International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 3 Issue 2, February 2015

# Stress Analysis of Cracked Plate for Selected Configurations: A Review

**Pravin R. Gawande[1], Ajay Bharule[2]**

[1]M.E. Student, Advance Manufacturing and Mechanical System Design, SSGMCE, Shegaon (M.S.) India
[2]Assistant Professor, Department of Mechanical Engineering, SSGMCE, Shegaon (M.S.) India

**Abstract:** ***In this paper an effort is made to review on the Stress Analysis of cracked plate for the determination of stress intensity factor near the crack tip .Cracks in plates with different configurations often occurs in both modern and classical aerospace, mechanical and civil engineering structure. The understanding of effect of loading mode and crack configuration on load bearing capacity of such plate is very important in designing of structure and in damage tolerance analysis. A number of Analytical, Numerical, experimental technique are available for stress analysis to determine the stress intensity factor near crack tip under different loading modes in an infinite /finite cracked plate made up of different material has been reported in this paper. An attempt has been made in the present work to present an overview of various techniques developed for stress analysis & stress intensity factor.***

**Keywords:** stress intensity factor, cracked plate, selected configurations

## 1. Introduction

In the lifetime of mechanical structures they are subjected to unfavorable changes in their structural properties mainly caused due to fatigue, environmental degradation, wear and errors in design and construction, overloads, unanticipated result from impacts. Aluminum and steel sheet metal plates are widely used in industrial applications such as aviation, automotive, ship-building industries etc. Plate's structures are highly sensitive to crack formation and crack growth and the outcome of this can affect the performance and reliability. Notches, holes, and other mechanical defects that are unavoidable structural component acts as a stress concentration zone which initiates the formation of cracks.

The knowledge of acuteness or severity of cracks is necessary in order to predict fatigue crack growth rate, critical crack length, and fatigue life of component. According to the linear elastic fracture mechanics (LEFM)stress intensity factor is the key parameter which determines the severity of cracks as it reflects the effect of loading (mode-I, mode-II, mode-III) , crack size and crack shape. Damage tolerance principle is the basis for modern structural design which requires tight inspection and maintenance plans, which adds the cost to the product. This increases the cost of ownership of these structures. But loosening inspection frequencies without compromising safety is highly needed throughout the service life. Damage tolerance analysis of structures is one of the fundamental tool in managing safety. The primary input to damage tolerance analysis is stress intensity factor which is used to determine crack growth life and critical crack length. Hence it is important aspect of stress analysis to predict stress intensity factor for different loading modes.

## 2. Stress Intensity Factor

The stress intensity factor is used in fracture mechanics to predict the stress state ("stress intensity") near the tip of a crack caused by a remote load or residual stresses. The magnitude of SIF depends on sample geometry, the size and location of the crack, and the magnitude and the modal distribution of loads on the material.

$$K_I = \sigma\beta\sqrt{\pi a}$$

Where,
σ= applied stress,
β= geometrical factor (dimensionless),
a = crack length,
For centre crack, length= 2a,
For edge crack, length= 'a'

### 2.1 Model Configurations

i. Plate with Edge Crack

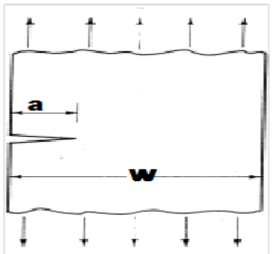



**Figure 1:** Plate with edge crack

ii. Plate with a Central Crack

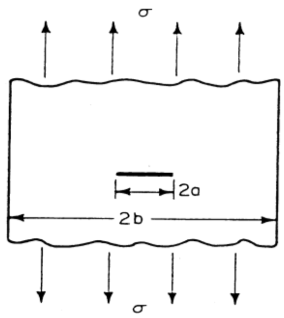



**Figure 2:** Plate with central crack

iii. Plate with Crack approaching a circular hole

ISSN (Online): 2347-3878
Volume 3 Issue 2, February 2015

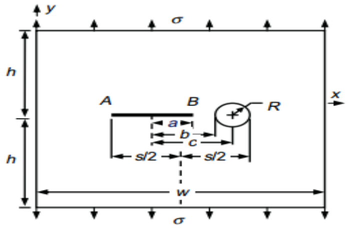



**Figure 3:** Plate with crack approaching a circular hole

iv. A crack propagating from a hole after ligament failure

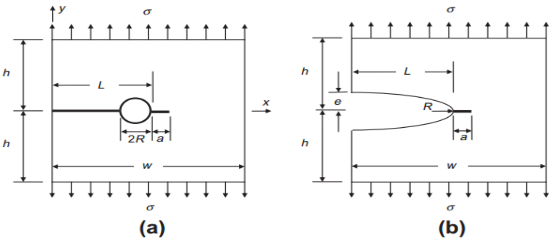
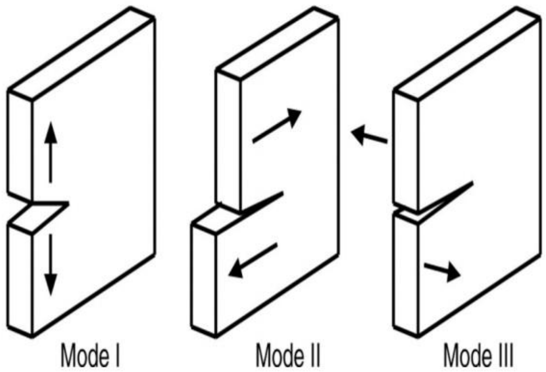



**Figure 4:** A crack propagating from a hole after ligament failure

### 2.2 Modes of loading

i. Mode-I loading
ii. Mode-II loading
iii. Mixed mode loading




## 3. Methods for Stress Analysis

Different approaches used for stress analysis are Analytical, Numerical and Experimental.

### 3.1 Analytical Approach

Distribution of stresses in a structure with boundary conditions, i.e. displacements and/or forces on the boundary can be determined by using either the closed form analytical methods or by approximate numerical methods. Boundary value problems can be solved analytically by using constitutive equations based on the elastic or plastic behavior of the material under load. Analytical or close-form solutions can be obtained for simple geometries, constitutive relations and boundary conditions.

**Interaction Energy Integral Method**

A domain integral method that is gaining in popularity due to its general applicability to a wide variety of crack problems is the interaction energy integral method. In the interaction energy integral method, auxiliary fields are introduced and superposed on top of the actual fields that come from the solution to the Boundary value problem. Through a suitable definition of the auxiliary fields, the interaction energy integral (a crack-tip contour integral surrounding a point on the crack front defined in the limit as the contour is shrunk onto the crack tip) can be related to the mixed-mode stress intensity factors. The interaction energy integral can then be expressed in domain form and evaluated as a post-processing step after the solution to the boundary value problem has been obtained using any suitable numerical method. The interaction energy integral approach for computation of mixed-mode stress intensity factors in two dimensional crack problems was introduced by Stern et al. Since then, the method has been commonly used for the extraction of stress intensity factors in two-dimensional bimaterial crack problems, see Shih and Asaro. Nakamura and Parks, and Nakamura used this approach to determine the mixed mode stress intensity factors along straight, three-dimensional bimaterial interface cracks. Interaction energy integrals for axisymmetric bimaterial crack problems have been derived recently by Nahta and Moran Gosz et al. have recently developed an interaction energy integral approach for extracting the mixed-mode stress intensity factors along three-dimensional planar interface cracks between dissimilar isotropic and linearly elastic solids. [2]

**Critical Plane-Based Multiaxial Fatigue Theory**

For the multiaxial fatigue models using the S–N (e–N) curve approach, the critical plane-based models have been gaining popularity due to their success in accurately predicting lives. The development of the critical plane approach is based on the observations that the fatigue crack nucleated along certain planes in the material. The planes are named ''critical plane'' and the stress (strain) components on it are used for fatigue analysis. Liu and Mahadevan examined various critical plane-based models and grouped them into two categories based on their underlying failure mechanisms. A number of the critical plane approaches are for the shear failure mode and some others are for the tensile failure mode. It has been found that the methods based on one failure mode perform poorly for the fatigue modeling of the other failure mode. [10]

**Element Free Galerkin Method**

This method of analysis is comparably simple and it produces an exact solution which is its great strength. It Have following steps

1. Moving least square (MLS) approximation
2. Weight functions
3. Discrete equation
4. Numerical integration [12]

**Non-linear Regression Analysis**

The stress intensity factor equations are obtained by using DataFit, a science and engineering tool to perform tasks of linear and non-linear regression analysis (curve fitting) as well as data plotting and statistical analysis. The accuracy of the software had been verified with the Statistical Reference Datasets Project of the National Institute of Standards and Technology (NIST).The software allows the user to solve any user defined regression model that includes a dependent (response) variable as a function of independent (predictor) variable(s) and at least one fitting parameter. The basic idea behind the regression analysis that DataFit uses is to choose a method of measuring the agreement between the actual/source data and a regression model with a particular choice of variables. This measurement of agreement is called the merit function, and is arranged so that small values represent close agreement between the source data and the regression model. The variables are then adjusted iteratively (in the case of non-linear regression) in order to minimize the merit function. Once the merit function has been minimized, it is possible to determine how well the model describes the data [16]

### 3.2 Numerical Approach

In Numerical Approach Following Method are include

i. Boundary Collection
ii. Finite difference
iii. Finite Element

Finite Element method is based upon discretization of material surface or space into several small plane or solid elements. The law of distribution of stress over the element is assumed and displacements at boundaries of adjacent element are matched to determine the shape of deformed body. The stresses are calculated making use of stiffness matrix. In recent years, with the advent of advanced software's, the FEA based software ANSYS, COSMOL, DIANA, ABACUS and NASTRAN have been very useful for stress analysis. These software's are preferred by users according to the type of stress analysis, the type of elements to be analyzed and the depth of accuracy required.

Finite Difference is similar technique in which elasticity equilibrium equation is applied and solved by using small but finite distance between adjacent points.

In Boundary collection stress function is determine by satisfying condition along boundary.

Numerical method invariably and theory of elasticity method in several cases depends upon use of computers for arriving at solution. [22]

### 3.3 Experimental Approach

Among the experimental method three have gain popularity, these methods are

i. Photoelasticity
ii. Brittle coating
iii. Electrical Strain Gauges

**Photoelasticity**

The name photoelasticity implies the use of light (photo) and elastically stresses model. This method was earlier used for plane bodies of complicated shape and geometries, particularly for the reason that such geometrical shapes were not amenable to mathematical analysis. Photoelasticity is an experimental method for measurement of stress and strain in which light is either passed through a model or reflected from the surface of loaded body. Photoelastic model is generally preferred in situation where and strain information is needed over extended region and thus whole field method.

Photoelastic stress analysis is a full field technique for measuring the magnitude and direction of principal stresses. When polarized light is passed through a stressed transparent model, interference patterns or fringes are formed. These patterns provide immediate qualitative information about the general distribution of stress, positions of stress concentrations and of areas of low stress using the principals of stress optic law.

$$\sigma_1 - \sigma_2 = \frac{N f_\sigma}{h}$$

$\sigma_1$ And $\sigma_2$ =maximum and minimum principal stresses at the point under consideration
N=Fringe order
$f_\sigma$=Material Fringe Value h= Thickness [22]

**Brittle Coating**

A brittle coating as the name suggest, is a material forming a thin layer on a base material and is brittle in nature particularly with respect to base material. Due to the brittle nature, the coating may crack when the body is subjected to certain minimum stress. Brittle coating is a Non destructive technique directly applicable on machine part to be analyzed in actual situation .the various type coating material like Stresscoat, Straintec, All-Temp, Glass-Lacquer are now available for application. Coating is normally air sprayed onto the component in the same way as spray paint. Thickness of coating is tried to be maintained uniform in the range of 0.05 to 0.2 mm. The coating is often dried at room temperature but seldom is it dried in oven [22]

**Electrical Strain Gauges**

Probably the most ubiquitous and reliable of all the tools of experimental stress analysis is the electrical resistance strain gauges. The principle of its action is that the electrical resistance of a conductor changes proportionally to any strain applied to it. Thus, if a short length of wire were bonded to the structure in such a way that it experiences the same deformation as the structure, then by measuring the change in resistance, the strain can be obtained. [6]

## 4. Literature Review

Veronique Lazarus, Jean-Baptiste Leblond, Salah-Eddine Mouchrif [1] evaluate the stress intensity factor (SIF) along the crack front after rotation by using Muskhelishvili's complex potentials formalism and conformal mapping.

M. Gosza et.al. [2] used interaction energy integral method for computation of SIF along crack fronts.

B.Bachir Bouiadjra et.al [3]. used FEM to compute SIF for repaired cracks with bonded composite patches, in mode-I and mixed mode.

Bo Cerup Simonsen, Rikard T. Ornqvist [4] presented a combined experimental and numerical procedure for development of model in large scale shell structure.

L. Liu et.al. [5] presented the analytical method for mixed mode SIF for a bimaterial interface crack in infinite strip.

C.G. Hwang, P.A. Wawrzynek et.al. [7] determined the mixed mode SIF for multiple crack system using analytical expression.

J.H. Chang, D.J.Wu et.al. [8] Presented numerical procedure based on the concept of the $J_K$ integrals for computation of mixed mode SIF for curved cracks.

Ali O. Ayhan [9] determined the mixed mode SIF for deflected and inclined corner cracks using analytical approach.

Yongming Liu et.al. [10] developed the solution for threshold SIF using a critical plane based multiaxial fatigue theory and Kitwaga diagram.

Nagaraj K. Arakere et.al. [11] investigated on mixed mode SIF for foam material using numerical (ANSYS & FRANC3D) and experimental approach.

Mohit Pant, I.V.Singh, B.K. Mishra et.al. [12] demonstrated element free Galerkin method for stress analysis.

F.J. Gomez et.al. [13] examined a novel notch SIF for U-shaped notch specimen under mixed mode by using analytical and experimental approach.

Ali O. Ayhan [14] determined the SIF in mixed mode for functionally graded materials using 3D Enriched Finite Elements.

Sabine Bechtle, Theo Fett et.al. [15] determined the SIF for kinked cracks with specimen loaded in tension and bending.
Ali O. Ayhan, Ugur Yucel [16] determined the mixed mode SIF for deflected and inclined surface &corner cracks by performing non linear regression analysis.

Liang Wu et.al. [18] used the domain integral method based on X-FEM for computation of SIF in mixed mode in 3D problem.

Garrett J. Pataky et.al. [17] shown the effect of anisotropy during mixed mode fatigue crack growth by using DIC and Analytical approach.

M. Beghinia et.al. [18] provided a simplified approach for evaluating SIF for inclined edge kinked crack by using analytical weight function.

Chaitanya K. Desai, Sumit Basu [19] determined the SIF for a crack in a bimaterial interface from the displacement fields obtained through Digital Image Correlation (DIC).

Rui Zhang, Lingfeng He [21] used Digital Image Correlation (DIC) method for determination of SIF in mixed mode.

Calvin Rans et.al. [23] determined SIF in cracked skin panels containing bonded stiffening elements by using analytical method

Paulo J.Tavares et.al. [24] presented hybrid methodology for the determination of the stress intensity factor (SIF) parameter, which entails combining experimental and numerical procedures to compute the SIF based of linear elastic fracture-mechanics concepts.

R. Evans, A. Clarke et.al.[25] determined SIF for an edge crack, a crack approaching a hole, or a crack propagating from a hole after ligament failure by using The Stress Check commercial FE software package, (Version 8.0.1) in mode-I loading.

## 5. Conclusion

In the recent past, many researchers have been used analytical solutions for the determination of stress intensity factor with some Numerical and experimental validations. An analytical solution used by researchers includes Interaction energy integral method, Critical plane-based multiaxial fatigue theory, Muskhelishvili's complex potentials formalism and conformal mapping, Element Free Galerkin Method etc. Many of them have developed solutions for mode-I and mode-II loading.

In this paper an effort is made to review on the stress analysis of cracked plate with different crack configurations. An attempt has been made in the article to present an overview of various techniques developed for stress analysis of infinite/ finite cracked plate.

## 6. Future Scope

Many researcher use analytical and numerical method to solve the stress distribution problem of a Infinite/finite cracked plate with different crack configurations. In experimental validation, whole field method especially photo elasticity has not got considerable exposure. So attempt has been made in this paper to introduce photoelasticity as a experimental method. So Experimental, Numerical and Analytical solution concerned with the stress analysis of cracked plate for selected configuration subjected to axial (tension, compression), shear and torsion loading conditions have scope for future work.

## References

[1] Veronique Lazarus, Jean-Baptiste Leblond, Salah-Eddine Mouchrif Crack front rotation and segmentation

in Mixed mode I + III or I + II + III. Part I: Calculation of stress Intensity factors: Journal of the Mechanics and Physics of Solids 49 (2001) 1399 – 1420
[2] M. Gosza, B. Moran An interaction energy integral method for computation of mixed-mode stress intensity factors along non-planar crack fronts in three dimensions: Engineering Fracture Mechanics 69 (2002) 299–319
[3] B. Bachir Bouiadjra, M. Belhouari, B. Serier Computation of the stress intensity factors for repaired cracks with bonded composite patch in mode I and mixed mode: Composite Structures 56 (2002) 401–406
[4] Bo Cerup Simonsen, Rikard T. Ornqvist Experimental and numerical modeling of ductile crack propagation in large-scale shell structures: Marine Structures 17 (2004) 1–27
[5] L. Liu, G.A. Kardomateas, J.W. Holmes Mixed-mode stress intensity factors for a crack in an anisotropic bi-material strip: International Journal of Solids and Structures 41 (2004) 3095–3107
[6] James Doyle Modern Experimental Stress Analysis: completing the solution of partially specified problems. John Wiley & Sons, Ltd (2004) 101
[7] C.G. Hwang, P.A. Wawrzynek, A.R. Ingraffea On the calculation of derivatives of stress intensity factors for multiple cracks: Engineering Fracture Mechanics 72 (2005) 1171–1196
[8] J.H. Chang, D.J. Wu Computation of mixed-mode stress intensity factors for curved cracks in anisotropic elastic solids: Engineering Fracture Mechanics 74 (2007) 1360–1372
[9] Ali O. Ayhan Mixed mode stress intensity factors for deflected and inclined corner cracks in finite-thickness plates: International Journal of Fatigue 29 (2007) 305–317
[10] Yongming Liu, Sankaran Mahadevan Threshold stress intensity factor and crack growth rate prediction under mixed-mode loading: Engineering Fracture Mechanics 74 (2007)332–345
[11] Nagaraj K. Arakere, Erik C. Knudsen, Doug Wells, Preston McGill, Gregory R. Swanson Determination of mixed-mode stress intensity factors, fracture toughness, and crack turning angle for anisotropic foam material: International Journal of Solids and Structures 45 (2008) 4936–4951
[12] Mohit Pant, I.V. Singh, B.K. Mishra Evaluation of mixed mode stress intensity factors for interface cracks using EFGM: Applied Mathematical Modeling 35 (2011) 3443–3459
[13] F.J. Gomez, M. Elices, F. Berto, P. Lazzarin A generalized notch stress intensity factor for U-notched components loaded under mixed mode: Engineering Fracture Mechanics 75 (2008) 4819–4833
[14] Ali O. Ayhan Three-dimensional mixed-mode stress intensity factors for cracks in functionally graded materials using enriched finite elements: International Journal of Solids and Structures 46 (2009) 796–810
[15] Sabine Bechtle, Theo Fett, Gabriele Rizzi, Stefan Habelitz, Gerold Schneider Mixed-mode stress intensity factors for kink cracks with finite kink length loaded in tension and bending: Application to dentin and enamel:
[16] Ali O. Ayhan,UgurYücel Stress intensity factor equations for mixed-mode surface and corner cracks in finite-thickness plates subjected to tension loads: International Journal of Pressure Vessels and Piping 88 (2011) 181e188
[17] Liang Wu, Lixing Zhang, Yakun Guo Extended finite element method for computation of mixed mode stress intensity factors in three dimensions: Procedia Engineering 31 (2012) 373–380
[18] Garrett J. Pataky, Michael D. Sangid, Huseyin Sehitoglu, Reginald F. Hamilton, Hans J. Maier, Petros Sofronis Full field measurements of anisotropic stress intensity factor ranges in fatigue: Engineering Fracture Mechanics 94 (2012) 13–28
[19] M. Beghinia, M. Benedetti, V. Fontanari, B.D. Monelli Stress intensity factors of inclined kinked edge cracks: A simplified approach: Engineering Fracture Mechanics 81 (2012)120–129
[20] Chaitanya K. Desai, Sumit Basu, Venkitanarayanan Parameswaran Determination of complex stress intensity factor for a crack in a biomaterial interface using digital image correlation: Optics and Lasers in Engineering 50 (2012) 1423–1430
[21] Rui Zhang, Lingfeng He Measurement of mixed-mode stress intensity factors using digital image correlation method: Optics and Lasers in Engineering 50 (2012) 1001–1007
[22] Dr.Abdul Mubeen Experimental stress analysis 2nd Edition Dhanpat Rai & Co.(2011-12)
[23] Calvin Rans, Riccardo Rodi, René Alderliesten Analytical prediction of Mode I stress intensity factors for cracked panels containing bonded stiffeners: Engineering Fracture Mechanics 97 (2013) 12–29
[24] Paulo J. Tavares, Frederico Silva Gomes, P.M.G.P. Moreira A Hybrid Experimental-Numerical SIF Determination Technique: Procedia Materials Science 3(2014)190–197
[25] R. Evans, A. Clarke, R. Gravina, M. Heller, R. Stewart Improved stress intensity factors for selected configurations in cracked plates: Engineering Fracture Mechanics 127 (2014) 296–312

## Author Profile

**Pravin Gawande** is a student of Master of Engineering in, Advance Manufacturing and Mechanical System Design, S.S.G.M. College of Engineering, Shegaon (M.S.) India. He received the B.E. degree in Mechanical Engineering from Yashwantrao Chavan College of Engineering, Nagpur.

**Ajay Bharule** is currently holding a position as Assistant Professor in Mechanical Engineering Department of S.S.G.M. College of Engineering, Shegaon (M.S.) India. He has 6 years of experience in academics. His research interests include Stress Analysis & Fracture Mechanics.