THE DEVELOPMENT OF A PLASTIC HINGE AHEAD OF A GROWING CRACK

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INTRODUCTION

The standard expression for calculating the crack tip opening displacement (CTOD) from a single edge notch bend specimen (1) is given by:-

$$\delta = \frac{K^2 (1-\nu^2)}{2E\sigma_{ys}} + \left[\frac{r_p (W-a_o)}{r_p (W-a_o) + a_o + z}\right] V_p \quad \ldots\ldots\ldots\ldots\ldots (1)$$

The first term in equation 1 represents the small scale yielding component of CTOD which is expressed as a function of the stress intensity factor. The second term is the plastic component of CTOD which is calculated assuming that a plastic hinge forms at a point $r_p (W-a_o)$ ahead of the initial crack tip. In BS 5762 an r_p value of 0.4 is assumed, as this is considered to be a lower bound for ferritic steels.

This paper presents the results of an experimental study to determine the effect of stable crack growth on the plastic rotational factor (r_p).

TEST DETAILS

Two unloading compliance R-curve tests were performed on deeply notched (a/W = 0.6) 20 x 40mm and 25 x 50mm single edge notch bend (SENB) specimens made from Ti-3Al-2V and Al 5183 alloys respectively. Both specimens were fitted with a double clip gauge arrangement to enable the position of the plastic hinge to be determined. On completion of the tests the instantaneous plastic rotational factor at each unloading (i.e. based on the current crack length) was estimated using the following relationship:-

$$r_{p_k} = \frac{1}{W-a_k}\left[\frac{V^u_{p_{k+1,k-1}} (z^u - z^l)}{V^u_{p_{k+1,k-1}} - V^l_{p_{k+1,k-1}}} - z^u - a_k\right] \quad \ldots\ldots\ldots\ldots (2)$$

where $V_{p_{k+1,k-1}} = V_{p_{k+1}} - V_{p_{k-1}}$

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RESULTS

The results of the two unloading compliance tests are presented in Fig. 1 and 2 as plots of r_p against stable crack growth. It is evident that in both cases the instantaneous plastic rotational factor increases with stable crack growth, rising from approximately 0.3-0.4 at the beginning of the test to almost 0.7 after 10mm of stable crack growth in the case of the 20 x 40mm Ti-3Al-2V SENB specimen. It is therefore clear that the assumption regarding the plastic rotational factor in BS 5762 is not appropriate in the presence of stable crack growth. Nevertheless since an overestimation of r_p results in the plastic component of CTOD being overestimated, equation 1 should yield conservative estimates of CTOD.

SUMMARY

An experimental study has been undertaken to determine how the instantaneous plastic rotational factor varies with stable crack growth in an SENB specimen. Limited results obtained from a Ti-3Al-2V alloy and a 5183 Aluminium alloy indicate that:-

1. The plastic rotational factor increases with stable crack growth.

2. The BS 5762 procedure for calculating CTOD should provide conservative estimates of the fully plastic component of CTOD after significant stable crack growth.

SYMBOLS USED

δ = CTOD
K = stress intensity factor
ν = Poisson's ratio
E = Young's modulus
σ_{ys} = yield strength
r_p = plastic rotational factor
W = specimen width
a_o = initial crack length
z = knife edge height
V_p = plastic component of mouth opening displacement
Subscripts k, k+1, k-1 = unloading numbers
Superscripts u = upper, l = lower

REFERENCES

(1) BS 5762: 1979 "Methods for crack opening displacement (COD) testing" British Standards Institution.

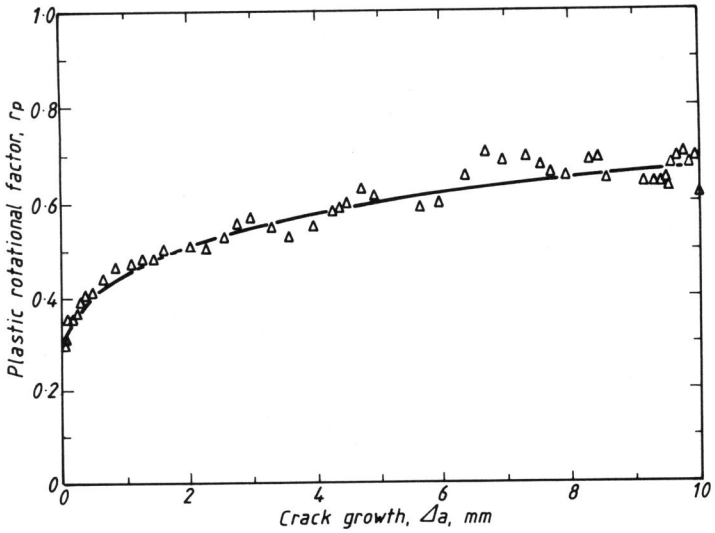

Fig.1 Variation of r_p with stable crack growth for 20×40mm Ti-3Al-2V SENB specimen.

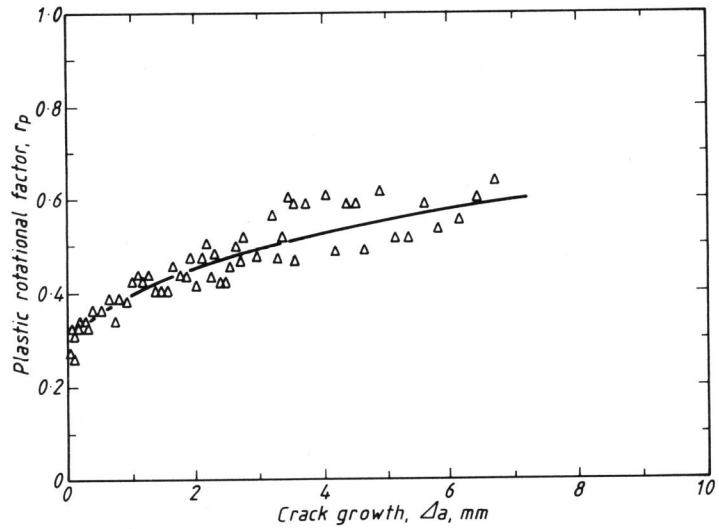

Fig.2 Variation of r_p with stable crack growth for 25×50mm Al 5183 SENB specimen.