right) \quad (1)$$

where P_R is cumulative probability of failure, *m* is the Weibull constant, σ_u is the reference stress and σ_w is the Weibull stress which is numerically calculated from following expression:

$$\sigma_w = \sqrt[m]{\frac{1}{V_0}\int_{V_{pl}}(\sigma_1)^m dv} = \sqrt[m]{\sum_j (\sigma_1^j)^m \frac{V_j}{V_0}} \quad (2)$$

where σ_1 is the first principal stress, V_0 is the reference volume, V_{pl} *is* the size of plastic zone, σ_1^j and V_j are the first principal stress and element volume respectively of the *j*th element which is in the plastic zone. Since certain materials own the same parameters, *m* and σ_u, at certain temperature [17], it could be assumed that the Weibull stress, $\sigma_{w,}$ of different types of specimens is the same. Based on this assumption, the data of two different types of specimens can be used to determine the *m* and σ_u and thereby estimate the fracture property of the third type of specimen.

The temperature corresponding to the lower shelf was selected as the test temperature to simplify proof procedure. At the lower shelf, for certain types of specimens, the scatter band of fracture toughness is very narrow. Hereby, it could be assumed that the load at fracture was constant and then P_R only could be 0 or 1. Once the cleavage fracture occurs, P_R will change from 0 to 1. Then the Weibull stress at this loading condition could be regarded as the critical Weibull stress and can be used to estimate the fracture toughness of 1 T SENB specimen.

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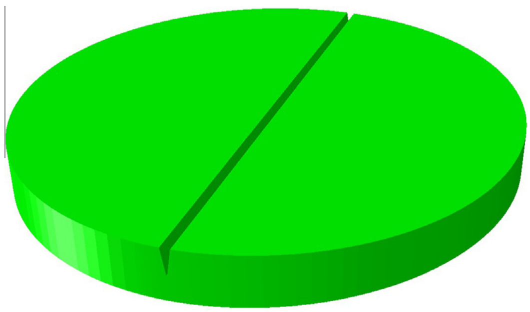

Fig. 1. LNSP specimen.

Table 1
Chemical composition of 16MnR steel (wt.%).

C %	Si %	Mn %	P %	S %	Nb %	Ti %	Cu %	Cr %	Ni %	Mo %	Als %
0.17	0.26	1.48	0.022	0.004	0.004	0.013	0.03	0.04	0.02	0.005	0.022

Table 2
Elastoplastic parameter of 16MnR at 77 K.

Young's modulus, E (MPa)	Poisson's ratio, ν	Yield strength, $\sigma_{0.2}$ (MPa)	Tensile strength, σ_b (MPa)
210,000	0.3	852	925

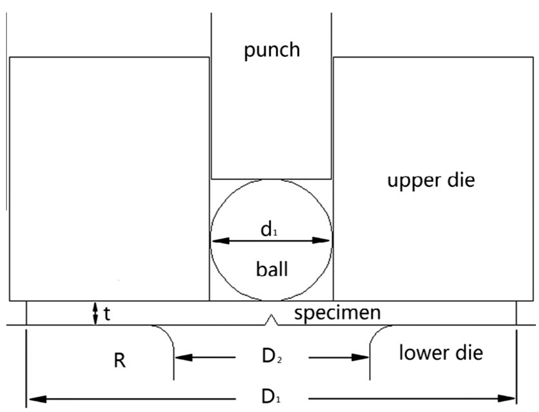

Fig. 2. Clamping holder for SPT.

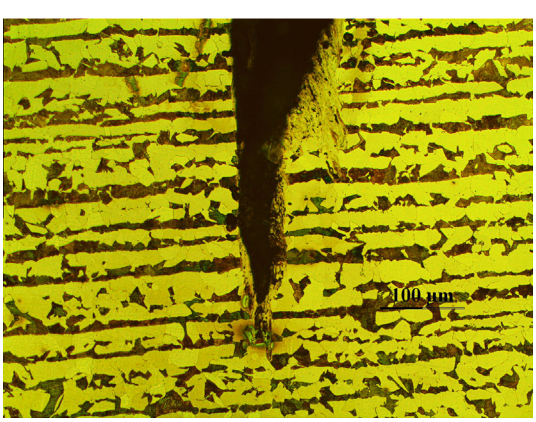

Fig. 3. Metallographic picture of notched SP specimen.

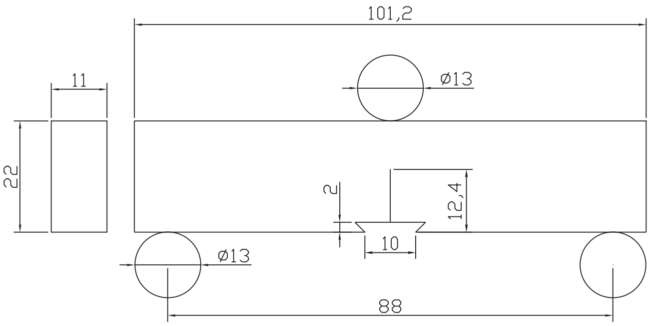

Fig. 4. Geometry of 0.4 T SENB specimen.

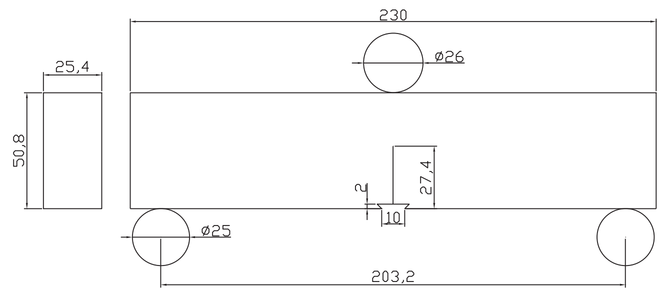

Fig. 5. Geometry of 1 T SENB specimen.

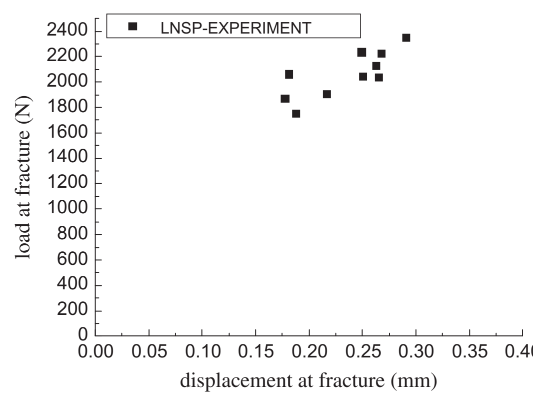

Fig. 6. The load and the displacement at fracture of 10 pieces of LNSP specimens at 77 K.

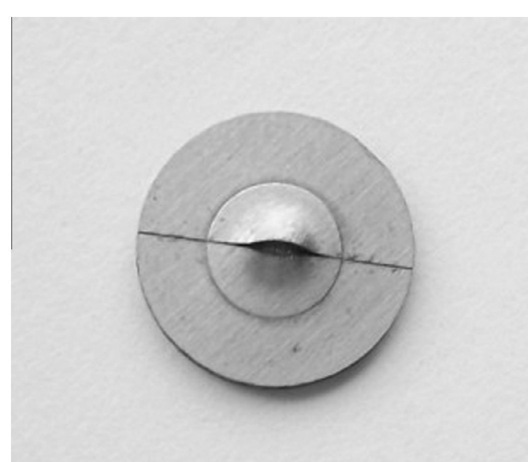

Fig. 7. LNSP specimen (post-tested).