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Crack Growth Determination in Three-Dimension Composite Material by Using Semi-Analytical Method

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Abstract: The semi-analytical method is presented by integrating the continuous dislocation model with the finite element method together. An efficient formulation, based on a semi-analytical finite element method, is described for elasto-plastic analyses of consolidation of an axi-symmetric soil body subjected to three-dimensional loading. Expressing the field quantities in the form of discrete Fourier series results in a set of modal equations that can be solved separately. This has the effect of con-siderably reducing the necessary storage and the cost of solving three-dimensional problems. The numerical method is applied to the problem of a laterally loaded pile in consolidating elasto-plastic soil.

Key words: Stress intensity factor · Semi-analytical method · FEA · MMC

INTRODUCTION

Semi Analytical Method: The semi-analytical method (SAM) is a fast integral technique for solving small 2-D. In order to determine its optimal context of utilization, computation times were compared with those of the finite element method. Semi analytical method proved to be 10 times faster than the FEM for problems involving 300 elements in the mesh (conducting regions only) and showed equal performances with the FEM with 850-900 elements. As the number of element further grows, the SAM loses its advantage over the FEM.

Cracks: Generally there are three modes to describe different crack surface displacement in Figure-1 Mode I is opening or tensile mode where the crack surfaces move directly apart. Mode II is sliding or in-plane shear mode where the crack surfaces slide over one another in a direction perpendicular to the leading edge of the crack. Mode III is tearing and anti-plane shear mode where the crack surfaces move relative to one another and parallel to the leading edge of the crack. Mode I [2] is the most common load type encountered in engineering design and will be explained here in more detail.

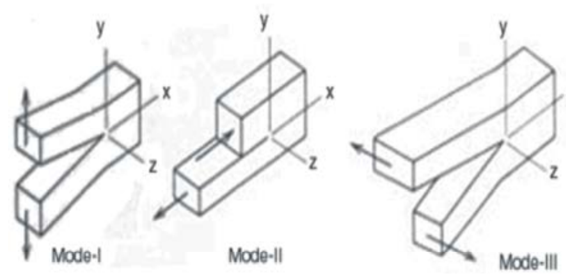

Fig. 1: Three types of loading on a cracked body

$$\sigma_y = \frac{K}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$

$$\sigma_x = \frac{K}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$

$$\tau_{xy} = \frac{K}{\sqrt{2\pi r}} \left(\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2}\right)$$

Composite Material: Composite material is a man-made to from more than one material with significantly different physical or chemical properties to suit a particular purpose.

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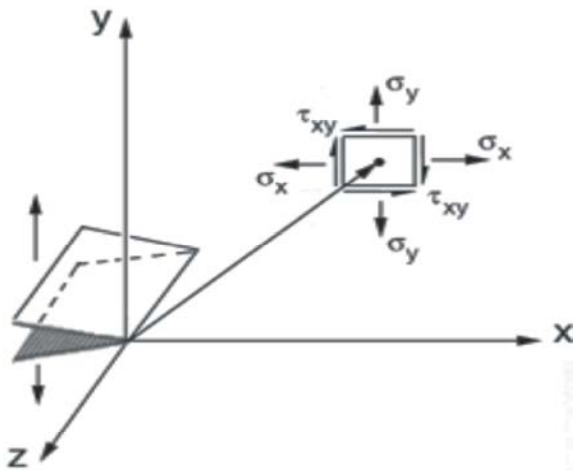


Fig. 2: Co-ordinate system for stress components

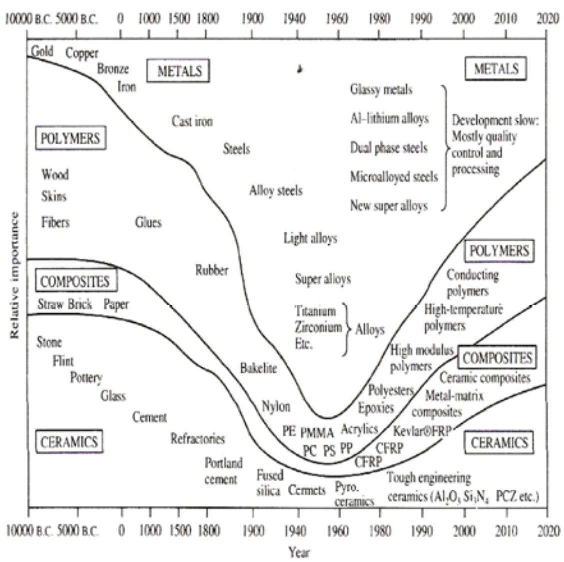


Fig. 3: The relative importance of metals, polymers, composites and ceramics as a function of time

These are also referred as advanced materials and needed for space missions, etc. where materials with very different properties are required. Say a material which is very light as plastic but tough as steel and can withstand very high temperature.

Silicon Carbide (Sic) fibers are used primarily in high-temperature metal and ceramic matrix composites because of their excellent oxidation resistance and high temperature strength retention. At room temperature the strength and stiffness of Sic Fibers are about the same as those of boron. Sic whisker reinforced metals are also Receiving considerable attention as alternative to unreinforced metals and continuous Fiber-reinforced metals. Sic whiskers are very small, typically 8-20ì in (20-51nm) in Diameter and about 0.0012 in(0.03mm) long, so that standard metal-forming process such as extrusion, rolling and forging can be easily used.

Classification of Composite Materials: There are four commonly accepted types of composite materials. These types are listed as follows;

- Fibrous composite materials that consist of fibers in a matrix
- Laminated composite materials that consist of layers of various materials
- Particulate composite materials that are composed of particles in a matrix.
- Combinations of some or all of the first three types

The major composite classes of structural composite materials are available and these classes will be categorized as following;

- Polymer-Matrix Composites
- Metal- Matrix Composites
- Ceramic- Matrix Composites
- Carbon- Carbon Composites
- Hybrid Composites

Literature Review: *XI-QIAO FENG, YUN-FEI SHI, XU-YUE WANG, BO LI, SHOU-WEN YU, QIANG YANG [1]* in the present paper, Determination of the stress intensity factors of cracks is a fundamental issue for assessing the performance safety and predicting the service lifetime of engineering structures. In the present paper, a dislocation-based semi-analytical method is presented by integrating the continuous dislocation model with the finite element method together. Using the superposition principle, a two-dimensional crack problem in a finite elastic body is reduced to the solution of a set of coupled singular integral equations and the calculation of the stress fields of a body which has the same shape as the original one but has no crack. It can easily solve crack problems of structures with arbitrary shape and the calculated stress intensity factors show almost no dependence upon the finite element mesh. Some representative examples are given to illustrate the efficacy and accuracy of this novel numerical method. Only two-dimensional cases are addressed here, but this method can be extended to three-dimensional problems.

KHOO SZE WEI AND SARAVANAN KARUPPANAN [2] in the present paper Shaft is a rotational body used to transmit power or motion. Due to cyclic loading conditions, surface cracks frequently grow in the shaft. Normally these cracks will propagate with a semi-circular shape and cause premature failure to the whole system. In order to prevent the catastrophic incident, there must be a monitoring system that provides an early warning during the operation of the shafts.

The semi-analytical or experimental method applied previously had its own limitations and disadvantages. Hence, there is a great need to determine the stress intensity factor in cracked shafts by using finite element method. The objective of this study is to determine the stress intensity factor for cracks emanating from a shaft by using finite element method and also to verify the finite element results with those obtained semi-analytically the scope of this study is focused on the semi-circular crack and the crack loadings considered are Mode I and Mode III. This study is divided into two phase, the results obtained from the finite element analysis were compared with those obtained semi-analytically. The relationship between dimensionless stress intensity factor and the normalized relative crack depth is present in the results and discussion section. The results obtained numerically and semi-analytically had been compared and the derivation in term of percentage is relatively small in conclusion.

SPIROS GEORGE PAPAIOANNOU, PETER D. HILTON, ROBERT A. LUCAS [3] in the present paper a concept which allows for the development of efficient finite element techniques in the analysis of plane elastic structures containing cracks is discussed. It consists of combining a specially defined finite element in the region surrounding each crack tip with conventional CST elements describing the remaining portion of the geometry considered. For the special element a pair of displacement functions is chosen which adequately represents the singular character of the elastic solution at the crack tip. The application of this concept is illustrated through a specific numerical method developed by W. K. Wilson for the calculation of mode I stress intensity factors.

Wilson's method was coded and used to analyze an infinitely long strip under tension with a line crack perpendicular to its axis of symmetry. Circular inclusions of different material properties were assumed to be present near the tips of the crack and their effect on the mode I stress intensity factor was investigated.

CHRISTINA BJERKÉN, CHRISTER PERSSON [4] in the present paper a method for obtaining the complex stress intensity factor (or alternatively the corresponding energy release rate and mode mixed) for an interface crack in a bi-material using a minimum number of computations. A crack closure integral method for homogeneous materials developed by Ricky and Kanninen has been modified to include mismatch in material properties. This was achieved directly from the nodal forces at the crack tip and the displacements near the tip as obtained from a finite element analysis using only four-node constant strain elements. Numerical calculations for tensile and mixed mode loading show a good agreement with results from corresponding analytical solutions. The main advantages of this method are that it is straightforward and easy to use and that the number of calculations needed to obtain the stress intensity factors can be held to a minimum.

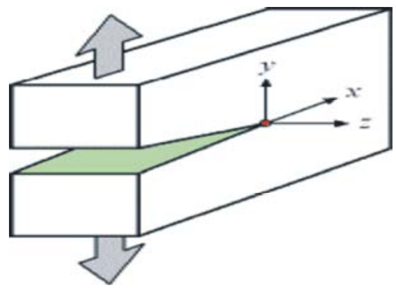
E.M.M.FONSECA, F.Q.MELO, R.A.F.VALENTE [5] in the present paper alternative methods to estimate the stress intensity factors (SIF) of notched round components having an axial hole and subjected to an axial force or a bending moment. The method is based on analytical equations proposed by (Harris 1997) and on alternative formulation using finite element method (FEM). The objective of this work is a contribution in fracture mechanics applied to tubular systems with typical defects generated in service or a consequence of the fabrication method. Computational effort is saved with this element in the evaluation of the stress field across the section carrying the defect. Numerical examples are presented to illustrate the proposed method referring to tubular structures with different end constraints and containing a circumferential notch. The comparisons with the elastic finite element showed satisfactory results and good agreement with others references.

A. M. AL-MUKHTAR, S. HENKEL, H. BIERMANN, P.HUBNER [6] in the present paper with welded joints, stress concentrations occur at the weld toe and at the weld root, which make these regions the points from which fatigue cracks may initiate. To calculate the fatigue life of welded structures and to analyze the progress of these cracks using fracture mechanics technique requires an accurate calculation of the stress intensity factor SIF. The existing SIFs were usually derived for one particular geometry and type of loading. In this study, the finite element method (FEM) was used to calculate the SIF.

The stress intensity factors during the crack propagation phase were calculated by using the software FRANC2D, which is shown to be highly accurate, with the direction of crack propagation being predicted by using the maximum normal stress criterion. In the current work, a new analytical approach for the weld toe crack in cruciform welded joints has been used. The SIF results from FRANC2D were compared with those from the International Institute of Welding-IIW and literature. A good correlation was obtained and the work results have bench marked which made it possible to use FRANC2D to simulate different weld geometries. The results of these comparisons are shown and the agreement is clearly well.

Formulas for Calculation

Mode I



$$\sigma_{xx} = \frac{K_I}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\left[1 - \sin\left(\frac{\theta}{2}\right)\sin\left(\frac{3\theta}{2}\right)\right]$$

$$\sigma_{yy} = \frac{K_I}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\left[1 + \sin\left(\frac{\theta}{2}\right)\sin\left(\frac{3\theta}{2}\right)\right]$$

$$\sigma_{zz} = \begin{cases} 0 & \text{(Plane Stress)} \\ \nu\left(\sigma_{xx} + \sigma_{yy}\right) & \text{(Plane Strain)} \end{cases}$$

$$\tau_{xy} = \frac{K_I}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\sin\left(\frac{\theta}{2}\right)\cos\left(\frac{3\theta}{2}\right)$$

$$\tau_{xy} = 0$$

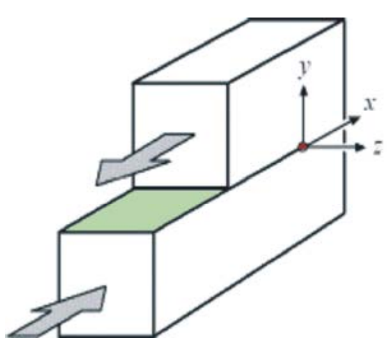
$$\tau_{zx} = 0$$

$$u_x = \frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}} \cos\left(\frac{\theta}{2}\right)\left[\kappa - 1 + 2\sin^2\left(\frac{\theta}{2}\right)\right]$$

$$u_y = \frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}} \sin\left(\frac{\theta}{2}\right)\left[\kappa + 1 - 2\cos^2\left(\frac{\theta}{2}\right)\right]$$

$$\tau_z = 0$$

Mode II



$$\sigma_{xx} = -\frac{K_{II}}{\sqrt{2\pi r}} \sin\left(\frac{\theta}{2}\right)\left[2 + \cos\left(\frac{\theta}{2}\right)\cos\left(\frac{3\theta}{2}\right)\right]$$

$$\sigma_{yy} = \frac{K_{II}}{\sqrt{2\pi r}} \sin\left(\frac{\theta}{2}\right)\cos\left(\frac{\theta}{2}\right)\cos\left(\frac{3\theta}{2}\right)$$

$$\sigma_{zz} = \begin{cases} 0 & \text{(Plane Stress)} \\ \nu\left(\sigma_{xx} + \sigma_{yy}\right) & \text{(Plane Strain)} \end{cases}$$

$$\sigma_{xy} = \frac{K_{II}}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\left[1 - \sin\left(\frac{\theta}{2}\right)\sin\left(\frac{3\theta}{2}\right)\right]$$

$$\tau_{yz} = 0$$

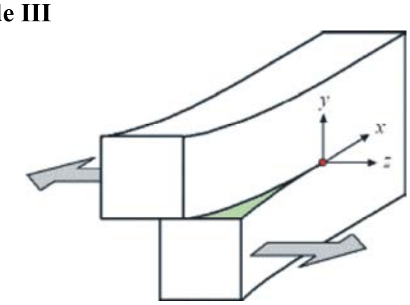
$$\tau_{zx} = 0$$

$$u_x = \frac{K_{II}}{2\mu}\sqrt{\frac{r}{2\pi}} \sin\left(\frac{\theta}{2}\right)\left[\kappa + 1 + 2\cos^2\left(\frac{\theta}{2}\right)\right]$$

$$u_y = -\frac{K_{II}}{2\mu}\sqrt{\frac{r}{2\pi}} \cos\left(\frac{\theta}{2}\right)\left[\kappa - 1 - 2\sin^2\left(\frac{\theta}{2}\right)\right]$$

$$\tau_z = 0$$

Mode III



$$\sigma_{xx} = 0$$

$$\sigma_{yy} = 0$$

$$\sigma_{zz} = 0$$

$$\tau_{xy} = 0$$

$$\tau_{yz} = \frac{K_{III}}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)$$

$$\tau_{zx} = -\frac{K_{III}}{\sqrt{2\pi r}} \sin\left(\frac{\theta}{2}\right)$$

$$u_x = 0$$

$u_y = 0$

$$u_z = \frac{K_{III}}{\mu}\sqrt{\frac{r}{2\pi}}\sin\left(\frac{\theta}{2}\right)$$

Composite Materia Properties: Different materials are suitable for different applications. When composites are selected over traditional materials such as metal alloys or woods, it is usually because of one or more of the following advantages

- Cost
- Weight
- Strength and stiffness
- Dimension
- Surface properties
- Thermal properties
- Electric property

Toughness of Metals:

Material	K_c (MPa·$m^{1/2}$)	Yield Strength (MPa)
Aluminum Alloy		
2014	18-31	380-470
2020	19-27	525-240
2024	21-37	305-455
2124	21-36	440-460
2219	28-41	340-345
7049	21-38	460-510
7050	25-41	430-510
7075	16-41	395-560
7475	33-44	395-515
7079	24-33	505-540
7178	17-30	470-540

Ferrous Alloy

Material	K_c (MPa·$m^{1/2}$)	Yield Strength (MPa)
Cast Iron	20-22	120-290
Rotor Steel (A533)	204-214	-
Pressure-vessel Steel (HY130)	170	-
High-Strength Steel	50-154	-
Mild Steel	140	-
Medium-Carbon Steel	51	-
4330V	86-110	1315-1400
4340	44-91	1360-1660
D6AC	62-102	1495-1570
9-4-20	132-154	1280-1310
18Ni	50-110	1450-1905
AFC77	79	1530
Titanium Alloy		
Ti6Al4V	77-116	815-875

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