FRACTURE TOUGHNESS TESTS OF NUCLEARGRAPHITES

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Introduction

Institute's(JAERI) graphite moderated, gas-cooled reactor, the High Temperature Engineering Test Reactor(HTTR) has been under construction since 1990 and will be critical in 1997[1-3]. This reactor has a graphite core stacked by fuel blocks made of isotropic fine-grained graphite, IG-110 and reflector blocks of near isotropic coarse grained graphite, PGX. These graphite blocks are exposed under high irradiation induced stresses due to high temperature and neutron irradiation during operations. To avoid brittle fracture of these blocks during the reactor operations, fracture resistance against brittle fracture due to inherent defects and crack propagation were discussed for its designs, which required fracture toughness of these graphites[3].

Many studies[4-8] on the fracture toughness evaluation of graphite materials were reported and new testing methods were proposed, however, the discussions on the precise test methods and its validity is not completed, because of lack of standard testing methods approved, except tentative testing methods and fracture toughness data.

Main purposes of present study is to propose the recommendation of test methods and its procedures for valid fracture toughness of the graphite materials.

Experimental

Blocks of purified isotropic fine-grained nuclear graphite, IG-110(Toyo Tanso LTD) and pseudo-isotropic coarse-grained nuclear graphite, PGX(UC LTD) were machined to make the single edge notched specimens(SEN: 60mm gage length, 20mm width(=W) and 10mm thickness(= B)) with sharp notch(notch length = a, notch radius, r<0.01mm) at the center position of gage section. Ligament ratio, (1-a/W) of these specimens are 0.74 to 1.

Tensile, 4-point bending and 3-point bending tests were performed with these notched specimens.

Tensile or bending load was loaded on these specimens using bi-loading machine designed by the authors. Tensile or bending strength tests were performed by vertical loading actuator(maximum capacity;100kN) or the combination of horizontal loading actuators(maximum capacity;100kN). Vertical positioning of the specimen was settled by guide roller and roller support rail. Vertical and horizontal fracture load were measured by micro-load cells(maximum capacity; 100kN, 10mm diameter, Hotaka-seiki LTD) located in the grip cells.

Strain measurements of the notched specimens under tensile and bending loading were carried out by strain gage adhered on the surface of these specimens.

Stress intensity factor, K_I under tensile and bending loading with these notched specimens of both graphites were calculated by the ASTM STP draft[9].

Results and Discussion

Stress intensity factor, Kmax obtained by tensile, 4-bending and 3-bending tests were calculated by the eq.(1)-(3) with peak loads, Pmax. Fig. 1 shows Kmax values of both graphites obtained by tensile, 4-point and 3-

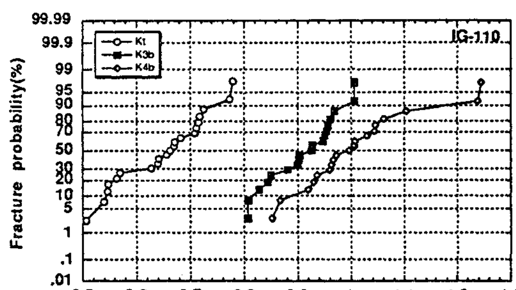

Figure 1. Kmax data scattering obtained by tensile, 3-point and 4-point bending tests.

point bending tests. Lowest values of Mmax of

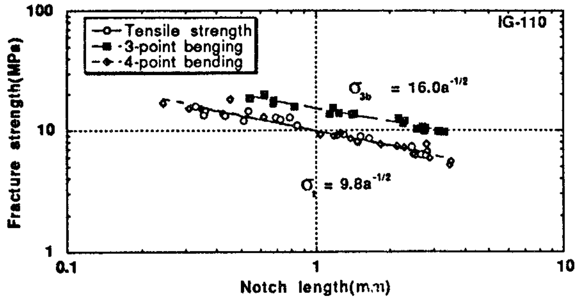

Figure 2. the relationship between notch length and strength.

both graphites are obtained by tensile strength tests, whereas highest values are obtained by 4-point bending tests. These values of both graphites exhibit wide ranged data scattering and there are no remarkable difference in these distributions obtained by tensile and bending tests. Mean values are obtained as the values corresponding to 50% fracture probability in the figure.

Fig. 2 shows the relationship between Kmax

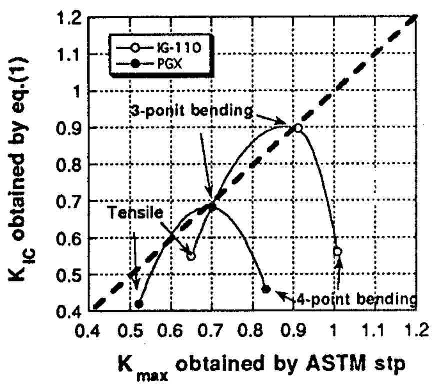

Figure 3. The relationship between Kmax and K_{IC}

and notch length of IG-110. It is clear that fracture strength increase with decrease of notch length and there is remarkable differences in the relations obtained by the tensile, 4-bending and 3-bending tests. Solid lines in the figure are derived by the following equation;

$$\sigma f = Aa^{1/2} \qquad (1)$$

where A is constant and σf is fracture strength obtained by tensile and bending tests(= σt, $\sigma 3b$, $\sigma 4b$). Good correlation's between these lines by eq.(1) and data are obtained. This fact indicated that the fracture theory proposed by Paris[10] is applicable to evaluate fracture toughness of both of graphites, and constant A in eq.(1) have the relation with K_{IC} as the following:

$$K_{IC} = A\,\pi^{1/2} \qquad (2)$$

Then, K_{IC} values of both graphites are obtained by eq.(2) and compared with Kmax obtained by the ASTM standard in Fig. 3. It is clear that KIC obtained by eq.(1) exhibits lower K values that obtained by the ASTM standard and only the values obtained by 3-point bending method show very closed value between Kmax and K_{IC}.

Conclusions

Two types of nuclear graphites, IG-110 and PGX are tested by fracture toughness tests with notched specimens by tensile, 3-point and 4-point bending loading and the following results are obtained;

There is good correlation between notch length, a and fracture strength, σf and well expressed as $\sigma f = A\,a^{1/2}$, where A is constant., and lowest fracture toughness values of both graphites are obtained by eq.(1), and very closed values between ASTM standard and eq.(1) were obtained by 3-point bending method.

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