LOAD CONTROL VS. DISPLACEMENT CONTROL — THEIR INFLUENCE ON THE *J*-RESISTANCE CURVE

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Two J_{IC}-multi-specimens are made, where the specimens are loaded under load control (LC) and under displacement control (DC), to investigate whether there exists an influence of the loading conditions on the shape of the J-resistance curves. The material tested was a low-strength structural steel. Both tests show the same crack-initiaton toughness, J_i, but for the LC-specimens the slope of the J-Δa-curve is larger. This means that the crack-growth toughness of the LC-specimens is larger than of the DC-specimens.

INTRODUCTION

To describe the resistance of materials against initiation and growth of quasi-static cracks in the regime of elastic-plastic fracture mechanics J-resistance curves (J_R-curves) are recorded. Here the J-integral, J, is plotted as a loading parameter over the crack extension Δa.

It is generally accepted that up to the point of initiation of crack growth, J_i, the curves are independent of the specimen geometry or loading conditions, unless certain specimen dimensions are not too small. So J_i is regarded as a material property.

In the region of stable crack growth the J_R-curve is influenced by specimen geometry. Within this region there probably exists a lower bound of the slope of the curve which fact is useful for design purposes.

The onset of unstable crack growth is known to depend on both specimen geometry and loading conditions, i.e. whether the specimen is loaded under load or displacement control.

Now the question arises whether the J_R-curves are influenced by the loading

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conditions in the region of stable crack growth, too. This is the subject of this work.

A PRECEDING PAPER

In ASTM STP 591 S. R. Novak [1] reports of a large effect of the loading conditions on the shape of stress-intensity-resistance curves (K_R-curves) for a A572 structural steel (yield strength σ_{YS} = 345 MPa, ultimate tensile strength σ_{TS} = 570 MPa). A double clip-gauge method was used to calculate the values of the crack-tip-opening displacement, COD, which were converted into K-values. For the load-controlled tests Compact Specimens were used, the displacement-controlled tests were made on Crack-Line-Wedge-Loading Specimens, see ASTM E561 [2]. The specimen width was W = 200 mm, the thickness B = 38 mm.

Fig. 1 shows some results of this work. The K_R-curves of the load-controlled tests lie above the displacement controlled tests. In all tests considerable stable crack growth was observed before "catastrophic" (cleavage?) fracture occurred (designated with a cross in Fig. 1). It is not clear why even the initiation toughness is influenced by the loading condition and why the displacement-controlled tests failed before the load-controlled tests.

The results of [1] did not get further attention,may be because the load- and displacement-controlled tests were not performed at the same machine. This is the reason why a similar test has been made in the current work.

OWN EXPERIMENT

The material investigated was a structural steel St50. The chemical composition in % is 0.34 C, 0.54 Mn, 0,33 Si, 0.019 P and 0.021 S. The tensile test resulted σ_{YS} = 260 MPa and σ_{TS} = 520 MPa.

Compact Specimens were machined according to ASTM E813 [3] with a thickness of $B = 25$ mm and a width of $W = 50$ mm. Two multi-specimen J_{IC}-tests were made on a Schenck servohydraulic machine. The tests of Series 1, (Specimens 1 to 5) were conducted under clip-gauge-displacement control. The loading rate was $\dot{v} = 0.002$ mm/s. Series 2 (Specimens 6 to 11) was tested under load control. Here the loading rate was decreased successively from 300 N/s down to 5 N/s to get about the same $\dot{v}$ as for the displacement-controlled test. Each specimen was fatigued and immediately tested to exclude a possible influence of strain-aging. Specimen 11 was loaded beyond the maximum load, though the test was performed under load control. The specimen was unloaded partially at the maximum load and re-loaded until the F-v-line became horizontal. Then it was unloaded again, and so on. For the estimate of J the unloading points were connected to determine the area under the F-v-curve.

TABLE 1: Data of the Tests Performed Under Displacement Control (Spec. 1 to 5) and Under Load Displacement Control (Spec. 6 to 11)

Spec.	a[mm]	F[N]	F_{max}[N]	v[mm]	Δa[mm]	$J\left[\frac{kJ}{m^2}\right]$
1	25.58	33700	33700	0.91	0.341	88
2	23.90	41740	41740	0.99	0.645	115
3	24.91	39220	39220	1.38	1.14	160
4	23.74	41900	43600	1.60	1.90	200
5	24.14	39810	40600	1.71	2.42	210
6	26.59	31340	31340	0.94	0.292	89
7	24.13	39400	39400	1.06	0.540	116
8	24.74	37640	37640	1.12	0.509	121
9	23.56	44730	44730	1.40	1.16	168
10	23.99	43200	43200	1.71	1.69	217
11	23.51	42280	45120	1.96	2.93	≈268

In Table 1 the experimental results are summarized, in Fig. 2 the two $J-\Delta a$-curves are presented. The two curves show the same crack-initiation toughness, $J_i = 66$ kJ/m^2, but during ductile tearing the slope of the displacement-controlled test is always lower than of the load-controlled test. So the difference in J for a given Δa increases with crack extension. Near the maximum load (between points 10 and 4) the relative difference of J is about 14%.

DISCUSSION

It should be noticed that the tests fulfill the Hutchinson and Paris [4] condition for J-controlled crack gowth which justifies the use of J for crack growth,

$$\frac{b}{J}\frac{dJ}{da} \gg 1. \tag{1}$$

b is the ligament length, $b = W - a$.

Additionally, the EGF-Recommendations [5] give the J-validity with

$$J_{max} = (b_0 or B)\frac{\sigma_f}{25} \approx 390kJ/m^2 \tag{2}$$

and

$$\Delta a_{max} = 0.06b_0 \approx 1.5mm. \tag{3}$$

Here b_0 is the initial ligament length and the flow stress $\sigma_f = \frac{1}{2}(\sigma_{YS} + \sigma_{TS})$. Within the first 1.5 mm of crack extension all three conditions are satisfied.

It has been worked out by Kolednik [4] that the crack-initiation toughness, J_i, and the crack-growth toughness are different. J_i is a kind of specific energy to produce the critical COD at the original crack tip. The crack-growth toughness can be derived from the Griffith' energy balance during crack-growth. It is connected to the slope of the J_R-curves. This can be also deduced from John and Turner [5].

So we can conclude that the crack-growth toughness of our material does depend on the loading conditions. At a given crack extension it is larger for the load-controlled test than for the displacement-controlled test. For the linear parts of the two J_R-curves (within $\Delta a \approx 1$ mm) we have $\frac{dJ}{da}$ load control= 106 MJ/m^2 and $\frac{dJ}{da}$ displ.control = 89 MJ/m^2. So the difference in the crack-growth toughness of the two tests is 19%.

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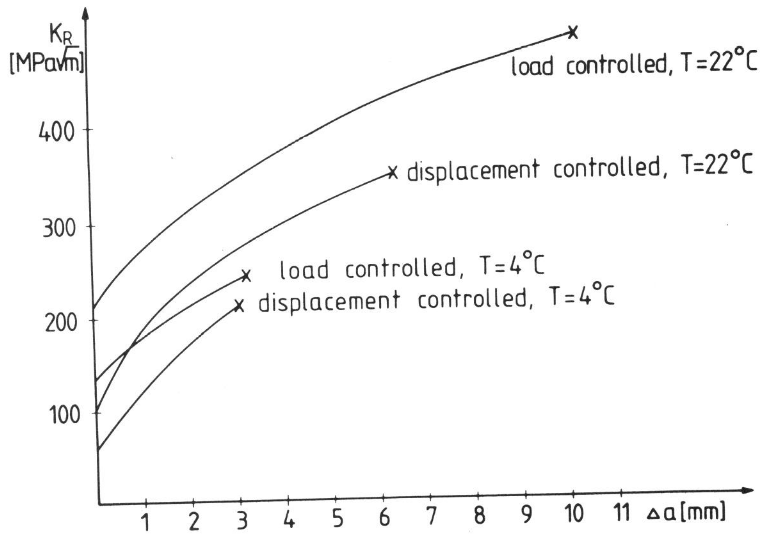

Figure 1: J_R-curves of a structural steel A572 tested under load control and under displacement control, from [1]

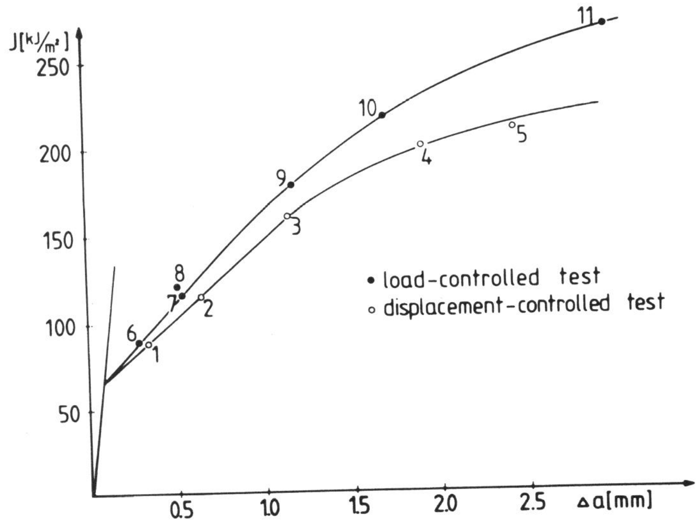

Figure 2: J_R-curves of a structural steel St50 tested under load control and under displacement control