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# On the role of process regions at stationary and growing cracks

AKADEMISK AVHANDLING

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av

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# ON THE ROLE OF PROCESS REGIONS AT STATIONARY AND GROWING CR

The thesis comprises the following parts, refered to below as papers I

I. 'On the small crack fracture mechanics' International Journal of Fracture 22 (1983) 203-216.

II. 'On the formation of necks at crack tips under plane stress conditions' Proceedings of the 3rd International Conference on Numerical Methods in fracture Mechanics, Swansea (1984) 353-362

III. 'A one step solution technique for elastic-plastic self-similar problems' Report from the Division of Solid Mechanics, TFHF-3015, Lund institute of Technology, Lund, Sweden (1985).

IV. 'Using elastic-plastic plane stress programs to calculate anti-plane strain' Report from the Division of Solid Mechanics, TFHF-3016, Lund institute of Technology, Lund, Sweden (1985).

V. 'Process region characteristics and stable crack growth' Report from the Division of Solid Mechanics, TFHF-3019, Lund institute of Technology, Lund, Sweden (1985).

## Introduction

Studies of crack behaviour and fracture are generally perforn
continuum analysis. Thus the process region is either not conside
assumed to be point-sized. In the latter case it is often ascribed a
property, usually the ability to consume energy.

A major step towards the understanding of the fracture process wa
as the concept of the autonomy of the near tip field was introdu
Barenblatt [1]. He also introduced a cohesive modulus as a descriptio
material behaviour in the crack tip vicinity. This implied again t
process region was small in some sense. In an elastic surround
smallness of the process region must be related to some sig
geometrical length, usually the crack length. This introduces the
about what happens in the case of small cracks. Paper I tries to ansv

question.

For an elastic-plastic material it is logical to compare the size of process region with the size of the plastic region. One then finds that process region often is big enough that its extension must be considered. such case is necking in thin plates. In this case the process region - necking region - is determinable by continuum mechanics, i.e. the m structure does not play the same role as it does for instance at plane st The necking phenomena near crack tips is studied in paper II.

At plane strain (in the crack tip vicinity) the decohesion canno described by means of continuum mechanics. Micro-structural processes, instance formation and opening of voids or micro-cracks play an impor role. However, simple models of the process region can be designed for us analysis. The model used here is the Barenblatt line model, but its lengt not regarded as small compared to all other significant length dimensi The discontinuous behaviour is modelled by a relationship between boun stress and displacement and not between stress and strain as for a continu

In order to perform some investigations for the early stages of development of the process region a method was devised by which the loa finite element computation could be applied in one single step instea several steps as is normally required. This technique is described in p III.

Since most elastic-plastic mode I crack problems cannot be so analytically there could be some doubt about the finite element (FEM) used. In paper IV a method is described in which a FEM code develope in-plane stresses can be modified for solution of anti-plane strain probl For anti-plane strain there are several analytical solutions available to c problems (mode III problems). This gives an opportunity of indirect testi the in-plane FEM code. As a by-product paper IV envisages methods modifying, the FEM code for other problems, for instance heat conduction.

Paper V deals with mode I, plane strain. The early stages of development of the process region, its development to instability and steady-state case are investigated. Both large and small cracks considered.

## Necking in thin plates

Necking is the dominant process at fracture of thin plates. This continuous cross-sectional slip and needs a three-dimensional analys fully understood. Dugdale [2], however presented a solution for a crack developing necks by using a two-dimensional approach. He assumed that plasticity was confined to a narrow line shaped region the crack tip.

Drucker and Rice [3] later argued that the Dugdale model is c only at plane stress and the Tresca flow rule. At plane strain the stress exceeds the yield stress in regions off-side the necking reg both Tresca and von Mises materials. At plane stress the effective less than the yield stress for both materials in the whole plane out necking regions. However, since the plastic flow rule implies tha increments should be normal to the flow surface a Dugdale region i Mises material is impossible, at least at uni-axial remote stress. It possible for the author to show that the Dugdale solution is e consistent with the Tresca yield criterion for very small cracks (unp work), since the effective stress is exceeded in regions near the cent crack. A natural development is therefore to consider the plasticity the necking region. Numerical solutions for von Mises materials reve diffuse plastic zone develops ahead of the crack tip, see e.g. Swedl [4]. They, however, could not consider the possibility of necking be their two-dimensional analysis.

In paper II, a finite element analysis, the developing necking re modelled by means of a slowly progressing node release. Both Tresca Mises materials were investigated. It was possible to show conditions for necking are fulfilled for both Tresca and von Mises m For both materials the necking region was generally embedded in region. For a certain ratio of hardening modulus versus yield stre Tresca material plasticity was absent outside the necking region. cases a diffuse plastic region appeared together with a necking whereas for the non-hardening von Mises material, a diffuse plas resulted together with a vanishing necking region. The results c those obtained by Hutchinson [5], who did not consider the possi necking.

## The role of the process region in an elastic surrounding

For a pilot study of the role of the process region (paper I) linear elasti was assumed throughout together with a line shaped process region. somewhat different models of the cohesive properties of this region were with rather small differences in results. On the other hand the re obtained with these reasonably realistic process region models (i.e. finite cohesive strength) turned out to be very different from re obtained by assuming a point-sized process region, especially for s cracks. Even for cracks with the minimum length allowed by ASTM-convention for linear fracture mechanics the difference was substa - about 5 per cent as regards the critical load. Fig. 1 shows the rela difference in critical load as predicted by large crack fracture mecha (the so called linear fracture mechanics) and as found by use of one of process region models in the study.

The procedure used allows treatment of arbitrarily small cracks, eve the infinitesimal limit.

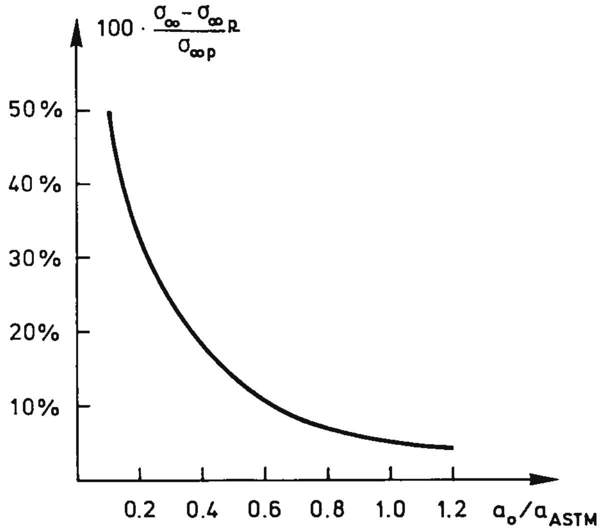

Figure 1. The relative difference in maximum remote stress $\sigma_\infty$ as predi by large crack fracture mechanics and a process region model. $a_{ASTM}$ i minimum crack half-length allowed by the ASTM-convention.

## FEM-treatment of self-similar elastic-plastic problems

In elastic-plastic cases at plane strain finite element computatic generally very laborious because the load has to be increased in increments. This also has a negative influence on the numerical ac However, in a few cases the load can be applied in one single step cases are the steady-state and cases of self-similarity. The early st the development of the process region are characterized by self-sim This implies that the same solution holds, apart from a length scale for all different stages. Of course, at the development of the process this is only approximately true and only in a sufficiently close neighb of the crack tip.

A characteristic feature of self-similarity is that the whole histor development is embedded at each instant in the current stress-strai This fact is taken advantage of in paper III which contains the desi method whereby the load can be applied in one single step. The me used in paper V.

## On the control of the accuracy of the FEM code

Very few analytical solutions exist for mode I and II crack problems, a few such solutions are available for mode III. Therefore control of t code is difficult. In existing FEM codes for elastic-plastic p specializations to in-plane stress and strain are common but seldom anti-plane strain case. However, a way was detected to use the FEM c plane stress in anti-plane strain computations without any changes program, but simply by making certain specializations, translatio interpretations of variables and parameters. The procedure is descr paper IV. An indirect control of the FEM-code used was made by treat Hult-McClintock [6] problem. The accuracy turned out to be very goo displacements on the crack surfaces were found to coincide wi analytical solution with a maximum error of 0.2%.

As a by-product a way was found to adopt a plane stress FEM solutions of problems in general which are governed by the Poisson ec As an illustration a problem of stationary heat conduction was treated a maximum error of less than 0.2% in temperatures along a certa resulted.

## The role of the process region in an elastic-plastic surrounding

Paper V deals with the development of the process region, stable growth and onset of global instability for both long and short cracks investigation is carried out by means of finite element methods.

Four different types of materials were studied. After some investig the influence of the strain hardening turned out to be fairly small i range of practical interest. Therefore - and also due to some circumstances - the number of material types was reduced to two, dif only as regards the cohesive strength of the process region.

For one material the cohesive strength was put to $\sigma_D = 3\sigma_Y$ where the yield stress. This corresponds approximately to the maximum po cohesive strength in the plastic region when strain hardening is very For the other material the cohesive strength $\sigma_D = 2.5\sigma_Y$ was chosen.

The difference in cohesive strengths may appear to be small, turned out to imply quite remarkable differences on the shape of the p zone, on the process region size, on the amount of stable crack growth a the instability (fracture) load. The plastic region size was compara smaller for the material with the lower cohesive strength. The process was larger than the forwards extension of the plastic zone for this mat but it was not so pronounced for the material with the higher co strength. Figs. 2-3 show the plastic and process regions for the two mat

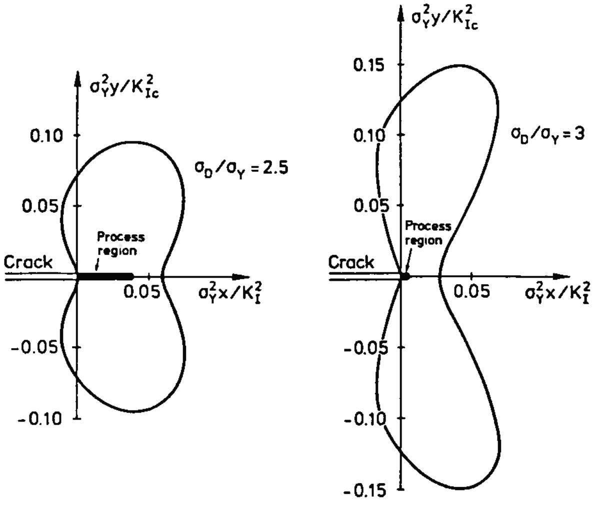

Figure 2. Plastic and process regions at the early stages of the deve process region.

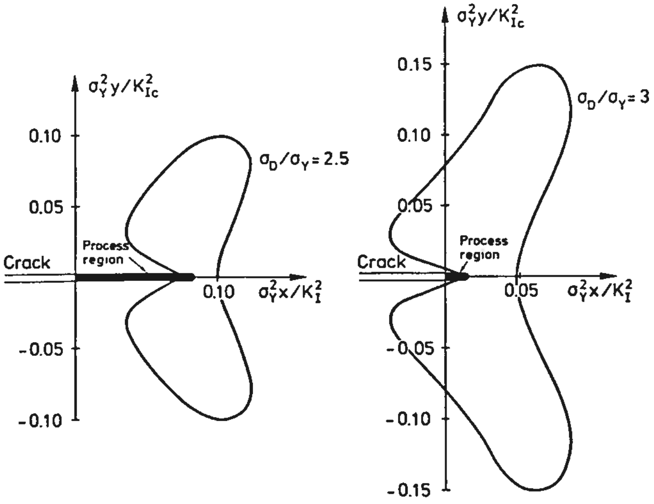

Figure 3. Plastic and process regions at steady-state.

at the early stages of the development of the process region and at state conditions.

The energy consumed in the process region per unit of crack gr remarkably large. Thus it amounts to about 80% of the total dissipated for the material with the lower cohesive strength and to more than h energy for the material with the higher cohesive strength The rel large extension of the process region and its dominating role in the dissipation implies that analyses of stable crack growth carried out un assumption of a vanishing small process region should be regarde caution. The existence of a HRR-singularity at stationary cracks existence of a ln(r)-singularity at moving cracks should therefore taken for granted. This has been pointed out earlier by Broberg [7].

The influence of the cohesive strength on the fracture toughness out to be more pronounced than a proportional one. The progress seems to be due to the influence of the process region characteristics plastic region. Thus, see Fig. 3, low cohesive strength seems to c 'embrittlement', since obviously the development of the plastic re impeded.

Small cracks are studied as well as large cracks. The amount o crack growth decreases, as expected, with decreasing length of the crack. Probably, for very small cracks the stable phase dis completely as found in the pilot study, paper I. However, cracks small to induce such a result were not studied.

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