A Simple Iterative Key Curve Method for Determining JR Curve

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ABSTRACT

An Iterative Key–Cutve Method (IKCM) is presented to determine crack extension, which avoids to calibrate function $H(\frac{\triangle}{w})$ and makes the measurement of larger crack extension possible. The IKCM is simple in the test and may reduce the requirements to the experimental accuracy.

1 INTRODUCTION

In order to reduce the testing costs and the requirements to their accuracy, the Key–Curve method described by Ernst et al (1979) was presented to implement single speciment techniques for some experimental situations such as static and dynamic loading, high temperatures or corrosive enviroments only with the records of load–load displacement(Joyce et al.1989, Bruminghaus et al. 1989 and kobayashi et al 1986).But a Calibration function $H(\frac{\triangle}{w})$ with different constant crack lengths must be obtained by testing specimens with smaller overall dimensions (sub–sized specimens) or blunt notches, it is difficult to keep the crack length constant up to large deformation during loading. Usually the calibrating specimens would have some differences in the material properties and in the speciman geometries, that shall limite the applications of key–curve method.

2 THE ITERATIVE KEY CURVE METHOD

Based on the assumption that the load P is independent of the crack growth history and given for any definite combination of load line displacement $\triangle$ and crack length a (Ernst et al 1981)

$$\frac{P}{WB(b/w)} = H\left(\frac{\triangle}{w}\right) \cdot g\left(\frac{a}{w}\right) \quad (1)$$

The function $g(a/w)$ is given by

$$g(\frac{a}{w}) = \exp(-\alpha\frac{b}{w}) \quad (2)$$

$$\alpha=0 \quad \text{(3–PB–specimen)}$$

$$\alpha=-0.522 \quad \text{(CT–specimen)}$$

The P–$\triangle$ curves are nonlinear caused by crack blunting before the crack initiating, this section of P–$\triangle$ curve can be used to caculate $H(\frac{\triangle}{w})$as no crack growth (a=const). After crack initiating the crack length varies as crack growing, and $H(\frac{\Delta}{W})$cann't be caculated directly from the P–△ curves of prefatige cracked specimens.

Observing the function $H(\frac{\Delta}{W})$it may be a monotonic raising curve, so the iterative key curve method is presented, where the function $H(\frac{\Delta}{W})$and $H'(\frac{\Delta}{W})$can be determined directly from the testing specimens.

$$da_{i+1} = \left(\frac{b}{\eta}\right)_i \left(\frac{H'_i}{H_i}\frac{1}{w} - \frac{\Delta F}{F}\frac{1}{\Delta_{i+1}-\Delta_i}\right)(\Delta_{i+1}-\Delta i) \tag{3}$$

$$H_{i+1}\left(\frac{\Delta}{W}\right) = \frac{F_{i+1}}{WB(b/w)^2_{i+1}}\frac{1}{g} \tag{4}$$

$$H'_{i+1}(\Delta/w) = \frac{\left(\frac{F}{(b/w)^2 g}\right)_{i+1} - \left(\frac{F}{(b/w)^2 g}\right)_i}{\Delta_{i+1}-\Delta_i}\frac{1}{B}$$

$$\eta_i = 2 + \alpha\left(\frac{b}{w}\right)_i$$

where i=1 indicates crack initiating point and H_1, $H'_1$are initial values in eq(4) which depend on the location of crack initiating point. The crack initiation point can be deteeted by the eletrical potential technique, acoustic emission technique, metallographic method as well as unloading compliance technique. With these method supplementary instruments are required and would be difficult to be applicated in high temperatures and corrdsive enviroments.

Analysing the P–△ curve before and after crack initiation point, it can be seen that the crack blunting makes to shape plastic zone at the crack tip before the crack initiation, but the plastic zone would usually grow acceleratvely and the crack growth would reqire the additional work done by applied load and releasing elastic energy after the crack initiation, so there are different properties at two sides of crack initiation point. Observing the change of $\frac{dP}{d\Delta}$ –△ curve, the rate of $\frac{dP}{d\Delta}$changes obviously(step changes of $\frac{d}{d\Delta}\left(\frac{dP}{d\Delta}\right)$)at the crack initiation point. So the crack initiation point can be detected conveniently by the change of $\frac{dP}{d\Delta}$ – △(see Fig.1).

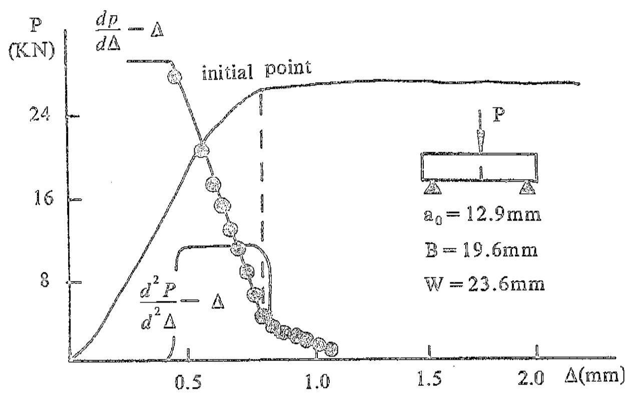

Fig.1 P–△ curve of the steel 45#

3 EXPERIMENT RESULTS AND DISCUSSIONS

The chemical compositions of the steel 45# used in the experiment are shown in Table 1. The mechanical properties are shown in Table 2. The eighteen 3PB specimens with B=19.70mm and B=8.60mm are investigated, the

Table 1. Chemical compositions (wt%)

Material	C	Si	Mn	S	P	Ni	Cr	Mo	Cu	Mg
steel 45#	0.45	0.20	0.60	0.04	0.04	0.25	0.25	0.25		
30CrMnSiA	0.30	0.95	0.90					0.90		
$LY_{12}cz$			0.50						4.2	1.5

Table 2. Mechanical properties

Material	Yield Strength $\sigma_s(MN/m^2)$	Tensile strength $\sigma_b(MN/m^2$	Elongation %	Ra %
steel 45#	350	650	17	35
30CrMnSiA	900	1100	10	45
$LY_{12}cz$	260	430	10	

cracks grow stably except T18 specimen with some faults in material. Also the 1CT specimens of steel 45#, 30CrMnSiA and Aluminum $LY_{12}cz$ are tested. The experiment results show that IKCM method have the accuracy required (see Fig.2).

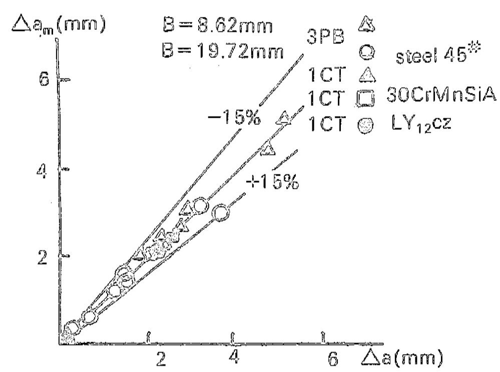

Fig.2 Comparision of caculated crack extension Δa with experiment observed crack extension Δa_m

For $H(\frac{\Delta}{W})$ functions being obtained from each testing specimen in IKCM method, it can reflect the variation of gemetries and some defferences in materials. If $H(\frac{\Delta}{W})$ function from calibration specimen is used, the $J_R$curves measured will be independent on specimen thickness, which is inadmissible in the many measurements done by other researchers. This would cause the divergence in the measurements of crack extensions. Our test results show that $H(\frac{\Delta}{W})$ would vary with specimen thickness, specimen gemetries and some differences in meterials (see Fig.3), and $J_R$curves can be obtained by caculating J−integral (see Fig.4).

$$J_{i+1} = \left[J_i + \frac{\eta A_{i,i+1}}{Bb_i}\right]\left[1 - \left(\frac{r}{b}\right)_i (a_{i+1} - a_i)\right] \quad (5)$$

$$J_M = J + \int_{a_0}^{a} \gamma \frac{J_{pl}}{b} da \quad (6)$$

$\gamma = 1 + 0.76b/w$ for CT specimen

$\gamma = 1$ for 3−PB specimen

where

J_M is modified J introduced by Ernst et al (1983).

J_{P1} is plastic part of J.

b is remaining ligament.

The error analysis of the influence of step length $l = \Delta_{i+1} - \Delta_i$ on the caculations of the crack extensions may be given. The errors of the caculating crack extensions in each step are

$$err = -\frac{d\Delta}{w} \frac{H''\left(\frac{\Delta}{w}\right)H\left(\frac{\Delta}{w}\right) - \left(H'\left(\frac{\Delta}{w}\right)\right)^2}{\frac{H'\left(\frac{\Delta}{w}\right)}{H\left(\frac{\Delta}{w}\right)} - w\frac{dF}{d\Delta}\frac{1}{F}} \tag{7}$$

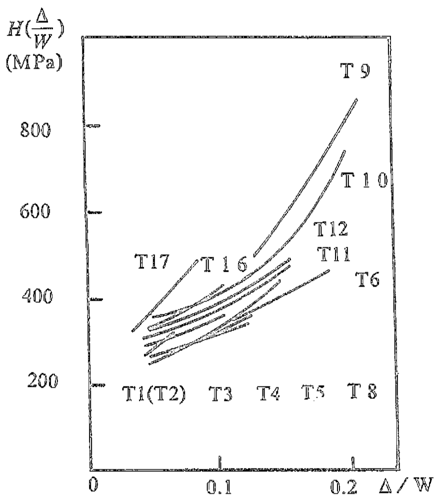

Fig3. variations of $H(\frac{\Delta}{w})$ functions

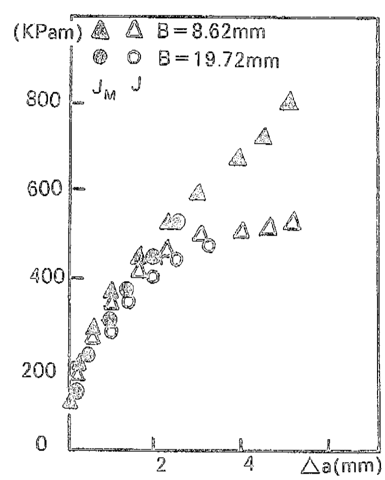

Fig4. J_R curves

For $H(\frac{\Delta}{w})$ functions raising montonously the error would be small. For T16 specimen with $\Delta a = 2.233$mm, step length selected with $l = 0.35$mm causes the error 1.75% with $l = \frac{1}{2} \times 0.35$mm in caculating crack–extensions, and the error would be less than 3% in comparison with the caculation in enough short step length. So only five point is required to be selected in the caculation, and would give good accuracy in caculation for T16 specimen.

All that show the IKCM method would be simple and can give the accurate caculation of the crack extension, it would be valid in the measurements of J_R curves.

REFERENCES

Ernst, H.A., Paris, P.C., Rossow, M and Landes, J.D. (1979): Analysis of load–displacement relationship to determine J–R–curve and tearing instability material properties, in Fracture Mechanics, ASTM STP677. PP.581–599.

Joyce, J.A and Hackett, E.M. (1989): Transition range drop tower J–R curve testing of A106 steel, Experimental Mechanics, PP274–278.

Brüninghaus, K., Falk, J., Twickler, M and Oahl, W. (1989): Determination of crack resistance curves under static and dynamic loading by analysis of load displacement relationship. Engineering Fracture Mechanics, Vol 34, PP989–1000.