INVESTIGATION ON THE INFLUENCE OF COMPONENT GEOMETRY ON STRESS STATE USING 3-DIMENSIONAL ELASTIC-PLASTIC FINITE ELEMENT ANALYSES

C. Hafer and W. Dahl*

The effect of component geometry in fracture behaviour has been investigated numerically by using three-dimensional elastic-plastic finite element analyses for wide plates containing defects. By changing the geometry the local state of stress, which is responsible for the fracture behaviour, is varied. The results are discussed in terms of the J-integral. Mean values and the distributions along the defect fronts across the thickness are considered. Special emphasis is given to the discussion of the local stresses, strains and a stress state characterizing constraint quantity.

INTRODUCTION

Failure predictions of cracked components in the elastic-plastic region require the application of safety concepts based on fracture mechanics. Quantitatively good predictions of the component behaviour may only be obtained if the conditions of (critical) toughness values determination and the component situation are adapted. For such an adjustment it is necessary to know the local state of stress near the crack tip quantitatively. For that purpose systematic three-dimensional elastic-plastic FE-analyses of tension loaded wide plates with regard to the local loading situation have been performed.

DESCRIPTION OF GEOMETRIES, MATERIAL AND FE-CALCULATIONS

To study the influence of component geometry on stress state several DECT-plates were analysed. By variation of thickness and crack length different loading situations were simulated. Firstly, the thickness has been varied between 10 and 100 mm. Because

* Institut für Eisenhüttenkunde der Rheinisch-Westfälischen Technischen Hochschule Aachen, Intzestraße 1, D-5100 Aachen.

realistic defects, i.e. short cracks were of special interest, wide plates with a total crack length of 2a=5 mm and a width of 300 mm have been investigated. Secondly, the variation of a/W-ratio with crack lengths of 5, 10, 20, 30 and 60 mm followed for 30 mm thick and 300 mm wide DECT-plates. A Fe 690 steel was used for this investigation. The computations for the wide plates were performed at a temperature of T=293 K with a corresponding yield stress value of R_{eL}=736 MPa. At this temperature a J-integral value of 95 N/mm has been determined experimentally at crack initiation.

The elastic-plastic displacement controlled computations were performed by the general purpose finite element program ABAQUS by Hibbit et al. (1) apllying the von Mises yield conditions and isotropic strain hardening. Small strain theory (J-analysis) as well as large strain theory (stress analysis) have been used. J-integral values were calculated with the virtual crack extension method after Parks (2). The uniaxial stress-strain curve was represented by a multilinear approach. Herein the experimentally observed Lueders-strain region was taken into account. Young's modulus and Poisson's ratio were taken to be E = 210 GPa and ν = 0.3, respectively.

For the three-dimensional calculations isoparametric 20-noded elements with reduced integration were used. Around the crack tip these elements were collapsed to produce a 1/r-singularity in the strains. In contrast to an only J-integral aimed FE-analysis the two-dimensional basic meshes for the wide plates are substantially refined especially in the crack tip region to calculate meaningful local stress distributions, see the insert in Figure 1. The part around the crack tip with element sizes of 0.1, 0.15, 0.25, 0.35, 0.5 and 0.75 mm is identical for all calculated wide plates. By reason of symmetry conditions only one eighth of the wide plates has to be modelled in the 3-D case using 5-7 element layers for half the thickness.

The 30 mm thick specimens are devided in 5 layers with element thicknesses of 7.5, 4.0, 2.0, 1.0 and 0.5 mm. This division has been scaled down for the 10 mm and 20 mm thick wide plates. Thicknesses of 60 mm and 100 mm have been reached by adding further element layers, i.e. one and two, respectively, in the midplane. Therefore the fine division in the near surface region is identical.

RESULTS

Subsequently the local loading situation of the investigated geometries will be discussed. Besides local J-integral results along the crack front special emphasis will be given to the discussion of local stresses, strains and stress state characterizing constraint quantities, e.g. the ratio of the mean (hydrostatic) stress to the equivalent (von Mises) stress.

The results were established at the begin of stable crack growth, when the mean J-integral value J_m reaches the initiation value J_i. The J_m values represent, of course, mean values of the distributions along the defect fronts across the thickness evaluated by 3-D FE-computations and can be compared to experimentally obtained J-values.

Local Stresses and Constraint

As a first result the distributions of the opening stress σ_y along the defect fronts are presented in Figure 1. These curves are plotted at those x-positions, at which $\sigma_y = \sigma_y(x)$ in the mid-plane reaches its maximum value. Due to the different geometries and the different amounts of plastic deformation these positions are not identical for all the solutions.

For a constant crack length ratio of 0.017 (Figure 1a) the maximum opening stresses in the mid-plane are laying close together. Across the thickness the stress values remain nearly on a constant level over a wide area, which size is extended with increasing thickness. Longer cracks lead to higher opening stresses, see Figure 1b.

In order to describe the multiaxiality of the stress state there exist different measures of the local constraint which may be used conveniently for different fracture mechanisms. For brevity only the so-called h-value is discussed in this paper. The distributions along defect fronts for the state of crack initiation in Figure 2a show that at least near the mid-plane the h-values of the different geometries arelaying very close together. In the 10 mm thick wide plate the constraint decreases strongly whereas it falls more slowly in the thicker plates. For longer cracks the constraint has much higher values, particularly near the mid-plane. Qualitatively this is the same result as for the σ_y-distribution.

Fracture Mechanics Loading Parameter J-integral

In Figure 3a the J-distributions along the defect fronts are presented for the different thick plates. In the 10 mm thick specimen, the local J-integral has its maximum value in the mid-plane of the specimen and then decreases to the surface as expected. For B = 20 mm the J-integral value in the mid-plane stays nearly constant over half the ligament. In the thicker plates the J-Integral raises from the mid-plane, reaches a maximum value and then decreases strongly. With increasing thickness this maximum is shifted nearer to the specimen surface with higher local J-integral values.

This behaviour can only be found for very short cracks. With the increase of crack length ratio the expected J-distribution with maximum values in the mid-plane of the specimens appears again, see Figure 3b.

The occurence of a maximum out of the specimen mid-plane cannot be explained with the existing stress distribution. Therefore the local strains in the ligament have to be taken into account.

The highest strains occur directly in front of the crack. They raise with decreasing thickness because of the lower constraint. Figure 4 shows the local strains across the thickness. Compared to Figure 3, similar distributions can be observed. But there are some differences. The maximum values of strains lie closer to the mid-plane of the specimens.

This originates from the playing together of stresses and constraint. Just at the decrease of constraint the raise of strains is possible, but only on the necessary condition of sufficient high stresses. Therefore the strains near the surface have lower values.

SUMMARY AND CONCLUSION

The results of detailed 3-D J-integral and stress analyses show that the geometry of a component has a strong influence on the local distribution of stresses, strains, constraint and the fracture mechanics loading parameter J-integral. Only the local stress and stress state provide an explanation for the failure behaviour of cracked components. For that reason the local stress state has to be taken into account for a safety assessment of a structural component.

REFERENCES

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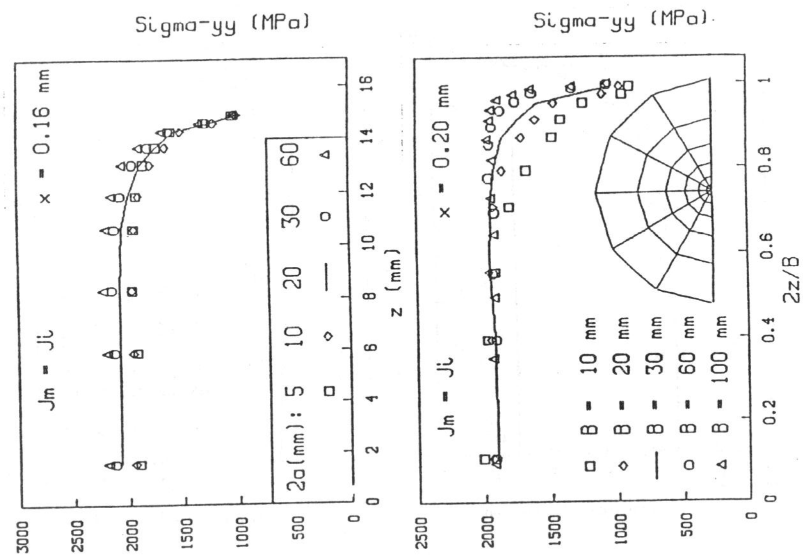

Figure 1. Defect opening stress across the thickness

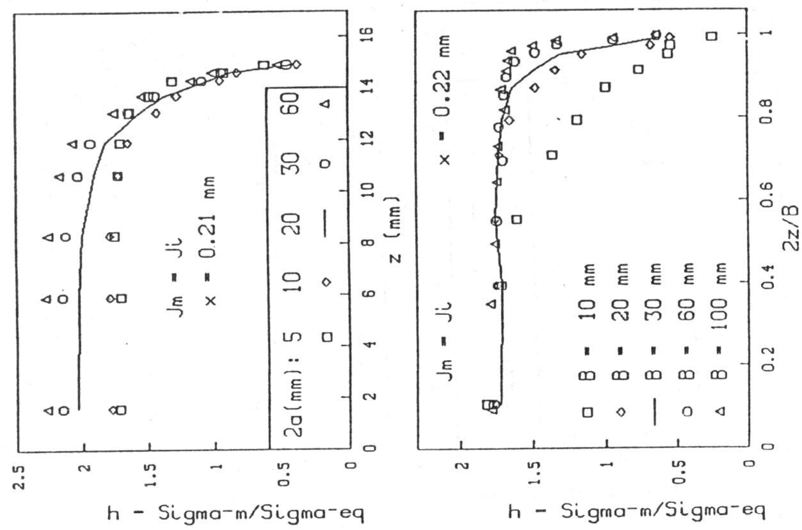

Figure 2. Multiaxiality of stress state across the thickness

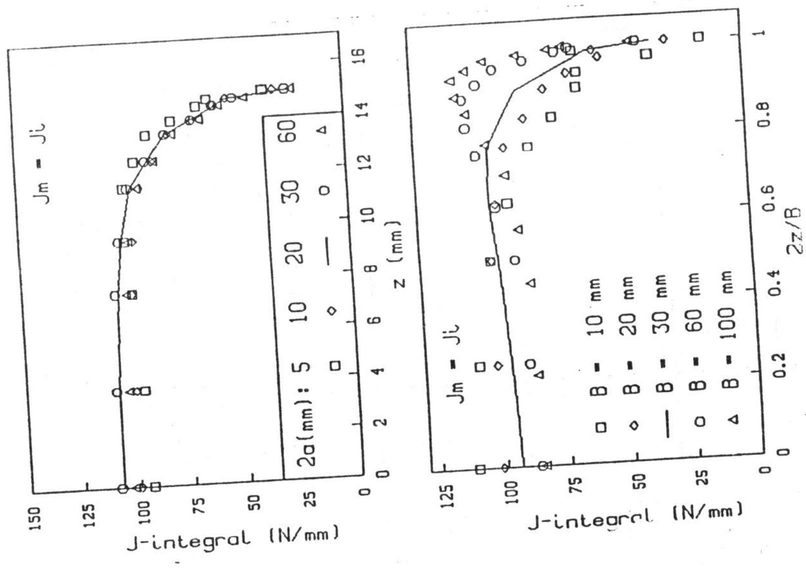

Figure 3. Local J-distribution along the crack front

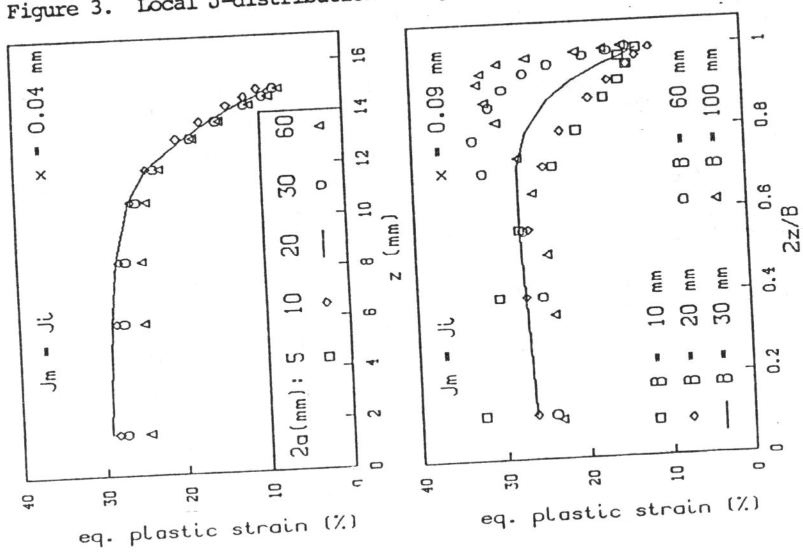

Figure 4. Equivalent plastic strain across the thickness