X-RAY FRACTOGRAPHY ON FRACTURE ANALYSIS OF ACTUAL ACCIDENT

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The X-ray fractographic technique was applied to an actual fracture accident. The main results are summarised as follows;
(1)Instrumented Charpy impact tests of nodular cast iron were conducted, and at the room temperature the dynamic K_{Id} values were nearly equal to the static values of K_{IC}.
(2)The plastic zone size was determined from the distribution of the half value breadth near the fracture surface. It was related to the dynamic fracture toughness parameter, K_{Id}, and the yield strength, σ_Y, by

$$\omega_y = 0.142(K_{Id}/\sigma_Y)^2$$

(3)The K_{Id} value estimated from the plastic zone size of the actual fractured surface of a cam in a press machine was 35.8MPa$\sqrt{m}$.

INTRODUCTION

Failures in operation sometimes result from defects in engineering structures and machines. The purposes of fracture analysis are to determine the causes of failure and to use the information of failure accidents. It is important to obtain the quantitative analysis from the fracture surface. The X-ray diffraction technique(1) as well as Electron Fractography has been widely used for fracture analysis of engineering structures (2)(3).

In the present study, the electron fractography and the X-ray fractographic technique were applied to an actual fracture accident of machine part. The half value breadth was used as the X-ray fractographic parameter to estimate the depth of plastic zone size and the stress intensity factor of crack occurrence.

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DESCRIPTION OF FRACTURE

The fractured plane cam was used on Press Machine. Figure 1 shows the assembly of the cam mechanism. It was found that one cam was missing from each of several cams when the press was put into operation. The cam was connected by two screws with the cam-shaft which rotated and used to produce reciprocating motion. The material used for the cam was nodular cast iron with the chemical composition(wt%); 3.63C,2.79Si,0.20Mn,0.02P,0.01S,0.03Mg.

The material was austenized at 1153K for 30 min and oil quenched, then it was tempered at 470K for 2 hr to achieve a hardness of Rockwell C 50 to 55. The structure was consisting of graphite nodules in a martensite matrix. The yield strength was 1189MPa. The crack extended across the cam-boss and the microscopic feature of fracture surface by scanning electron micrograph(SEM) shows a typical brittle fracture. The tensile stress, which may be originated from the driving force, concentrated on the threads of the tapper hole and caused brittle fracture.

X-RAY FRACTOGRAPHIC EXPERIMENT

To obtain the basic data for X-ray fractography, instrumented Charpy impact test(4) and unloading compliance fracture toughness test(5) were conducted by using precracked specimens of three kinds of nodular cast irons, whose matrix were martensite, bainite, and ferrite. Charpy impact specimens were machined to the dimensions suggested in ASTM Standard A 370-68 and unloading compliance specimens were in ASTM E813-81. The instrumented Charpy impact test were carried out under dynamic loading and the unloading compliance technique were under ordinary static loading. Dynamic fracture toughness K_d was evaluated as follows, as recommended by ASTM Committee E-24;

$$K_d = Y(P_Q\ S)/(B\ W^{2/3}) \qquad (1)$$

where,P_Q; which is given by the peak strain value, a crack "pop-in" occurred. In the low temperature range, each of dynamic K_d-values satisfied ASTM E399 condition.

The distribution of the half value breadth near the fracture surface, given by each of the specimens, was measured with the X-ray diffraction method. The area irradiated by X-ray was 2mmϕ and stress direction of measurement was crack extension. The diffraction profile of (211) plane was obtained by Cr-Kα X-rays from the area of 2mmϕ, and was measured by removing successively the surface layer by electro polishing.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows the record of load-time curves obtained from the instrumented Charpy impact test. Absorbed energy (C_V) in individual structure was calculated from these curves. Impact tests were conducted at various temperature. The relationship between C_V and temperature is shown in Figure 3, and evaluated K_{Id} versus temperature is in Figure 4. Load-time curves also showing that at the low end of the transition temperature range the fracture was brittle, and at the upper end the fracture was ductile.
Figure 5 shows the results of J_R curves of ductile cast irons, obtained from unloading compliance fracture toughness tests. The J_R curves for bainite and ferrite indicate higher toughness than martensite. The measured static J_{IC} values at the room temperature were 5.5kN/m for martensite, 26.5kN/m for bainite , and 30.7kN/m for ferrite. The K_{IC} values were calculated from equation;

$$K_{IC} = \sqrt{E \cdot J_{IC} / (1-\nu^2)} \qquad (2)$$

These calculated values were nearly equal to the K_{Id} values obtained at room temperature.

QUANTITATIVE ANALYSIS OF FRACTURED CAM

Figure 6 shows the distribution of the half-value breadth of (211) X-ray reflections near the fracture surface of toughness test specimens at room temperature. You can see the half-value breadth distribution obtained by standard fracture toughness tests were nearly identical to those by instrumented impact Charpy tests. As the depth increases, the half-value breadth gradually diminishes. At a certain depth, the half-value breadth approaches to constant. The plastic zone size(ω_y) is defined as the distance where the half-value breadth to initial pre-fracture value. The relation between ω_y and K_{Id}/σ_Y is shown in Figure 7. It is noted that ω_y is proportional to square of K_{Id}/σ_Y, as follows;

$$\omega_y = \alpha(K_{Id}/\sigma_Y)^2 \qquad (3)$$

Now we got the values α for martensite was 0.142, for bainite was 0.131, and for ferrite was 0.127. The distribution of the half-value breadth beneath the fracture surface of actual fracture shows in Figure 8. The distribution is similar to that obtained by laboratory tests. The plastic zone size is determined to be 0.13mm from the half-value breadth distribution. By substituting this value into equation(3) with α value 0.142, the K_{Id} value was calculated to be 35.8MPa$\sqrt{m}$. This value was just over the K_{IC} value (31.6MPa$\sqrt{m}$) of martensite nodular cast iron which was used for cam parts. It is found, on the other hand, that the bainite matrix has good toughness K_{IC} value (69.0MPa$\sqrt{m}$) in our laboratory test. So we judged necessary to change the matrix stracture to bainite for preventing this accident.

SYMBOLS USED

S = load span (as 40mm)

B = specimen thickness (as 10mm)

W = specimen width (as 10mm)

Y = f(a/w) (as given 2.66)

ν = Poisson's ratio (as given 0.27)

E = Young's modulus (as given 167GPa)

ω_y = plastic zone size

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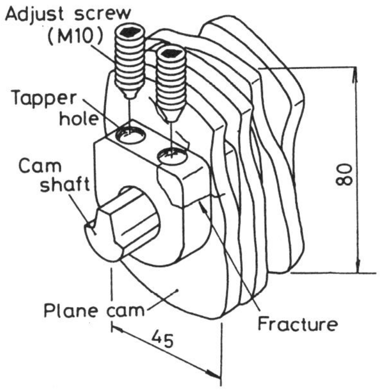

Figure 1 Plane cam assembly failed by brittle fracture.

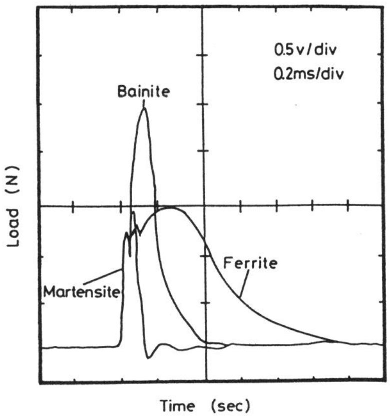

Figure 2 Recording the load-time curve.

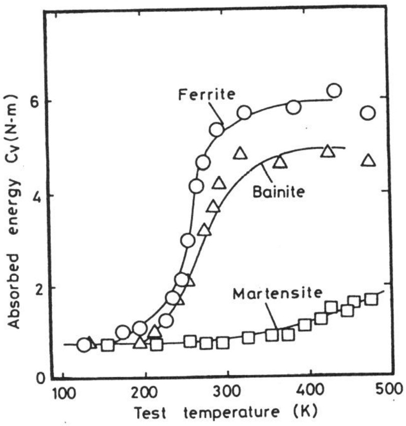

Figure 3 The relationship between C_v and temperature.

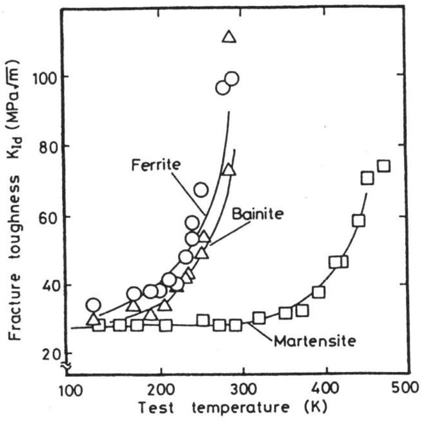

Figure 4 The relationship between J_d and temperature.

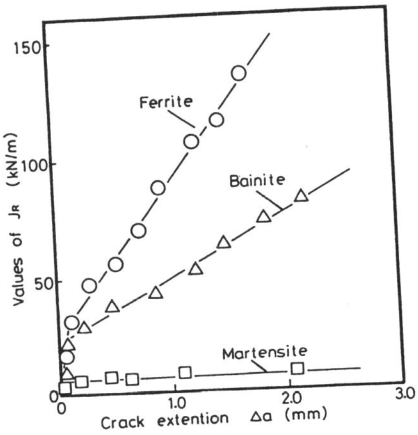

Figure 5 J_R curves of nodular cast iron.

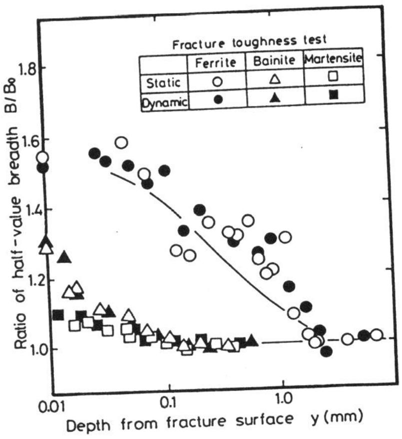

Figure 6 Half value breadth distribution .

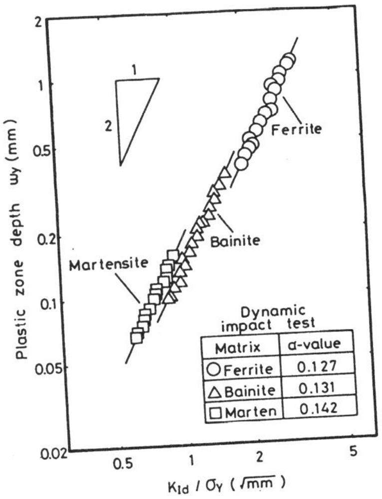

Figure 7 Relation between ω_y and (K_{Id}/σ_Y).

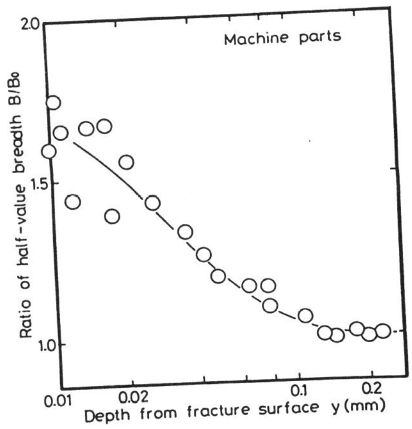

Figure 8 Half value breadth distribution near actual failure fracture surface.