11 b. J-Determination Using SEN-Specimens for the Structural Steel St E 460 (Ni - V)

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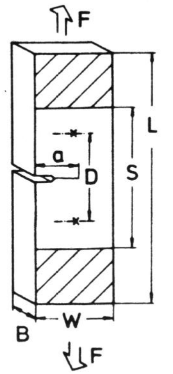
1. Introduction

As part of current research on the application of the concept of the J-integral to describe elasto-plastic failure, the following three points are considered:

1. J-determination according to the compliance method of Begley and Landes /1/ using single-edge-notched tension (SEN-) specimens,
2. determination of the critical value J_c at the onset of stable crack growth by the method of the J-resistance curve, and
3. the influence of geometric variables on J_c

2. Specimens and Material

Single-edge-notched tension specimens with thicknesses B = 10, 20, and 40 mm (SEN 10-, SEN 20- and SEN 40-specimens) were used (see Fig.1).



B = thickness (10, 20, 40 mm)
W = width (80 mm)
L = total length (850 mm)
S = free length (510 mm)
a = crack length (14 ... 48 mm)
D = gage length for the displacement reading V_g (400 mm)
F = force

Figure 1: Dimensions of the SEN-specimens used

These specimens precracked according to the ASTM-rules /2/ were clamped and loaded by jaws, as indicated by the cross hatched areas in Fig. 1.

They were taken from a 50 mm thick plate of the structural steel St E 460 (Ni - V). The chemical composition and the mechanical properties are given in Table 1.

Chemical Composition (wt %)								
C	Si	Mn	P	S	Al	Ni	V	N
.14	.33	1.59	.012	.004	.15	.33	.17	.015

Heat Treatment	Mechanical Properties			
	Yield Stress R_e (N/mm^2)	Ultimate Tensile Stress R_m (N/mm^2)	Elongation A (%)	Reduction of Area Z (%)
normalized	497	667	27	62

Table 1: Chemical composition and mechanical properties of the structural steel St E 460 (Ni - V)

The orientation of specimens was chosen longitudinal, and the direction of crack extension was transverse to the rolling direction. All tests were conducted at room temperature.

3. Results

The steps for the J-determination according to Begley and Landes' compliance method using the equation

$$J = -\frac{1}{B}\left.\frac{dU}{da}\right|_{V_g} \qquad (1)$$

(U = total strain energy)
are shown in Figs. 2, 3, and 4:

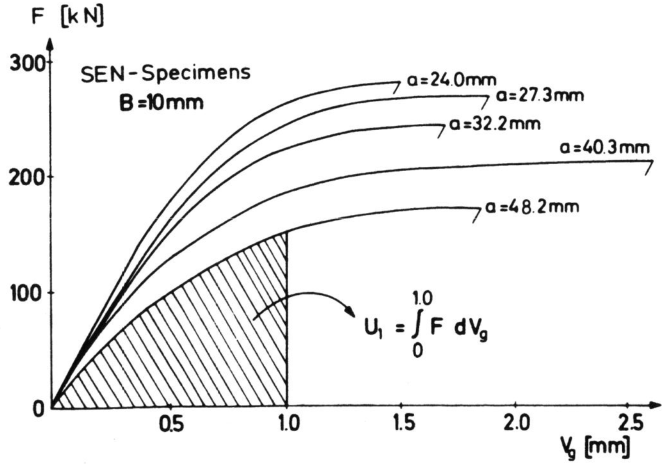


Fig. 2: Load-displacement diagrams for a series of SEN 10-specimens with different crack lengths a

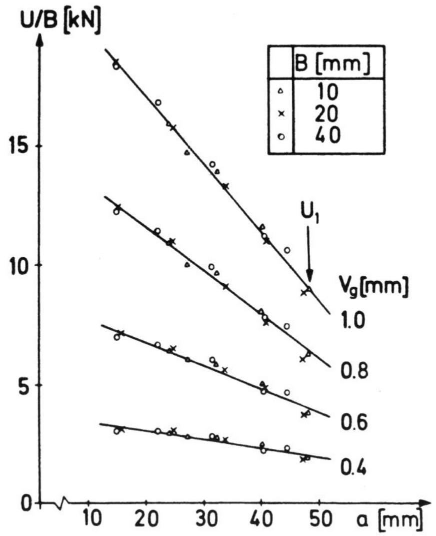


Fig. 3: Total strain energy per unit thickness for constant displacements V_g as function of crack length a for SEN-specimens with different thicknesses B

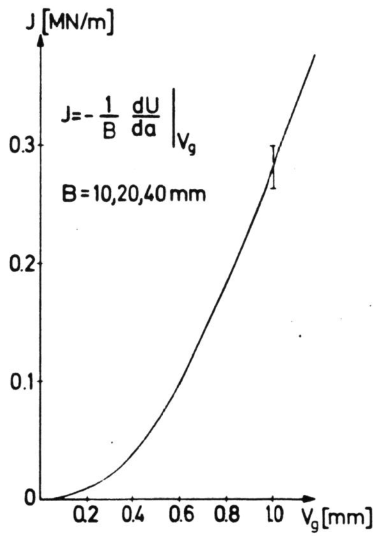


Fig. 4: J-Integral curve for the SEN-specimens

Energies U_i, which are necessary to load the specimens to different displacements V_{gi}, are determined from load-displacement diagrams, (see for example the energy U_1 in Fig. 2). These energies divided by the specimen thickness B are plotted against the crack length a (see Fig. 3). For the SEN-specimens investigated the $\frac{U}{B}$(a)-curves were straight lines for all displacements. The slopes of these straight lines give the J-Integral J (V_g) according to Eq.(1). The curve shown in Fig. 4 is independent of crack length and specimen thickness within the experimental scatter.

J_c-values at the onset of stable crack growth for the SEN-specimens were determined by use of the interrupted loading procedure /3/. Fig. 5 shows a plot of the corresponding resistance curve J (Δ a).

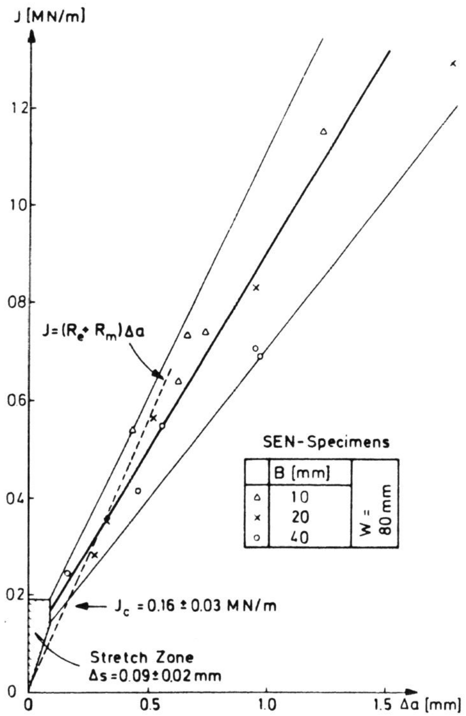


Fig. 5: Resistance curve J (Δ a)

The measurements of the crack extensions include both the stretch zone formation and the actual stable growth. From microscopic and scanning electron microscopic evaluations the stretch zone size $\Delta s = 0.09 \pm 0.02$ mm is found as indicated by the cross hatched area in Fig. 5. An extrapolation of the experimental J-Δa data to this value leads to J_c-values between 0.13 MN/m and 0.19 MN/m. Because of the steepness of the experimental scatterband a more accurate determination of J_c is not possible.

The blunting line procedure according to the recommendations of the ASTM group E 24 - 01 - 09 / 4/ yields questionable results because the blunting line

$$J = (R_e + R_m)\Delta a \qquad (2)$$

(R_e = yield stress; R_m = ultimate tensile stress), lies to the right of the actual values of the stretch zone and cannot be separated from the scatterband of the J-resistance curve.

In Fig. 6 the scatterband of the J_c-values for the SEN-specimens investigated is compared to J_c-values from 20 and 40 mm thick ASTM compact specimens (C 20 and C 40, respectively) as function of the dimensionless crack length a/W.

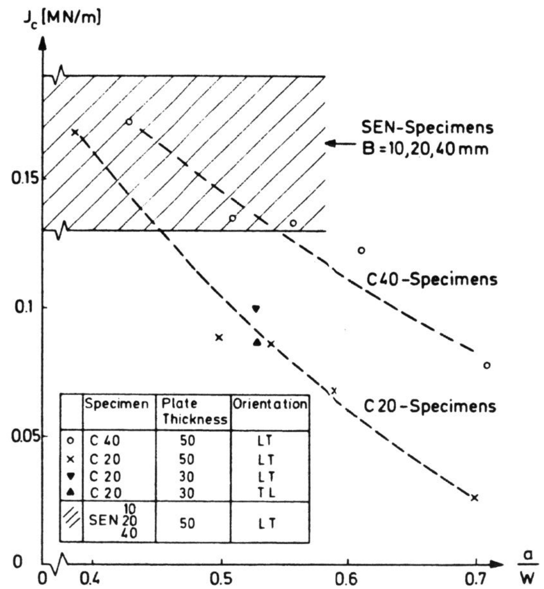


Fig. 6: Influence of geometric variables on J_c

The critical values J_c for the C 20- and C 40-specimens are determined using Begley and Landes' compliance method together with a potential method. The black triangles are mean values from two series of 4 and 6 C 20-specimens with two different specimen orientations which have been used to calibrate the potential technique in comparison to the interrupted loading procedure /3/. These C 20-specimens were taken from another 30 mm thick plate of the same melt as the other specimens.

Whereas the J_c-values from the SEN-specimens fall in a large scatter-band of $J_c = 0.16 \pm 0.03$ MN/m for all thicknesses and crack lengths investigated, the J_c-values from the C-specimens increase with growing specimen dimensions and decreasing crack lenth although the formal conditions for geometry-independent J_c-values /5/

$$W - a,\ a,\ B \leq (25 \div 50)\,\frac{J_c}{R_e} \qquad (3)$$

are fulfilled (except for the SEN 10-specimens and the factor 50 in Eq. (3)).

These somewhat unexpected results can only be understood, if one assumes, that at the onset of stable crack growth for these specimen dimensions the crack tip field is not yet J-dominated.

More experiments are under way.

4. Future Work

Future work will be

- to show,whether there is a crack length and/or thickness dependency on J_c for the SEN-specimens in the present scatter band,
- to confirm or to correct the dependence on crack length and thickness of the J_c-values for the C 20- and C 40-specimens,
- to find that range of parameter values,for which a material constant, J_c, can be determined.

5. Literature

(1) Begley, J.A.; Landes, J.D.: The J-Integral as a Fracture Criterion, Fracture Toughness, ASTM STP 514 (1972) 1 - 23

(2) ASTM E 399-74: Standard Method of Test for Plane Strain Fracture Toughness of Metallic Materials,Ann. Book of ASTM-Standards (1974) 432 - 451

(3) Blauel, J.G.; Hollstein, T.: Comparison of Different Methods for Determination of Critical J-values for the Steel 22 Ni Mo Cr 3 7; Paper presented at the Second European Colloquium on Fracture (ECF 2), Darmstadt, 9th - 14th Oct. 1978

(4) ASTM-Steering Committée of the E 24 - 01 - 09 Task Group on Elastic-Plastic Fracture: Recommended Procedure for J_{Ic} Determination, March 1977

(5) Landes, J.D.; Begley, J.A.: Test Results from J-Integral Studies: An Attempt to Establish a J_{Ic} Testing Procedure, ASTM STP 560 (1974) 170 - 184

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