APPLICATION OF HIGH DAMPING STEEL AND KEY CURVE METHOD TO INSTRUMENTED CHARPY TEST

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Although the instrumented Charpy test has the potential as an economical and simple fracture toughness test, improvement of its reliability is required. In the paper the high damping steel was used for the instrumented tap on the hammer so as to reduce the oscillation of the load signals. The key curve method using a couple of fatigue cracked and U-notched specimen was used to determine the fracture toughness and J-resistance (J-R) curve. The test procedure was applied to ASTM A533B steel with three different heat treatments and the availability of the procedure is discussed.

INTRODUCTION

In spite of economical advantages of the instrumented Charpy test, the reliability is not yet fully justified especially due to the oscillation of recorded load signals and to the difficulty in the determination of the fracture toughness. In order to reduce the oscillation of signals, application of an electric filter, numerical averaging, subtraction of pre-measured oscillation curve from the recorded signals, or insertion of a damper plate between the tap and specimen, are attempted.The counter-measures require delicate adjustment and would sometimes reduce or delay the absolute signals. Joyce et al.(1) proposed a key curve method to determine the fracture toughness and J-resistance (J-R) curve. Although the J-R curve is analytically introduced from the load-displacement relationship (Ernst et al.(2)), it requires multiple sub-size specimens. The improved key curve method was proposed by Ohtsuka et al.(3) using a couple of fatigue cracked and U-notched specimen.

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EXPERIMENTAL PROCEDURE

The material tested was ASTM A533B Cl.1 steel and the chemical compositions and the mechanical properties are listed in TABLES 1 and 2. Some of the materials were subjected to thermal aging by heating for 36 days at 400 and 500 °C. The test specimens were blunt U-notched or fatigue precracked Charpy type with side grooves, as shown in Figure 1. The $K_{f,max}$ of fatigue cycle was less than 18.6 MPa$\sqrt{m}$. The test was conducted by a 300 J Charpy machine at room temperature. The test velocity was 2 m/s. Applied load, P, and displacement, v, of the hammer were measured by strain gages on the tap and by an optical displacement meter, respectively. The oscillating load-displacement curves were smoothed by averaging the curve. The tap made by the Fe-12Cr-1.5Al high damping steel was replaced with the normal tap for the most of the test.

The J-R curves were obtained by the single specimen key-curve method (Ohtsuka et al.(3)) as follows. Denoting subscripts f and u as being fatigue pre-cracked and blunt U-notched specimens, respectively, the P-v curves of the two specimens are then superimposed. When the sizes of the two specimens do not coincide with each other, the latter curve was converted by

$$v = v_u W_f / W_u \qquad (1)$$

$$P = \left(\frac{P_u W_f}{W_u}\right)\left(\frac{1 - \alpha_f}{1 - \alpha_u}\right)^2 \qquad (2)$$

where W is the specimen width and $\alpha = a_0/W$ with a_0 being the original crack length. The J-integral at any displacement of the fatigue cracked specimen is calculated by

$$J = \frac{2}{B_N b_0}\int_0^v P d\delta \qquad (3)$$

TABLE 1 - Chemical Compositions of Materials.(wt%)

C	Si	Mn	P	S	Cu	Ni	Cr	Mo
0.20	0.28	1.46	0.020	0.013	0.16	0.61	0.14	0.51

TABLE 2 - Mechanical Properties of Materials.

Y.S.(MPa)	U.T.S.(MPa)	Fl.S.(MPa)	El.(%)	R.A.(%)
480	632	556	27.7	65.2

where B_N and b_0 are the net thickness and the original uncracked ligament (= $W-a_0$) of the specimen. The corresponding crack extension Δa is calculated as

$$\Delta a = b_0(1-\sqrt{P_f/P_u})+J/(4\sigma_f) \quad \cdots\cdots (4)$$

where σ_f is the flow stress (the average of yield strength and tensile strength) of the material.

EXPERIMENTAL RESULTS AND DISCUSSION

Effect of High Damping Steel

Figure 2 shows superimposed P-v records of fatigue cracked and U-notched specimens of as-received material, measured by the normal tap. Figures 3 to 5 indicate the similar P-v records of as-received and thermal aged materials, measured by the high damping tap. Comparing Figure 2 with Figure 3, effect of high damping steel on the reduction of load oscillation is apparent. Possible causes of the the oscillation of the load signals would be (a) cyclic contact of a specimen with the tap, (b) vibration of a specimen, or (c) vibration of tap and hammer. Connecting an electric leading wire with the specimen and the tap and turning on an electric current, the tap was found to be kept contact with the specimen after the first touch (Urabe (4)). The result denies the possibility of (a). Concerning (b), the bending load of the specimen was monitored by strain gages as shown as the broken line in Figure 6. In the figure, the solid line indicates the load history of the normal tap. The vibration of the specimen is negligibly small compared with that of the tap. According to the foregoing results, the vibration during the Charpy test is estimated by a spring model as follows. After the first impact of the tap on the specimen, they both begin to deform and to vibrate at the same displacement. As the stiffness of the tap is 60 times as high as that of the specimen, load fluctuation of the tap is enlarged, where that of the specimen is negligibly small. Therefore, relatively smooth load records by the high damping tap as in Figures 3 to 5 are considered to represent the nearly correct load histories which are induced to the specimens.

Results of Key Curve Method

Figure 7 compares J-R curves which were obtained from Figures 2 to 5 by the key-curve method. Solid symbols indicate the results for the high damping tap and the open symbols for the normal tap. The J-R curve of the as-received material measured by the high damping tap does not fully coincide with that by the normal tap. Application of the key curve method to the P-v record, measured by the high damping tap as in Figure 3, are apparently easier and the reliability of the J-R curve is considered to be improved than by the normal tap as in Figure 2.

J_{IC}, the J-integral at the initiation of crack growth, and the tearing modulus,

$$T_M = (E/\sigma_f^2)(dJ/da), \quad \cdots\cdots (5)$$

are determined from Figure 7 and are summarized in TABLE 3 where E and dJ/da are the modulus of elasticity and the slope of the J-R curve. It is seen in the table that the key curve method based on the P-δ records by the high damping tap distinguishes the effect of thermal aging on the decrease of the values of J_{IC} and T_M.

CONCLUSIONS

The instrumented Charpy test was conducted on thermal aged ASTM A533B steels. Comparing the load signals measured by the high damping tap with that by the normal tap, oscillation of load signals were apparently reduced. The key curve method using a couple of fatigue cracked and U-notched specimen was used to determine the fracture toughness and J-resistance curve. The effect of thermal aging on the decrease of the J_{IC} and the tearing modulus, T_M, was shown based on the load-displacement records using the high damping tap.

REFERENCES

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(3) Ohtsuka, N. and Matsumoto, Y., JSME International Journal, Series I, Vol.31, No.4, 1988, pp.738-743.

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TABLE 3 - Summary of J_{IC} and T_M.

Tap	Normal	High D.	High D.	High D.
Material	As-rec.	As-rec.	TA. at 400 °C	TA. at 500 °C
J_{IC} (N/mm)	57	60	38	23
T_M	209	294	230	116

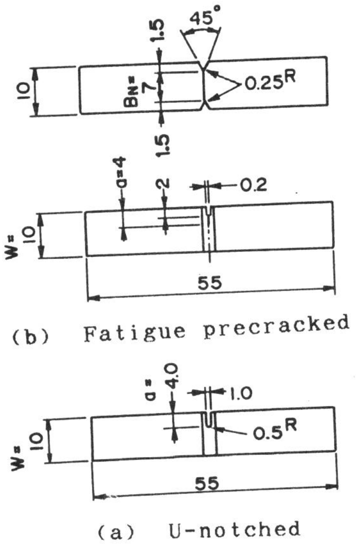

Figure 1 Geometry of test specimens.

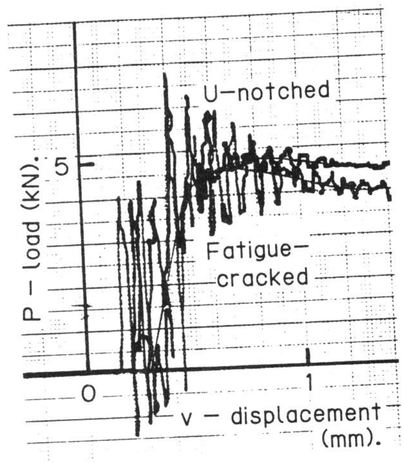

Figure 2 Superimposed P-v records of as-received material, measured by the normal tap.

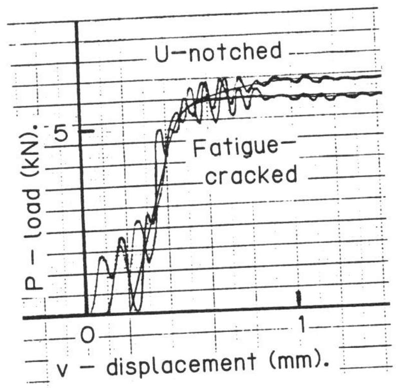

Figure 3 Superimposed P-v records of as-received material, measured by the high damping tap.

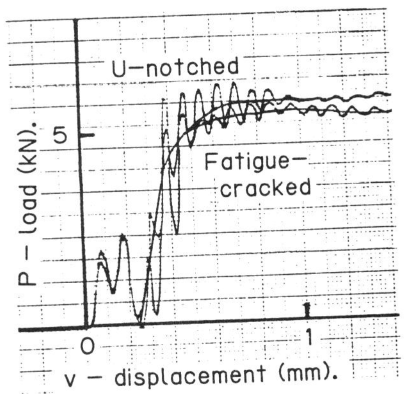

Figure 4 Superimposed P-v records of thermal aged material at 400 °C, measured by the high damping tap.

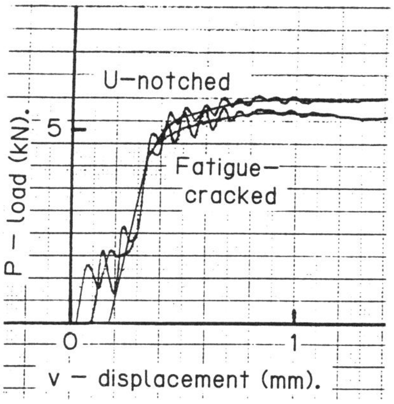

Figure 5 Superimposed P-v records of thermal aged material at 500 °C, measured by the high damping tap.

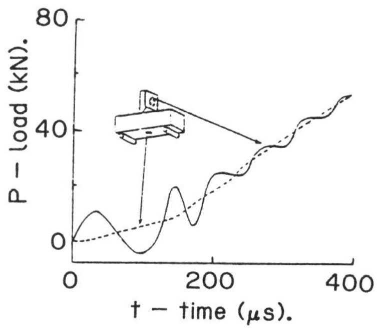

Figure 6 Comparison of load histories in a specimen and the tap.

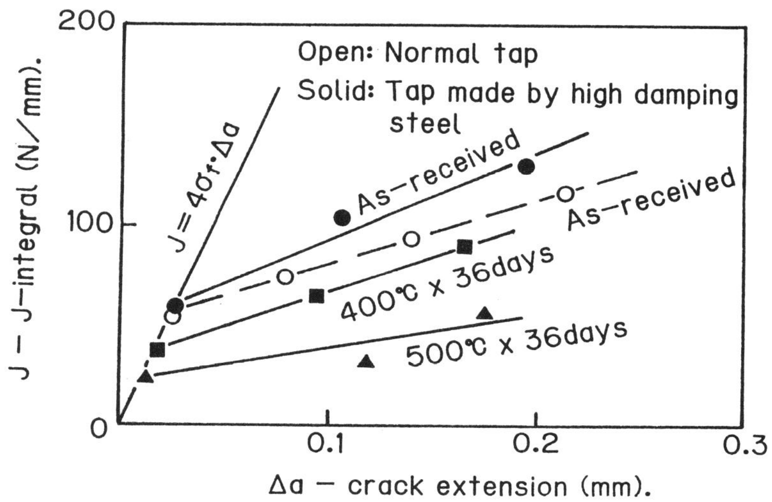

Figure 7 Comparison of J-R curves obtained by the single specimen key-curve method.