FURTHER EVIDENCE ON THE NORMALISATION OF J-R CURVES.

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INTRODUCTION

Casual examination of the literature shows that tearing toughness, described by conventional J-R resistance curves, is strongly geometry dependent. In such analyses J is evaluated from the area, A, under the load-displacement diagram using

$$J = \eta\ A/Bb \qquad \text{Eqn.1}$$

where η is a constant, 2 for standard three point bend pieces and about 2.2 for compact tension pieces, B is thickness, and b is ligament. The precise definition of dJ, taken from Eqn 1 after initiation, varies from one school of thought to another and will not be pursued here. All such definitions can be expressed as

$$dJ = \eta dA/\ Bb \text{ plus "correction" terms} \qquad \text{Eqn.2}$$

It was noted, however, (1) and (2) that much R-curve data for a given material and type of test could be brought to a single curve if the axes were scaled or normalised. Some fifty cases, bending, compact tension (CT) or tension as may be, were tabulated in (2) but few have been shown in graphic form other than the writers' own data from deep notch bend tests on HY 130 steel, (3).

The present note shows examples for some of the different scale factors that arise. Data are drawn from the results available from other workers and materaials other than HY130 to demonstrate the results are not peculiar to one circumstance. The relation between the curves for the different types of test, is not entered into here.

DISCUSSION

For contained yield, a non-dimensional scale for crack growth has been expressed by Rice et al (4) in terms of $\Delta a/c$ where $c = (EJ/\sigma_y^2)$, a measure of the plastic zone size that limits further work dissipation. An extension of that argument into un-contained yield suggests that c might remain a material property or be a geometric limitation, B or b. The dimensions of dJ/da are work per unit volume or stress. That suggests that if dJ/da, or its non-dimensional counterpart, $T = (E/\sigma_y^2)(dJ/da)$, is of physical significance it cannot be through a direct extension of the conventional fracture toughness, which is of dimensions work per unit area. It must therefore be thought of as an intensity of work per unit volume, ρ, and the related volume on which it acts. This is taken simply as Hhda where H is the extent of plastic deformation in, and h normal to, the crack plane so that provided H=B

$$dA\ \alpha\ \rho Bhda \qquad \text{Eqn.3.}$$

For a given geometry and state of stress (i.e. either plane stress or plane strain as defined below) the factor of proportionality does not matter. For pieces large in relation to a plastic zone size, h will be limited by the toughness of the material. For tests that reach the fully plastic state, the volume relevant to the dissipation of work will be related to the extent of slip line patterns so that for circumstances tending to plane stress (out-of-plane-slip) the limiting factor is B and for plane strain, (in-plane slip), it is b. For the fully plastic state plane stress deformation is met when b>B and plane strain when B>b. These restictions are not those familiar in lefm where the size of plastic zone to thickness is the governing ratio. The relation of a plastic zone size, r_{mm}, maximum possible for that material (in plane stress) and r_{iff}, at initiation in flat fracture, is also seen as relevant although evaluation of the terms is rather imprecise.

In any definition of dJ the dominant term is

$$dJ = \eta\ dA/Bb = \eta\rho Bhda/Bb \qquad \text{Eqn.4}$$

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The exact form of dJ will depend on the detailed definition being followed but the differences do not affect the scaling laws, only the numerical values obtained.
The behaviour is demonstrated most easily where two J-R curves both depend upon the same factor. Four cases are shown here, all for different circumstances and materials, two for cases that do not require scaling and two that scale with either $\Delta a/b$ or $\Delta a/B$ since the test pieces used were geometrically similar.
Fig.1 is after Ref 5 (Fig 3), $b>B>r_{mm}$, plane stress, same b, h = r so dJ α Δa;
Fig.2 after Ref 6 (Fig 5), $r_{mm}>B>b$, plane strain, geom: sim:, h = b so dJ α Δa;
Fig.3 after Ref 7 (Fig 26), $r_{mm}>b>B$, plane stress, same B, h = B so dJ α $\Delta a/b$;
Fig.4 after Ref 8 (Fig 6.4), $B>b>r_{mm}$, plane strain, geom: sim:, h = r so dJ α $\Delta a/b$.

There are thus three pair sets; plane stress, plane strain, and geometrical similarity. Within each pair the ruling factor differs although for the last two pairs the resulting law is the same. It is noted without further comment that the terms given here are based on steady state concepts and may not be adequate where the amount of crack growth is very small in relation to the ligament. Where the amount of growth is very large in relation to the ligament the additional terms in Eqn.2 may have to be taken into account. Some cases where two curves depend on different scale factors and also some side grooved data that may require separate treatment of what controls the scale factor will be discussed elsewhere.

References

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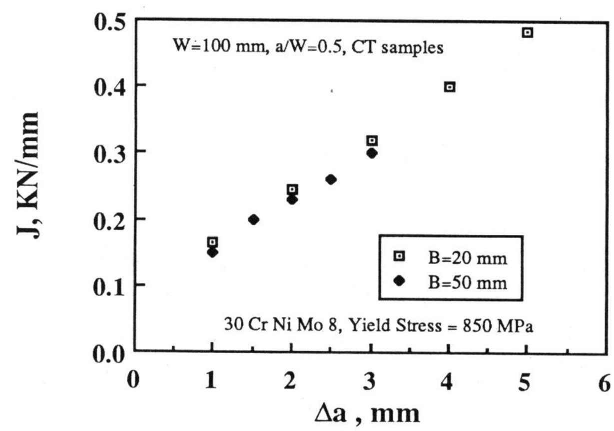

Fig. 1 Data from Ref. 5; dJ α Δa

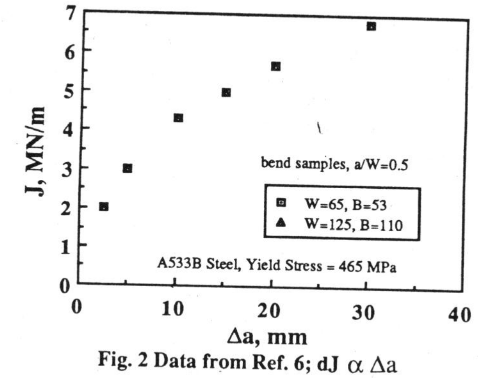

Fig. 2 Data from Ref. 6; dJ α Δa

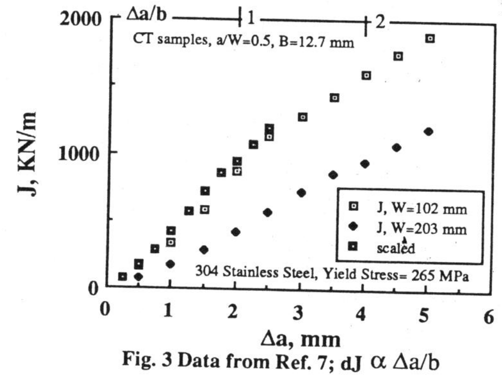

Fig. 3 Data from Ref. 7; dJ α Δa/b

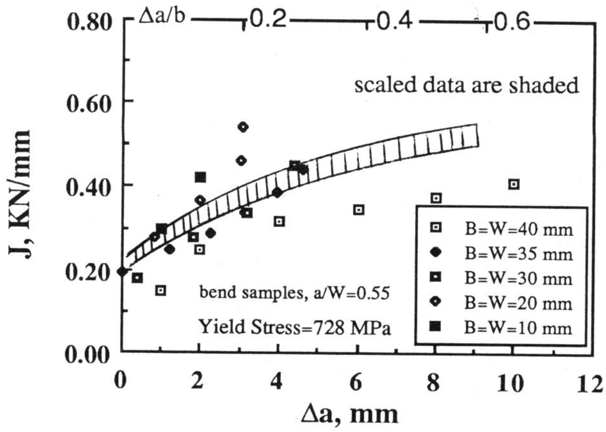

Fig. 4 Data from Ref.8; dJ α Δa/b