Numerical simulation of stable growing cracks controlled by incremental path-independent integrals

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1 INTRODUCTION

In a contribution to ECF6, Erbe (1986) discussed the advantages of path-area integrals proposed by S. N. Atluri and coworkers, see Brust et al. (1985).

With respect to this theoretical basis we present results of FE calculations on growing mode-I cracks. The numerically simulated crack growth is controlled by experimental data of load line displacement, V_{LL}, vs. crack growth, Δa. The J-resistance curves obtained from the experimental load vs. load line displacement curves are compared with the numerical values of the contour integral calculated along various paths around the crack tip.

Two CT 25-specimens have been investigated with different initial and final crack lengths and different thicknesses.

The results are part of a broader study with specimens of different geometries and stable growing cracks until instability.

2 THEORETICAL CONSIDERATIONS

The formally calculated increment of J_1

$$\Delta J_1 = \int_{\Gamma_\varepsilon} [\Delta W n_1 - (t_i + \Delta t_i)\Delta u_{i,1} - \Delta t_i u_{i,1}] ds \qquad (1)$$

is equivalent to $(\Delta T_p^*)_1$, see Brust et al. (1985).

With respect to incremental plasticity, Γ_ε being the near field path (nf) and Γ some far field path (ff), we can state that

$$(\Delta T_p^*)_{1_{nf}} = (\Delta T_p^*)_{1_{ff}} + \text{some area-term} \qquad (2)$$

The area-term vanishes in deformation theory of plasticity.

The summation of these incremental terms over the load history yields J_1 and $(T_p^*)_1$, respectively. If $W = \Sigma \Delta W$ is the total accumulated stress work density then equation (1) can be used in incremental plasticity. Otherwise, i. e. by requiring W to be the strain energy density, equation (1) can be used within the limits of the deformation theory of plasticity (Moran & Shih 1986).

Choosing Γ_ε, the near field path, to evaluate $\Delta J_1 = (\Delta T_p^*)_1$ for growing

cracks care must be taken because Γ_ε must be fixed with respect to the same material points. We come back to this point later.

On the other hand the Δa-step value of the FE analysis (Figure 1) is not arbitrary as has been discussed by several investigators following theoretical studies by Rice in 1966, see Nakagaki, Chen and Atluri (1979).

With these considerations in mind we try to give hints in our short study supporting the presumption that the near field values of J_1 or $(T_p^*)_1$ become constant on a level independent of the FE-mesh and the specimen geometry.

3 NUMERICAL INVESTIGATIONS

Our numerical calculations are based on experimental data got from compact tension specimens (Table 1). Incremental plasticity is used with v. Mises yield condition and small deformations are assumed (material nonlinearity only). The calculation is controlled by the experimental loadline displacement vs. Δa-curve and can be verified by comparison of the numerically with the experimentally obtained J vs. Δa-curve.

We used six different paths for the evaluation of the contour integral (Figure 2). Two of them are near field paths. Path 1 runs around the crack tip moving with the growing crack and, hence, passes different material points for each Δa. Path 2 surrounds the crack tip for the whole process of crack extension and is fixed to the same material points. Path 6 lies in the far field whereas the paths 3, 4 and 5 lie somewhere in between. The results of the numerical values together with the experimental J-resistance curves are shown in Figure 4a, b for both specimens.

The calculated J-values of path 1 tend to zero after initiation of crack growth supporting the presumption that J_{nf} levels against a constant value with further stable growing of the crack (results of path 2). The plane stress results of specimen #1 (Figure 4a) can be interpreted in this way showing the same qualitative tendency of the plane stress calculations of Brust et al. (1985). The results of our plane strain calculations for specimen #2 (Figure 4b) are somewhat different. The J-values of paths 2, 3 and 4 do not remain constant but start to decrease after some small amount of crack growth.

On the other hand, the stress field in the ligament is not altered significantly within the course of stable crack growth after initiation but just shifted by Δa (Figures 5a, b), in a similar way as the crack tip opening displacement is (Shih, deLorenzi and Andrews 1979 and Figure 3).

Clearly, these few calculations are not sufficient to confirm or disprove the presumption that the near-field values of J_1 and $(T_p^*)_1$, respectively, tend to a constant value with the growing crack. We cannot yet exclude the influence of the specimen geometry and FE-mesh size on the results. This is the aim of further investigations.

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Table 1: Geometries and material data of the investigated compact specimens CT 25

No	experimental results	W mm	B mm	a_0 mm	Δa_{max} mm
1	GKSS	50	5	25.3	6.7
2	BAM	50	25,sg 20%	29.4	2.8

	material	σ_{yield} MPa	J_i N/mm	FEM calculation
1	35 NiCrMo 16	431	22	plane stress
2	20 MnMoNi 55	459	156	plane strain

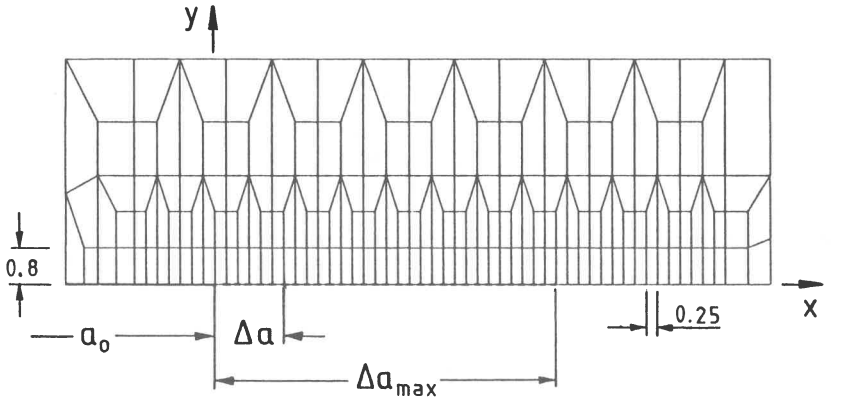

Figure 1. Detail of the FE mesh in the vicinity of the growing crack

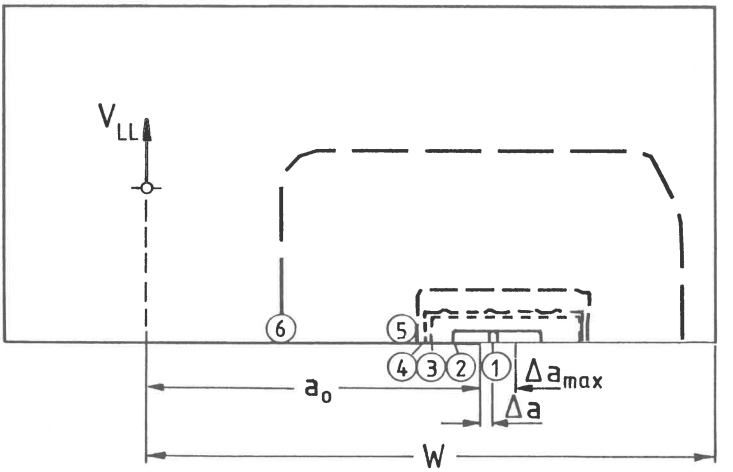

Figure 2. Upper half of the compact specimen with integration paths for the evaluation of J-integral

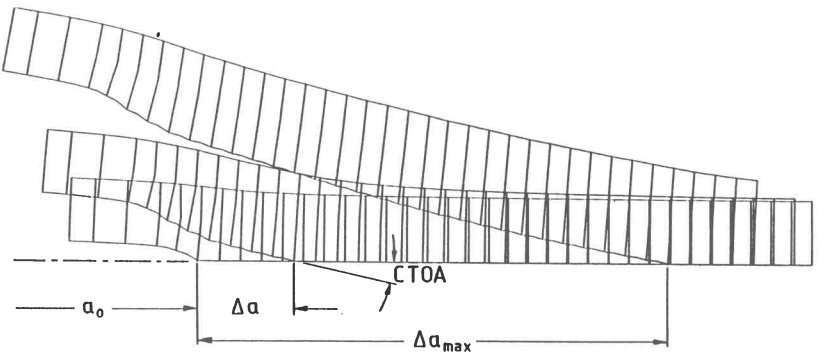

Figure 3. Deformed FE mesh in the vicinity of the growing crack at initiation, some Δa and Δa_{max}, respectively.

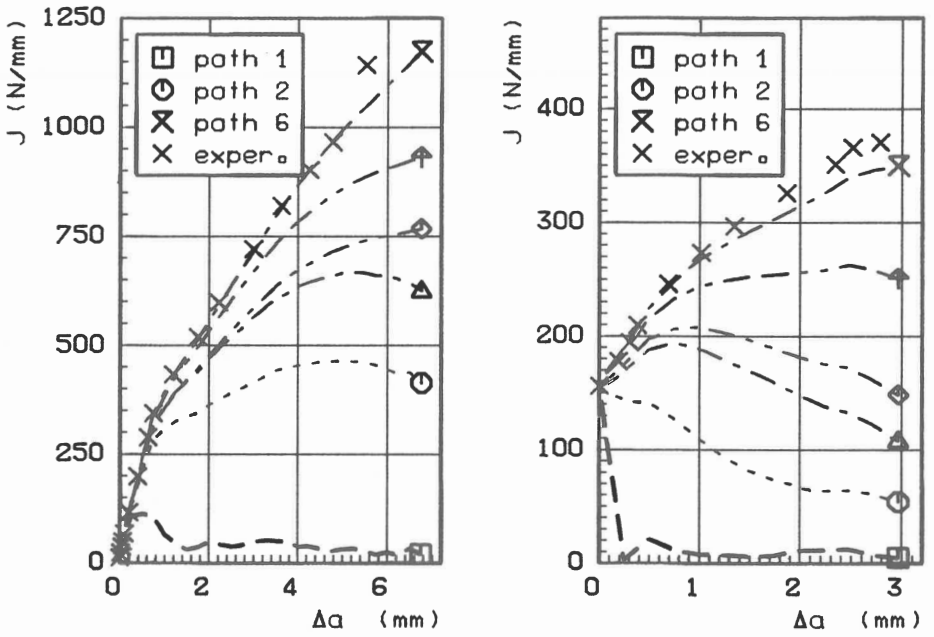

Figure 4. J-integral vs. crack growth, numerical and experimental results for

a) specimen #1 b) specimen #2

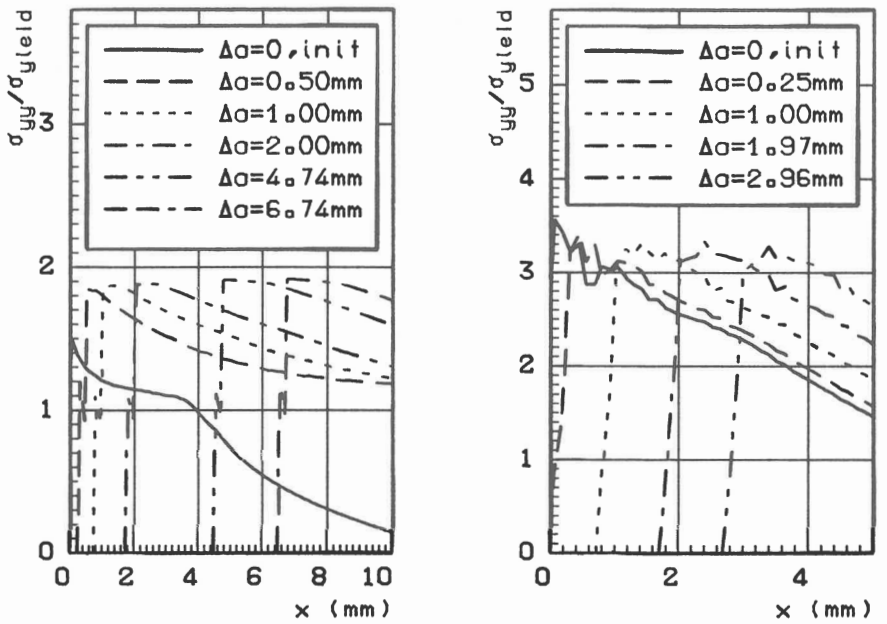

Figure 5. Normal stresses σ_{yy} in the ligament ahead of the growing crack for

a) specimen #1 b) specimen #2