X-RAY STUDY OF FATIGUE FRACTURE SURFACE OF NODULAR CAST IRON

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The fatigue tests were conducted by using compact tension (CT) specimens of nodular cast iron. X-ray diffraction profiles were measured on and beneath fatigue fracture surfaces. The main results obtained are summarized as follows:

(1) ω_y was determined on the basis of the distributions of the half-value breadth. It was related to K_{max} divided by σ_Y as

$$\omega_y = \alpha (K_{max}/\sigma_Y)^2$$

where the value of α is equal to 0.08

(2) The published data on the α-value determined for various kinds of steels are the following function of σ_Y:

$$\alpha = 0.15 [\sigma_Y/(143 + 0.772\sigma_Y)]^2$$

INTRODUCTION

In the present paper, X-ray fractography is applied to fatigue fracture surfaces of nodular cast iron (JIS FCD 60) which are widely used as machine parts. The fatigue tests were conducted by using compact tension (CT) specimens. The line broadening of X-ray diffraction profiles was measured beneath fracture surfaces of fatigue specimens.

EXPERIMENTAL PROCEDURE

The specimens used are as-cast spheroidal graphite cast iron (JIS FCD 60). The chemical composition of the material is as follows (wt. percent): 3.70C, 2.40Si, 0.40Mn, 0.04P, 0.018S. The yield and tensile strength are 392 and 579 MPa, respectively. The

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matrix of the material mostly consists of ferrite in an extremely small amount of pearlite.
A servo-hydraulic closed loop testing machine was used for fatigue tests, and the crack length was measured with a traveling microscope. The fatigue crack growth test was conducted under the constant ΔK condition.
X-ray diffraction profiles beneath the fracture surface was recorded by using an X-ray diffraction stress analyser. The area irradiated by X-rays was of 1 mm width and 10 mm length and was located on the fatigue fracture surface made under a constant ΔK-value at the middle of the specimen thickness. The distribution of the half-value breadth in the depth of direction was measured by removing the surface layer successively by electro-polishing.

EXPERIMENTAL RESULTS

Figure 1 shows the relation between da/dN and ΔK. When compared at the same ΔK, the rate was higher under R=0.5 than that under R=0.1. Figure 2 shows the distribution of B/B_0 beneath the fracture surface at several values of K_{max} and R. The value B/B_0 is high close to the surface, and approaches to one as the depth increases. ω_y can be defined as the depth where $B/B_0=1$ approaches to one. Figure 3 is shows the relation between ω_y and K_{max}/σ_Y. It is noted that ω_y is proportinal to the square of K_{max}/σ_Y for the case of fatigue. The relation is expressed as

$$\omega_y = 0.08 \left(K_{max}/\sigma_Y \right)^2 \tag{1}$$

DISCUSSION

Levy et al. derived $\alpha=0.15$ on the basis of the elastic-plastic finite element method for perfectly plastic material (1). The yield strength in the plastic zone σ_Y' is evaluated from the following equation:

$$\omega_y = 0.15 \left(K_{max}/\sigma_Y' \right)^2 = \alpha \left(K_{max}/\sigma_Y \right)^2 \tag{2}$$

or

$$\sigma_Y' = \left(0.15/\alpha \right)^{1/2} \cdot \sigma_Y \tag{3}$$

From the previously published data of α measured for the fatigue fracture surface of various steels and alloys, the value of σ_Y' was calculated by using equation (3) and correlated to σ_Y in Fig.4 (2-3). The following linear relation is obtained between σ_Y' and σ_Y:

$$\sigma_Y' = 143 + 0.772\sigma_Y \quad (4)$$

The result of the present study of nodular cast iron agrees with this equation. From equation (3) and (4), the α value is given as a function of σ_Y.

$$\alpha = 0.15\,[\,\sigma_Y/(143 + 0.772\sigma_Y)\,]^2 \quad (5)$$

In the analysis of failure accidents, the maximum stress intensity factor can be determined from the measurement of the maximum plastic zone by using α obtained from equation (5).

SYMBOLS USED

ΔK = stress intensity factor range (MPa$\sqrt{m}$)

K_{max} = maximum stress intensity factor (MPa$\sqrt{m}$)

da/dN = crack growth rate (m/cycle)

R = stress ratio

σ_Y = yield strength (MPa)

σ_Y' = yield strength in plastic zone (MPa)

ω_y = plastic zone depth (mm)

B = half-value breadth (deg)

B_0 = initial half-value breadth (deg)

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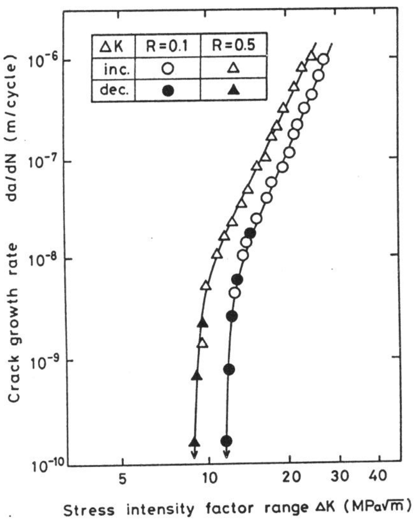

Fig. 1. Relation between da/dN and ΔK under R=0.1, 0.5.

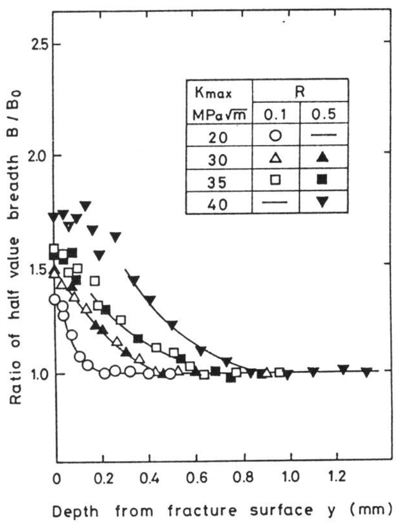

Fig. 2. Distribution of B/B_0 beneath fracture surface.

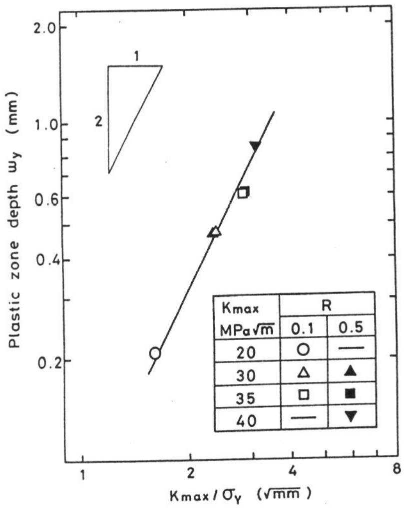

Fig. 3. Relation between ω_y and K_{max}/σ_Y.

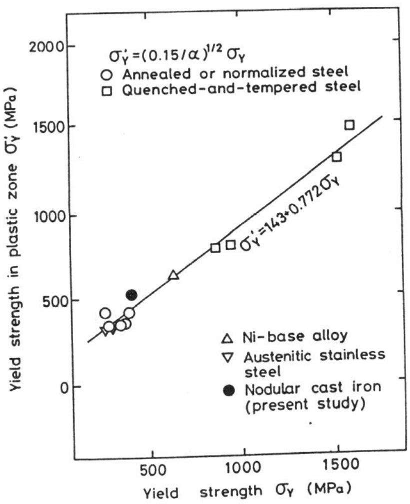

Fig. 4. σ_Y' determined from ω_y