A New Shape Specimen Determined the J1c Value of Nuclear Pressure Vessel Steel

Xu Wen-Qing
Beijing Institute of Nuclear Engineering, Beijing, PRC

INTRODUCTION

The J integral as proposed by Rice has two basic definitions, a two-dimensional energy line integral definition and an energy rate definition. The line integral definition cannot be used for this experimental determination. The energy rate definition can be used but the procedure is somewhat laborious.

Methods were developed for more easily determining J by approximation formulas. the first of these were proposed by Rice et al, where J could be estimated with reasonable accuracy for a deeply cracked bend-type speciman(Rice, 1973). This method is slightly inaccurate. This was first noted by Merkle and Corten(Merkle, 1974). Merkle and Corten gave a version. Landes et al. suggested a simple one-step equation based on experimental results(Landes,1979).

This paper is concerned with a new shape specimen. It is called the "W"-shape specimen. The "W"-shape specimens are smaller volume than the campact specimens. It is convenient to operate the "W"-shape specimens in hot cell. it can be put into surveillance capsules and can also do specimen irradiation in engineering test reactor.

ESTIMATION OF J VALUE FOR A "W"-SHAPE SPECIMEN

The size and geometry is shown in Fig.1. We suggest that J should be determined by the following expressions.

$$J = J_e + J_p \tag{1}$$

$$J_e = K_I^2/E' \tag{2}$$

where J_e = elastic contribution of J
J_p = plastic contribution of J
$E' = E$ (plane stress)
$= E/(1-\mu^2)$ (plane strain)
E = elastic modulus
μ = Poisson's ratio

$$J_p = \frac{1}{B}\int_0^{P_0} \frac{\partial \Delta_p}{\partial a}\Big|_p dP \tag{3}$$

Δ_p = plastic displacement between two loaded points.

For the SA508 class 3 steel, the experimental data showed that Lg Δ_p and Lg $\frac{P}{(W-a)^2}$ satisfied Fig.2 relation shown, so we get

$$lg\Delta_p = \sum_{i=0}^{n} A_i lg^i \frac{P}{(W-a)^2} \tag{4}$$

where, A are determinated by the material's properties.

Upon substituting (4) into (3), one has

$$J_p = \frac{2U_p}{B(W-a)} \tag{5}$$

where U_p=the area under the plastic part of the load-displacement curve(Fig.3).

Talking about the J_e, we can use Koiter's result(Koiter, 1973). An analysis by Koiter showed that K could be estimated for a deeply cracked specimen from a single load-displacement record by

$$K = \frac{2\sqrt{\pi}}{\sqrt{\pi^2-4}} \cdot \frac{P}{\sqrt{(W-a)}} + 2.243\sqrt{\pi} \cdot \frac{M}{\sqrt{(W-a)^3}} \tag{6}$$

where P = concentration load
M = moment
W = width of test specimen
a = crack length

In a "W"-shape specimen, the M varies with the displacement between two loaded points. So K_I could be estimated for a "W"-shape specimen by

$$K_I = 41.738\frac{P}{\sqrt{(W-a)^3}} - 1.462\frac{P}{\sqrt{(W-a)}} - 1.988\frac{u\,tg\alpha}{\sqrt{1-\frac{u\,tg\alpha}{L\cos\alpha}}} \cdot \frac{P}{\sqrt{(W-a)^3}} \tag{7}$$

where u = displacement between two concentration loads
L = distance between loaded point and ligamental central point

Eq.2 can be expressed in the following manner:

$$J = \frac{1}{E'}\left\{\left(41.738 - 1.988\frac{u\,tg\alpha}{\sqrt{1-\frac{u\,tg\alpha}{L\cos\alpha}}}\right)\frac{P}{\sqrt{(W-a)^3}} - 1.462\frac{P}{\sqrt{(W-a)}}\right\}^2 \tag{8}$$

THE EFFECT OF THE LIGAMENTAL SIZE

The "W"-shape specimen is very small. It is shown in Fig.1. It's ligamental size must be smaller than 5.2 mm, but its ligamental size can not be smaller than the minimal size of ligament for the material. We ever have studied the J-integral vs. displacement curves for the "W"-shape specimen given in Fig.2. It showed that the ligamental size can not be smaller than 3.8 mm for 12CrNi4MoVNbA steel. The experimental data showed that the size of the "W"-shape specimen is big enough to determine the J1c value of the SA508 class 3 steel. Fig.4 showed that using the small "W"-shape specimens to detect the J1c value of SA508 class 3 steel in the experiment is the same as using the large (20x24x120 mm) three bend specimens.

FRACTURE TOUGHNESS OF SA508 CLASS 3 STEEL

The method proposed here to obtain the J1c values for static ductile fracture is based on the J-R curve technique. As shown in Fig.5, each specimen is static loaded up to a desired displacement Δ (not to failure) and the corresponding J-integral value is evaluated. the fracture toughness J1c is then determined as a cross point of the blunting line and the J-R curve.

When the experiment temperature is near to transition temperature range or below it, the J1c values are evaluated with the formula (8).

The static fracture toughness data vs. temperature obtained are plotted by solid marks and solid line in Fig.6. The Japanese static data (hatched area) is also plotted in the figure for the purpose of comparison.

CONCLUSIONS

(1) Using the "W"-shape specimens of the 5mm length's ligament to determine the J1c value of the SA508 class 3 steel in the experiment is the same as using the

three bend specimens of the 12mm length's ligament, at room temperature.

Static fracture toughness tests are performed at various temperatures from -185° C to 20°C with the "W"-shape specimens made of nuclear pressure vessel steel SA508 class 3. The results are enveloped by the scattered band of Japanese static data. Therefore, using the "W"-shape specimens to determine the J1c value of nuclear pressure vessel steel SA508 class 3 is successful in experiment.

(2) It is convenient to operate the "W"-shape specimens in hot cell.

(3) The "W"-shape specimens have small volume, so it can be put into surveillance capsules.

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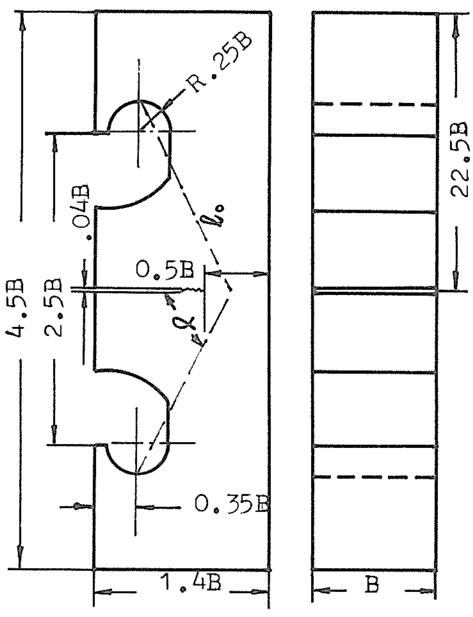

Fig.1 The size and geometry of "W" shape specimen

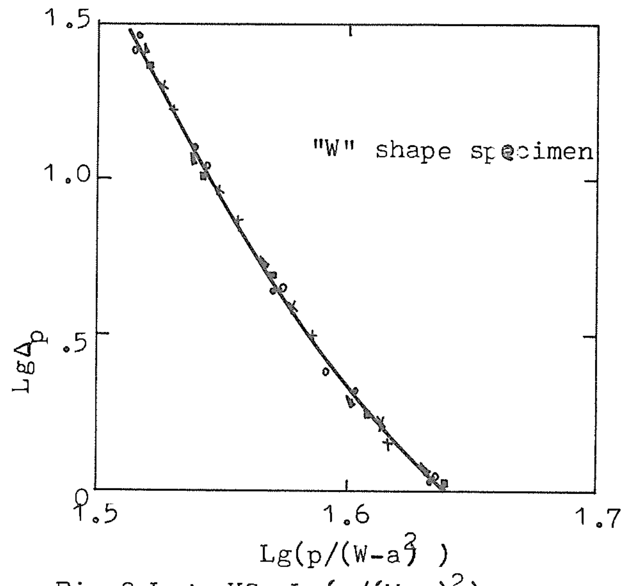

Fig.2 $Lg\Delta_p$ VS. $Lg(p/(W-a)^2)$ curve of A508 class 3 steel (RT)

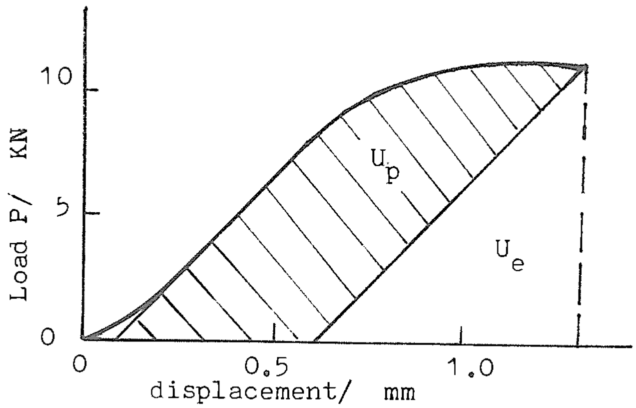

Fig.3 Load VS. displacement curve

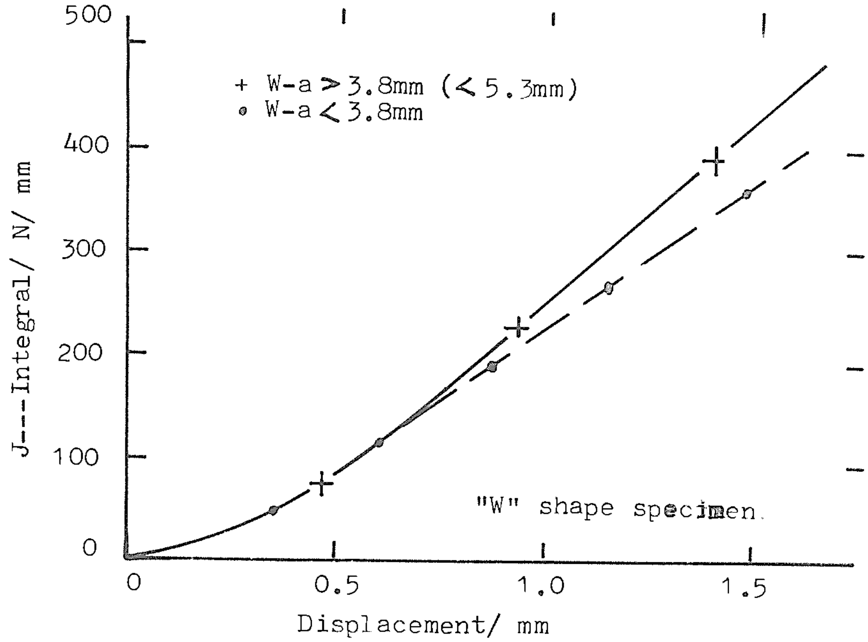

Fig.4 J vs. Δ curve of $12C_rN_i4M_oVN_bA$ steel (RT)

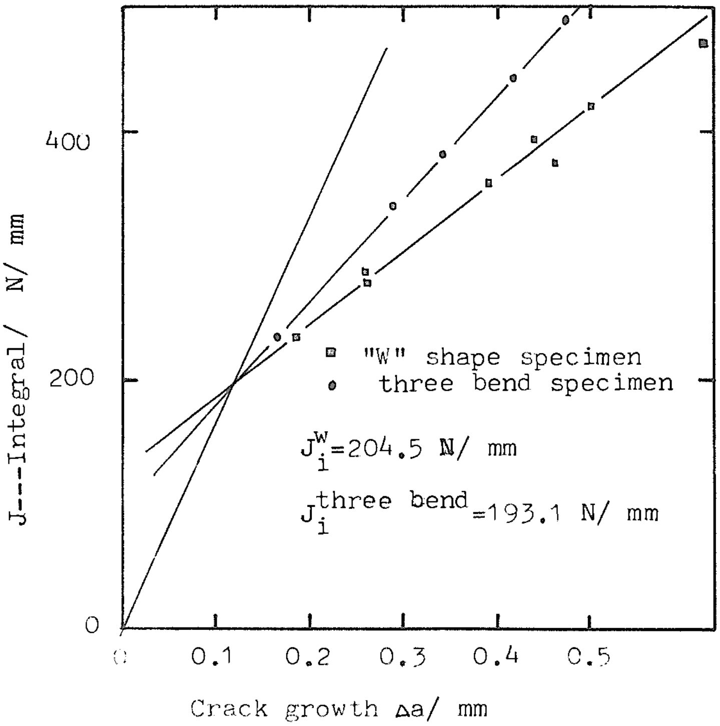

Fig.5J vs. R curve Of A508 class 3 steel (RT)

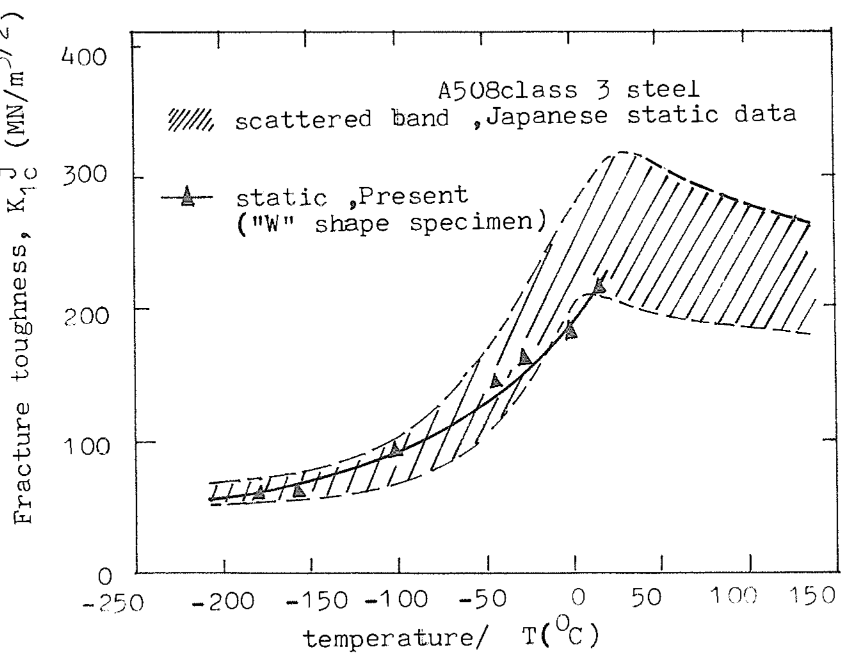

Fig.6 Fracture toughness of A508 class 3 steel V.S. temperature