GOVERNING PARAMETERS FOR SUB-CRITICAL CRACK-GROWTH ANALYSIS IN AREAS OF HIGH NOMINAL STRAIN

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ABSTRACT

The objective of the present study is to look for the governing parameters for subcritical crack growth analysis of cracks in areas of high nominal strain. An elastic-plastic finite element analysis of cracks emanating from an edge notch in a plate under bending forms the basis for assessment of various stress and strain intensity factors.

A new intensity factor based on the stress and strain field is recommended.

KEYWORDS

Subcritical-crack-growth; generalized plasticity; stress-intensity-factor; strain-intensity-factor; J- Integral, finite element analysis; cracks at notches.

INTRODUCTION

The main objective of the present study is to establish a simple and validated method of analysing crack propagation under conditions of generalized plasticity. Out of the four models generally used in the literature viz :

- Tomkins model (Tomkins 1968) based on the C.O.D.
- Wareing Tomkins model (Wareing 1978)
- Model based on the J - Integral (Dowling 1977, El Haddad et al. 1980, Mowbray 1976, Vardar 1982)
- Solomon - Model (Solomon 1982) based on the total deformation giving K_{ε} .

The last two fulfil the conditions of simplicity and the compability with the LEFM case and have been validated against a number of test results.

The advantage of using K over K_J (S.I.F. based on $\mathcal{J}$ - Integral) is however certain as far as the evaluation is concerned since various handbook results are available for a variety of geometry and loading conditions.

In the present study, we have attempted to compare various intensity factors for a particular geometry and presented a simple parameter which gives a reasonably good approximation of K_J.

GEOMETRY

The analysis is carried out on a single edge notched plate sujected to bending. Fig. 1 shows half of the structure. The choice of this geometry was guided by two reasons :

- bending type loading is quite common in Fast Breeder Reactor components
- circular notch permits simulation of stress and strain concentrations in the structure.

Three cracks were analyzed at the edge of the notch representing 50 %, 100 % and 150 % of the notch radius.

MATERIAL CHARACTERISTICS

Material used is a type 316 L stainless steel of French denomination 316 SPH.

Its mean properties at 20 °C are :

Yield stress	σ_y =	275 MPa
Ultimate stress	σ_u =	582 MPa
Young's Modulus	E =	192 GPa

Table 1 shows the rational strain hardening properties of the material.

TABLE 1 : Strain-hardening characteristics

σ MPa	175	250	270	290	320	425	863
ε_{pl}%	.0017	.0722	.1610	.3388	.9448	4.779	40.55

LOADING

Only monotonic loading was applied. The case of cyclic fatigue loading will be included in discussion. The analysis was conducted in plane-stress using a non-linear finite element programme NOVNL with normality rule, Von Mises criterion and isotropic hardening. The load was increased incrementally with the maximum applied stress at the edge of the plate given by :

$$\sigma = \lambda \cdot 100 \text{ MPa.}$$

The values of λ^{max} for the four cases analyzed (uncracked structure and three cracks) were respectively 4.0 ; 3.5 ; 3.0 and 3.0. The finite element model has 402 4-node elements and 477 nodes (Fig.1).

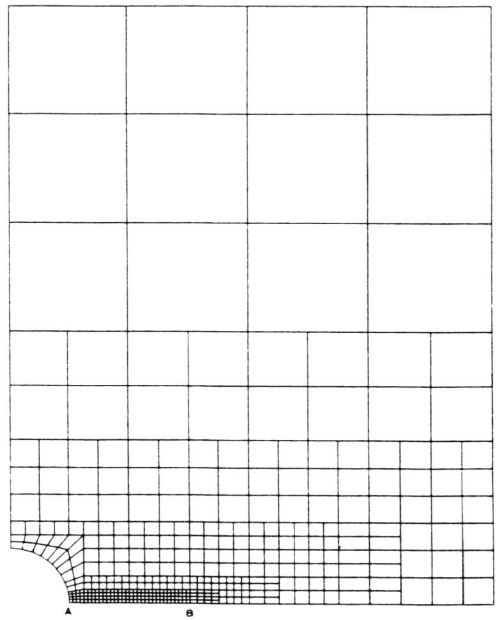

FIGURE 1 - GEOMETRY

RESULTS OBTAINED

Uncracked structure : Figures 2, 3 and 4 show respectively the stress, the strain and the plastic zone distribution in the ligament ahead of the notch for various values of λ. The results of figs 2 and 3 were later used to compute the values of K_σ and K_ε , K_σ being the S.I.F. corresponding to the application of the computed stress σ^{yy} on the prospective crack surface and K_ε , as already mentioned, corresponds to a fictitious stress of $E\,\varepsilon^{yy}$

Cracked structure : Table II shows the evolution of the $\mathcal{J}$ - Integral as a function of loading for the three cracks analyzed. Considering the radius of the notch as 1 mm, the units for the $\mathcal{J}$ - Integral are N/mm. The values given here are averaged over five contour-integrals all of which showed good stable values within 4 %.

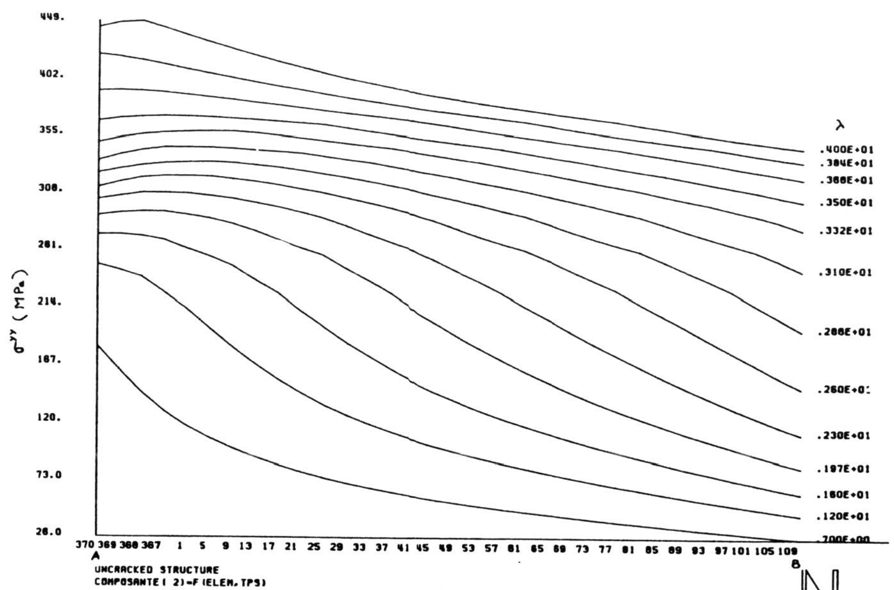

FIGURE 2

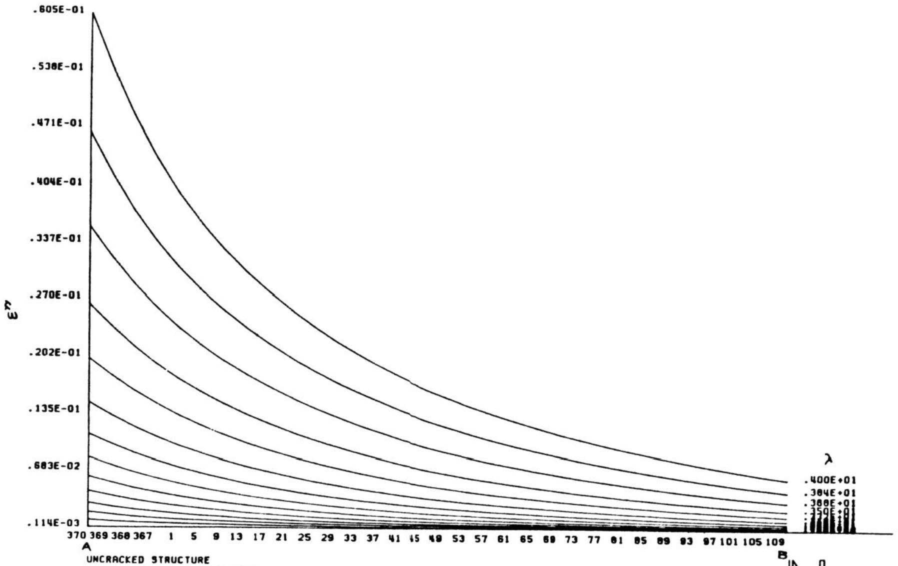

FIGURE 3

Table II : J- Integral as a function of load

λ	1.0	1.5	2.5	2.25	2.5	2.7	3.0
$J_{0.5}$	0.250	0.644	1.314	1.900	2.660	3.556	5.915
$J_{1.0}$	0.392	0.950	2.130	3.180	5.05	7.750	16.18
$J_{1.5}$	0.540	1.438	3.752	6.850	14.10	25.20	51.98

In order to compare various intensity factors, the following were computed :

- K_J : S.I.F. derived from the J- Integral results.
  $K_J = \sqrt{E.J}$ (plane stress)
- K_{el} : Elastic S.I.F. obtained from first loading step which is elastic
- K_{cp} : Plasticity corrected S.I.F. Usually in literature, the plastic correction is based on the Irwin's formula :

$$K_{cp} = K\ (a + r_y)$$

where $r_y = \frac{1}{2} \left(\frac{K}{\sigma_y} \right)^2$ (plane-stress)

- K_σ (K_ε) : Elastic S.I.F. based on the application, on the crack faces, of the computed stress σ^{yy} (ε^{yy}) in the uncracked structure. K_σ, K_ε are evaluated numerically.
- $K_\gamma = \sqrt{K_\sigma K_\varepsilon}$ representing the geometric mean between K_σ and K_ε
- $K_{\gamma c}$: Plasticity corrected K_γ . In view of the fact that K is based on the non-linear stress-strain behaviour using the strain hardening characteristics of the material, it seemed appropriate to base the plasticity correction on the Flow-stress of the material :

$$\sigma_F = (\sigma_y + \sigma_u)\ /_2$$

Fig.6 and 7 show the various intensity factors for the three cracked geometries analyzed.

DISCUSSION OF RESULTS

Considering K_J as the standard for comparison, it will be noted that :

- K_{cp}, the plasticity-corrected elastic S.I.F. commonly used in the literature underestimates K_J more and more as the nominal strain in the prospective cracked region increases.
- K_ε , the strain-intensity-factor highly overestimates the crack behavior at least for two cracks ; the higher the nominal strain, the higher the conservatism. Moreover, as the crack moves out of the influence of notched plasticity (the third crack), K_ε is no longer conservative since it is

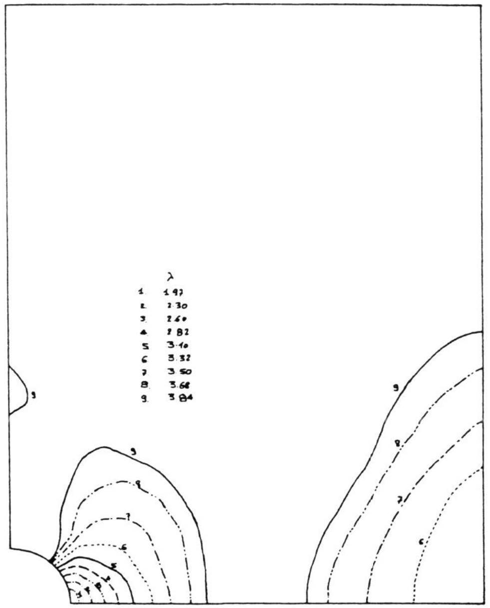

FIGURE 4 - EVOLUTION OF THE PLASTIC ZONE IN UNCRACKED PLATE

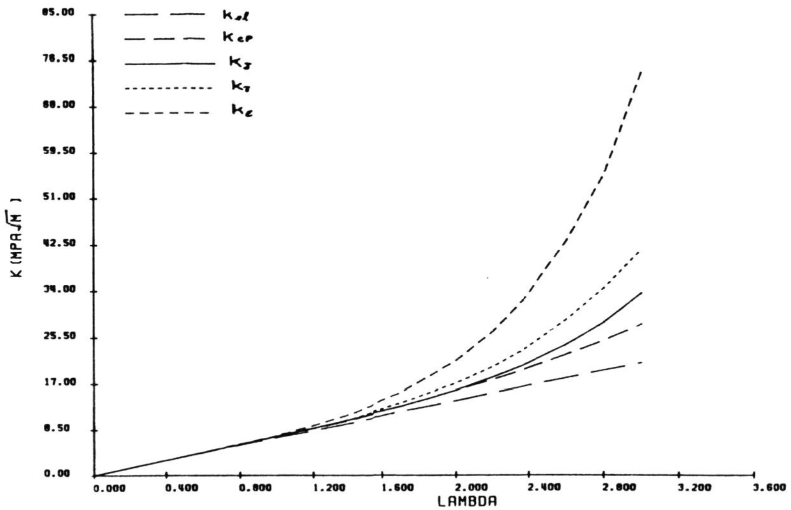

FIGURE 5 - EVOLUTION OF S.I.F. AS A FUNCTION OF LOAD (Crack = 0,5 * A)

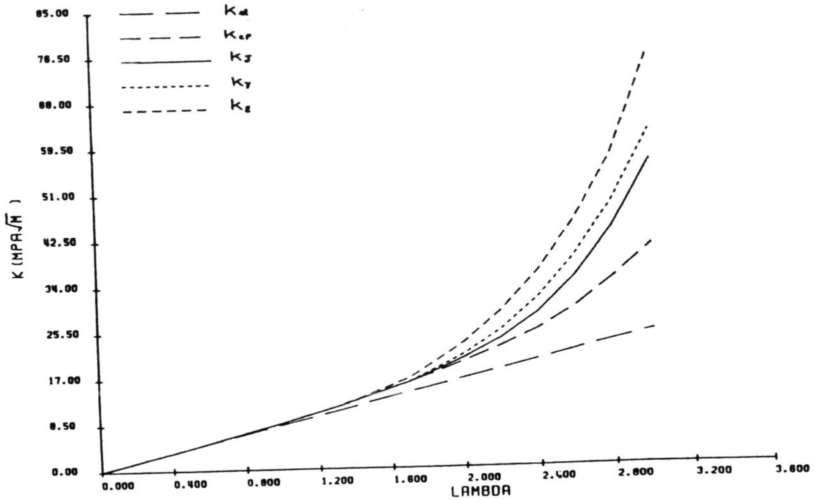

FIGURE 6 - EVOLUTION OF S.I.F. AS A FUNCTION OF LOAD (Crack = 1 * A)

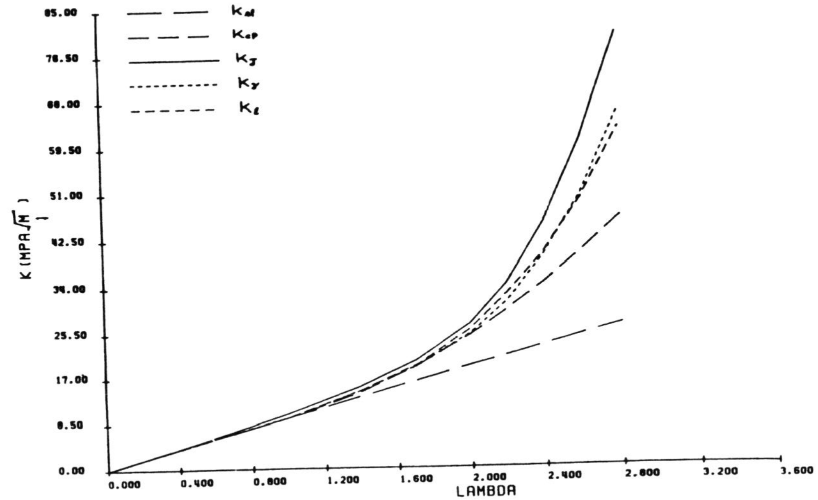

FIGURE 7 - EVOLUTION OF S.I.F. AS A FUNCTION OF LOAD (Crack = 1,5 * A)

used without any plasticity correction factor. K_{ε} should therefore be used with caution.

- The proposed parameter $K_{\gamma} = \sqrt{K_{\sigma} \, K_{\varepsilon}}$ corrected for the plasticity effects seems to correlate best with the value of K_J. It integrates both the stress and the strain field in the area of the prospective crack and overcomes the disadvantages of using K_{ε}.

- A final remark would be in order, concerning the use of these parameters in the fatigue crack propagation analysis. Strictly speaking, one has to evaluate all parameters based on a non-linear cyclic analysis. If we replace the parameter P formally by $\triangle P$ for fatigue crack propagation predictions, the resulting error would depend on the cyclic behavior of the component under the applied loading. However, in literature very often this formalism is used for simplicity reasons, under the assumption that the redistribution of stress and strain field would be negligible. Here again the proposed parameter K_{γ} has an advantage over K_{ε} since K_{γ} would be less affected by the redistribution than K_{ε} due to the dual relation between stress and strain.

CONCLUSION

The present study deals with the analysis of various intensity factors based on stress and strain fields in areas of high nominal strain. The computations are performed on a single edge notched plate subjected to bending using a non-linear finite-element programme. It is shown that a new parameter $K_{\gamma} = \sqrt{K_{\sigma} \, K_{\varepsilon}}$ gives a good correlation of results with the S.I.F. derived from the $\mathcal{J}$- Integral for a large range of applied loads. In addition certain advantages of using K_{γ} are high-lighted.

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