2.2WOL test method

Employed in the present WOL test were block-shaped test specimens (Fig.1) having a notch of a certain opening size under a hydrogen penetration environment. The WOL testing aims to determine relationship between stress intensity factor K at crack tip and the crack propagation rate. Since the notch opening size is constant, the value of K at crack tip decreases with crack propagation; at the same time, the crack propagation rate also declines eventually to zero. The value of K corresponding to zero crack propagation is defined as threshold stress intensity factor K_{IHE}. Fig.3 shows the setup of the present WOL test. Its procedures were as follows: A bolt was screwed into the WOL test specimen, producing an initial opening displacement of 0.05~0.25 mm as measured by a clip gauge installed at the knife edge of the opening on the specimen. The specimen was placed and underwent cathode electrolytic hydrogen charging in a 0.1N-NaOH solution in order to generate a crack from the tip of the notch. The specimen was subjected to an extremely severe delayed fracture test environment, as the current density of the cathode electrolytic charging was at a higher 65 mA/cm^2. Crack length was measured using a projector with a 50 magnifications. The measurement was conducted every 15~60 minutes. Crack propagation rate da/dt was derived by dividing the average crack propagation length Δa of the specimen's both surfaces with hydrogen charge time Δt. Stress intensity factor K_{Ii} at initial crack opening displacement was derived from stress intensity factor K_{I0} and crack length a_i, using Equations-(1)~(3)[2)] below. Crack propagation was considered to have stopped when da/dt reached 10^{-4} mm/min, and the value of K at this crack propagation rate was defined as threshold stress intensity factor K_{IHE}.

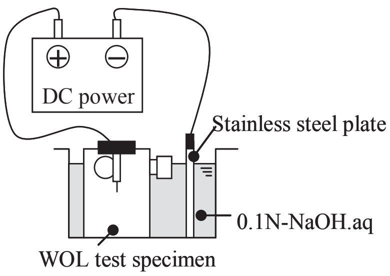

Fig.3 Diagrammatic illustration of WOL test.

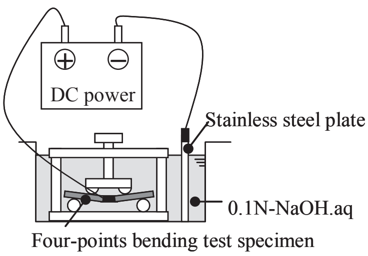

Fig.4 Diagrammatic illustration of four-point bending test.

$$V_0 = \left(\frac{K_{I0}}{E}\right)\sqrt{a_0}\left\{\frac{C_6(a_0/W)}{C_3(a_0/W)}\right\} \cdots\cdots\cdots\cdots (1)$$

$$P_i = \left\{\left(\frac{a_0}{a_i}\right)\times\left(\frac{a_i + c_1}{a_0 + c_1}\right)\right\}\frac{EBV_0}{C_6(a_i/W)} \cdots\cdots (2)$$

$$K_{Ii} = \frac{P_i}{B\sqrt{a_i}} C_3(a_i/W) \cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

$$C_3(a/W) = 30.96(a/W) - 195.8(a/W)^2 + 730.6(a/W)^3 - 1186.3(a/W)^4 + 754.6(a/W)^5$$

$$C_6(a/W) = \exp\begin{bmatrix} 4.495 - 16.130(a/W) + 63.838(a/W)^2 \\ -89.125(a/W)^3 + 46.815(a/W)^4 \end{bmatrix}$$

E: modulus of longitudinal elasticity 210,000(MPa),
P_i: equivalent load (N), B: specimen thickness (mm),
W: specimen length (mm),
V_0: initial crack opening displacement (mm),
a: crack length (mm), a_0: initial crack length (mm),
c_1: distance between load point and knife edge (mm)

2.3 Four-point bending delayed fracture test method

Fig.4 shows the setup of the present four-point bending delayed fracture test. Its procedures were as follows: Each of the specimens having a semicircular notch with a 0.3 mm radius and receiving a certain load underwent cathode electrolytic hydrogen charging in a 0.1N-NaOH solution in order to examine delayed fracture generation. The current density of the cathode electrolytic charging was 65 mA/cm^2. The value of K at the depths of the notch was derived by Equation-(4) cited from Raju & Newmann[3)]. The load strain applied to the bending test specimen was verified by a strain gauge, while judgment as to the generation of delayed fracture was made after 100h or hydrogen charging.

$$K = \alpha\sigma\sqrt{\pi a} \cdots\cdots (4)$$

σ: stress