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OPTICAL EXPERIMENTAL ANALYSIS AT THE INTERSECTION OF CRACK FRONT WITH THE FREE SURFACE

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Summary

At the intersection of the crack front with the free surface appears a vertex singularity. Refined three dimensional photoelasticity and moiré interferometry are used together in order to establish the displacement singularity. Although there are some differences between the analytical and experimental results, they are in a good agreement.

Keywords: crack front, free surface, displacement singularity

Introduction

At the intersection of a crack front with a free surface it is produced a boundary layer in which the classical two dimensional linear elastic fracture mechanics (LEFM) is not valid any more. In the point of intersection appears a vertex singularity and the stress singularity order depends upon Poisson's ratio. Subsequent to 1980 several analytical and numerical analyses include boundary layers and varying intersection angle effects in both through and part through cracks. It is clear that when a straight crack front intersects a free surface at right angles, a vertex stress singularity results and it has the same value as the classical (LEFM) singularity. When the angle changes its value, the value of the stress singularity becomes different. The extend and influence of a boundary layer or transition zone inside the specimen, where the classical stress intensity factor (SIF) varies is a problem still open to question.

Analytical Background

The vertex singularity introduces a three dimensional state of stress near the point of intersection of the crack border with the free surface. Several methods are used: the variables separable eigenfunction series expansion, asymptotic methods, or strictly numerical methods including finite element and boundary integral approaches. Following Benthem [1], we define the vertex singularity order or dominant eigenvalues λ_u and λ_σ from the truncated equations:

$$u_i = r^{\lambda_u} f_i(\theta, \varphi)$$
$$\sigma_{ij} = r^{\lambda_\sigma} F_{ij}(\theta, \varphi) \quad i,j=1,2,3 \qquad (1)$$

for displacement and stress components, where $\lambda_\sigma = |\lambda_u - 1|$. Table 1 presents a summary of the results of several investigators together with their respective methods of analysis.

Table 1

Summary of analytical Results

Author	Method of Analysis	Vertex stress singularity Order λ_σ^a for various values of ν: 0	0,15	0,30	0,40	0,50
Benthem [1]	EF	0,5	0,484	0,452	0,413	0,332
Kawai et. al [2]	EF	0,5	0,48	0,43	0,37	
Bazant et al [3]	FEM	0,5	0,484	0,452	0,413	0,352[b]
Burton et al [4]	FEM	0,499	0,485	0,445	0,370	
Blom et al [5]	FEM			0,452		0,323[e]
Shivakumar et al [6]	FEM	0,497		0,451	0,407	0,356[f]
Takakuda [7]	FEM	0,5	0,49[c] 0,475[d]	0,452	0,413	0,332

EF-Eigenfunction Series; FEM-Finite Element Method; IEM-Integral Equation Method; [a]For crack border-boundary surface intersection angle of 90°; [b]ν=0,48; [c]ν=0,10; [d]ν=0,20; [e]ν=0,499; [f]ν=0,45.

Experimental Results

Around 1980, Professor C.W. Smith and his colleagues undertook a series of experimental studies of the vertex stress singularityproblem and the corresponding boundary layer effect using the tandem application of two optical methods, refined frozen stress photoelasticity and standard and high density moiré interferometry. They investigated both through cracks [8], [9] and surface flaws [10] and also included limited investigations of flaw border-boundary intersection angles other than right angles [10]. Smith and Constantinescu [11] are revising the latest experimental results. See [8-11] for details. Results from the moiré and photoelastic studies are compared with Takakuda's results in Fig.1 [11]. Clearly, discrepancies exist, and the experimental displacement singularity has a higher value than the analytical one. However, since the algorithms used for converting experimental data into dominant eigenvalues were

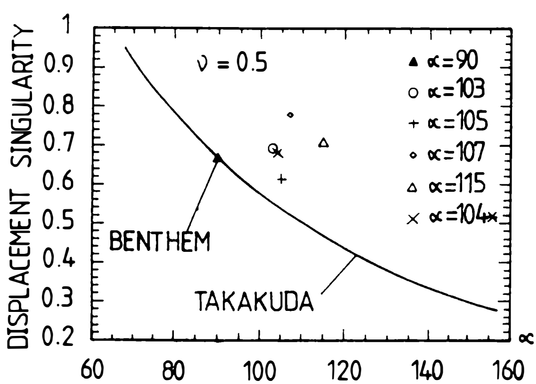

Fig.1 Comparison of Analytical and Moiré Experimental Results for Dominant Eigenvalues for Various Crack Border-Free Surface Intersection Angles, α. (*-Photoelastic)

quasi two-dimensional, and idealized for 90° crack front-crack border intersection angle and, in view of the crack front irregularities in the moiré experiment and the thickness averaging effect in the frozen stress surface slices, it is surprising that all these factors do not have a greater influence on the experimental results.

Conclusions

The analytical effect of changing the crack border-free surface intersection angle has not been accuratly assessed experimentally, but preliminary studies seem to indicate less deviation from the Benthem result than predicted by Takakuda.

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