11 a. On the Determination of Material Fracture Parameters in Yielding Fracture Mechanics

Blauel, J.G. and Hollstein, T.

Fraunhofer-Gesellschaft e. V.
Institut für Festkörpermechanik
Rosastrasse 9, D-7800 Freiburg

One of the prime tasks of yielding fracture mechanics is to define material values which clearly describe the failure behavior of a cracked component when larger plastic deformations appear. Critical values of the crack tip opening displacement δ and of the energy-integral J are widely discussed and investigated as possible candidates [1, 2] . The condition for their applicability is that they can be determined from relatively small specimens in a simple laboratory test. In the following a few comments are given on the progress which has been made in solving the experimental problems of such a procedure, and some of the open questions which still exist in this field are shown.

As the critical point for which a J-integral value or a crack tip opening displacement is to be determined has been chosen [3] the onset of stable crack growth. This choice is a conservative one - may be even too conservative - but it is believed that this point is material specific and can be determined unambiguously. A direct current potential method and the well known interrupted loading procedure are used to determine the relevant values of load F_c and displacement V_{gc} for the onset of stable crack growth [3] . Results from a test series at room temperature of 20 mm thick compact thoughness specimens from the structural steel St E 460 are shown in Fig. 1:

For each specimen together with the force F and load point displacement V_g the potential change $\Delta\varphi$ - picked up at the open end of the specimen - has been recorded. A curve with a minimum appears. Having passed it the specimen was unloaded, heat tinted and broken open. The dark seam on the fracture surface - followed in this example by a light band from an additional fatigue loading - is the stable crack growth that this specimen experienced during loading.

A microscope is used to quantitatively evaluate the increase in fracture area and the maximum of stable crack growth in the middle of the specimen. This is done in Fig. 1 for a series of identical specimens which are loaded to different levels. An extrapolation of the measured values of maximum stable crack growth can be made to $\Delta a^{max} = 0$ and one finds V_{gc} and F_c, the critical values of displacement and load which characterize the onset of stable crack growth. At the same time this procedure proves that the minimum of the potential curve describes just this point.

This result has been confirmed for different materials and for test temperatures from -150 to 300^0 C. But up to now there is not a complete physical understanding of that phenomenon and therefore still difficulties exist to explain the curves of a continuously increasing character that are sometimes found. In addition it would be useful to investigate in more detail the influence of geometry and material parameters with the goal to develop a quantitative evaluation of the potential measurement for a R-curve.

Having the critical load F_c or the critical opening displacement V_{gc} critical J-values J_c can be evaluated in a straightforward way: The curves in Fig. 2 are developed for 30 mm thick compact toughness specimens using the compliance technique of Begley and Landes [1]. The material is the reactor pressure vessel steel 22 Ni Mo Cr 37. A critical J-value of 0.2 MN/m is deduced for the onset of stable crack growth at room temperature using either V_{gc} = 2,1 mm from a specimen with a crack length a = 68 mm or V_{gc} = 1,4 mm from a second potential measurement in a specimen with a = 54 mm. The influence of other parameters than the crack length may be studied in the same way.

A more detailed information can be drawn from the results when plotting them in the manner of crack resistance or R-curves. Fig. 3 shows an example from another series of tests with a second plate of the steel 22 Ni Mo Cr 37 and some of the implications of this method for a meaningful determination of critical material values J_c may be discussed here:

J-values are evaluated for the maximum load at which the test had been interrupted and plotted against the respective measured maximum stable crack growth without considering the principal error from violating the condition of monotonic loading. The points fall on lines which clearly can be extrapolated back to $\Delta a^{max} = 0$, which is the point of onset of stable crack growth again. This procedure in this case delivers a critical J-value

$$J_c = 0{,}25\ \mathrm{MN/m}.$$

But there are measurement points even below this extrapolation value. It could be shown by a detailed scanning electron microscope study [3] that these lowest J-values describe the formation of a stretch zone at the primary crack tip which can be taken into account as a quasi crack extension as indicated by the so-called blunting line $J = (R_e + R_m)\Delta a$. Following the proposed procedure of the ASTM Committee E 24 - 01 - 09 [4] the intersection of the blunting line with the R-curves delivers a maximum mean value

$$J_c = 0{,}31\ \mathrm{MN/m}$$

for this material and these conditions. The hatched area indicates stretch zone sizes that have really been found on the fracture surfaces. They are smaller than predicted from the blunting model. The limit line in Fig. 3 delivers a critical J-value of $J_c = 0{,}28$ MN/m at the intersection with the R-curve. This is about half way between the Δa against 0 extrapolation and the ASTM procedure.

Fig. 4 shows results from a series of 75 thick compact toughness specimens of the same material as in Fig. 3 but with different crack lengths. The J-values for the maximum loads are plotted against the corresponding stable crack growth averaged from 9 measurements along the crack front. The J-values are labeled J_c because the specimens broke after essentially linear load displacement diagrams at maximum load. In terms of the ASTM procedure these are valid critical J-values. The amount of stable crack growth in the predominantly cleavage fracture is much smaller than in the

thin specimens - it is in the range of permill. But it can still clearly be distinguished from the average stretch zone size Δs that has been measured by aid of a scanning electron microscope on the fracture surfaces. All points are lying to the right of the formal blunting line. The large scatter does not allow to draw a unique R-curve so that a minimum toughness value of

$$J_c = 0.09\ \mathrm{MN/m}$$

has to be assumed in this case.

This is an example to demonstrate that many problems still have to be solved before a formal procedure for the J_c-determination as offered by ASTM can be accepted.

References:

(1) Begley, J.A., Landes, J.D. (1972): The J-Integral as a Fracture Criterion, in: Fracture Toughness, Philadelphia, Pa. 1972, ASTM Spec. Techn. Publ. No 514, 1 - 23

(2) Hollstein, T., Blauel, J. G. (1978): On the Characterization of Elasto-Plastic Material Behavior Using the Concepts of Crack Opening Stretch and J-Integral Nuclear Technology, Vol 15, 297 - 310

(3) Blauel, J.G., Hollstein, T. (1978): Zur Ermittlung kritischer J-Integralwerte, Archiv für das Eisenhüttenwesen, Heft 12

(4) ASTM-Steering Committee of the E 24 - 01 - 09 Group on Elastic-Plastic Fracture: recommended Procedure for J_{Ic}-determination. March 1977

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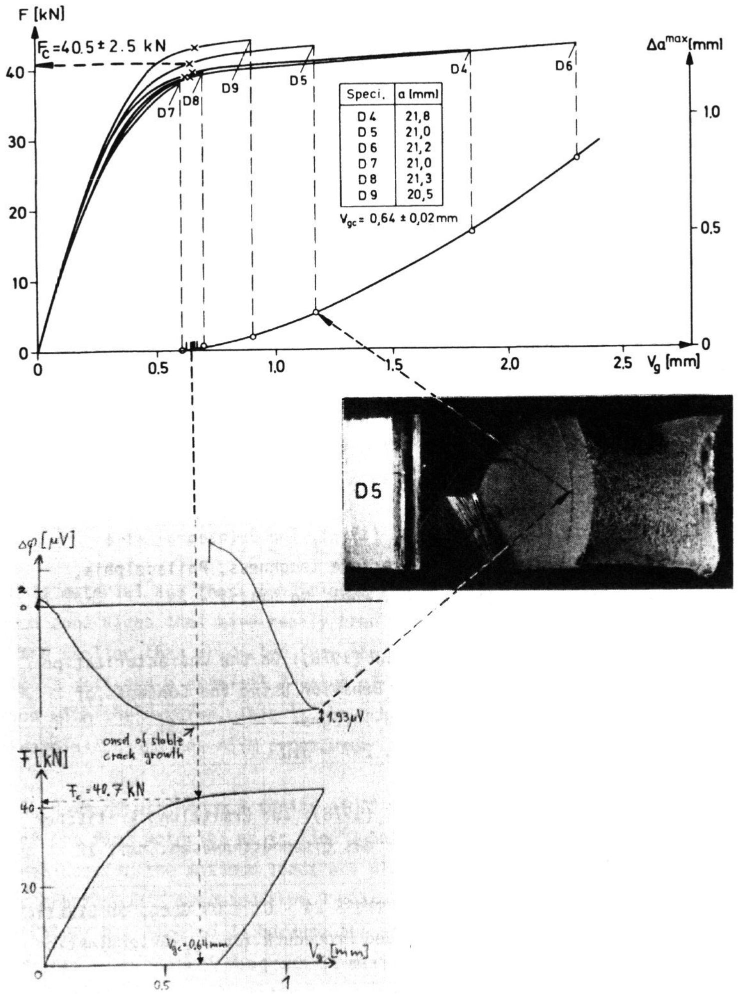

Fig. 1: Determination of critical load F_c and critical opening displacement V_{gc} by the methods of direct current potential and interrupted loading

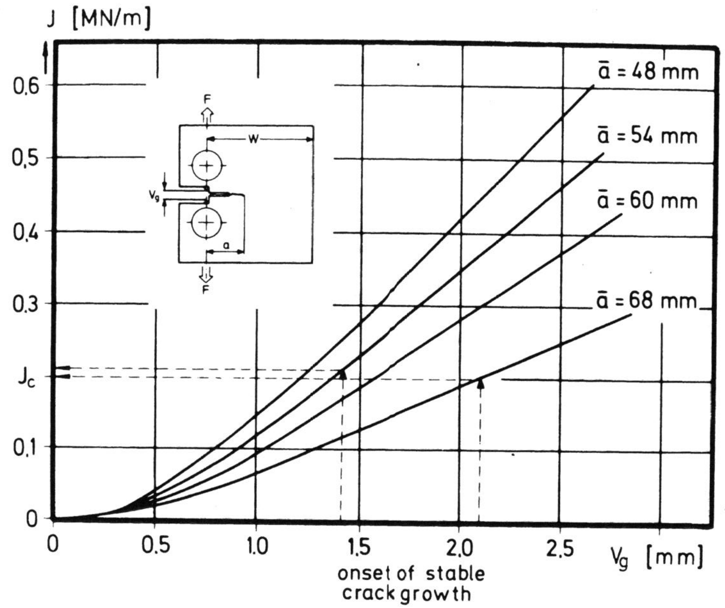

Fig. 2: Direct determination of critical J-integral value

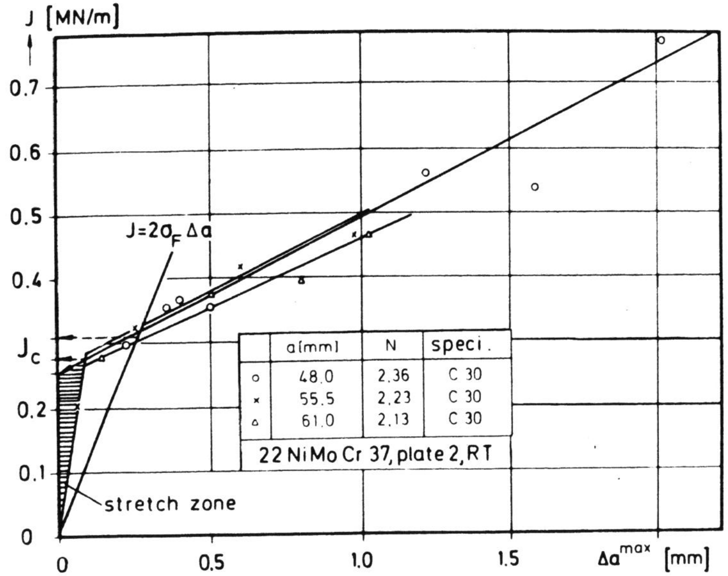

Fig. 3: R-curve procedure for determination of critical J-integral values for onset of stable crack growth

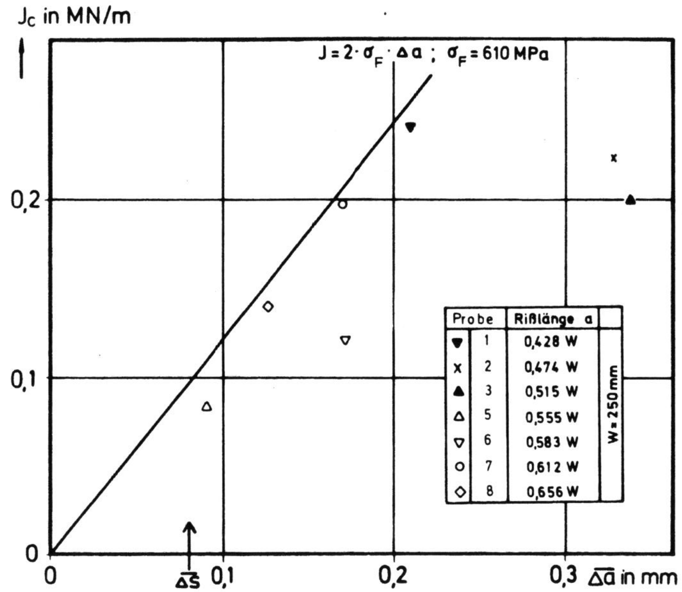

Fig. 4: Critical J-integral values for a series of C75 specimens (material as in Fig.3)