Fatigue Analysis of Single and Double Riveted Joints

S.JosephIrudaya Raja[1], S.Sivaganesan[2] Sathishkumar G[3] R.Sridhar[4]

[2]Associate professor, Department of Mechanical Engineering

[1,3,4]Assistant Professor, Department of Mechanical Engineering,

[1,2,3,4]Vels Institute of Science Technology & Advanced Studies-Chennai, India

*Email: joerajj78@gmail.com

Abstract

SIF of multiple cracks located in opposite direction in a rectangular plate subjected to far field loading condition has been determined numerically. The comparison of SIF values for a single and multiple cracks determined for semi-elliptic crack and semi-circular crack.

Keywords: *SIF, ANSYS 15*

1. Introduction

In engineering structures, such as pressure vessels, aerospace components and the petrochemical companies, different kinds of cracks occur during service life because of fatigue loading, welding process, corrosion, or built in material defects. Many no of cracks propagate into three-dimensional cracks and it may be simplified into 3-D planar cracks for the purpose of design and analysis. Usually, for convenience, these 3D cracks are simplified into circular (a/c = 1.0), elliptical (a/c = 0.2) and straight cracks. Because of the complexity of elastic 3D cracked bodies, analytical solution is possible only for single embedded circular and elliptical cracks subjected to simple far field tensile loading in the elastic range. For a single and surface crack no closed-form solution is available, though many semi-analytical solutions have emerged.

1.1. Various Failure Modes

A great attention has been focused on fatigue damage of riveted lap joints because the phenomenon is so vital that fatigue must be considered in the design of those structures. Rivets are common mechanical fasteners, which have been most widely used in aircraft structures due to their cost effectiveness, flexibility, high resilience, durability and provide a permanent tamper-proof bond. When riveted joint structures are exposed to fatigue loading, the vicinity of rivet holes will be lead to elevated local stress concentration, at which fatigue damage will be accumulated and fatigue cracks may initiate and propagate. Furthermore, due to service efficiency, the riveted joint structures are optimized to carry out the maximum loads with the minimum weight.

Riveted joints have been identified as being prone to fatigue cracking. The fatigue loading may lead to failure of structures and components even when the load level is much lower than the ultimate strength of the material, causing serious consequences. Fatigue failure becomes a major failure mode in riveted lap joints that dynamically respond to fatigue loading by the internal pressurization of the fuselage, which need a proper treatment at the design stage.

Since the 1988 Aloha Airlines accident in which a large portion of the fuselage crown of a Boeing 737 tore separated during flight due to the fatigue cracks initiated from rivet holes in the lap joint, much attention has been paid to the fatigue damage assessment of riveted lap joint structures. The fatigue life of structures can be analysed by two different groups of approaches. The first one is based on the S–N approach which deals with the Miner damage accumulation rule, and the second one is based on fracture mechanics and Conventional fatigue assessment as applied in many industries is deterministic, that is, it results in a single estimate of fatigue life. In fact, there is a large amount of uncertainties in the fatigue damage assessment, and the parameters governing fatigue damage may be identified as random variables. The accumulated fatigue damage of structures under service loads is a stochastic process, fatigue life appears to be scattered. Probabilistic methods can be used to provide tools to better assess the effect of uncertainties and random variables on structural fatigue life and to limit the risk of unacceptable consequences at design and during the service life. The fatigue probabilistic analysis provides information about the structures in service that can be used to define the risk based maintenance actions.

The failure of the riveted joint occurs when these joints are subjected to fatigue loading. The fatigue loading of these joints causes a crack initiation and propagation which leads to final fracture of the joint. Fatigue of the pressurized fuselages of transport aircraft is a significant problem now days. Many researchers have made an attempt to ensure a sufficient lifetime and safety, and formulating adequate inspection procedures for these joints. In most transport aircraft, fatigue occurs in lap joints, sometimes leading to circumstances that threaten safety in critical ways. The problem of fatigue of lap joints has been considerably enlarged by the goal of extending aircraft lifetimes. Fatigue of riveted lap joints between aluminium alloy sheets, typical of the pressurized aircraft fuselage, is the major topic of the present work.

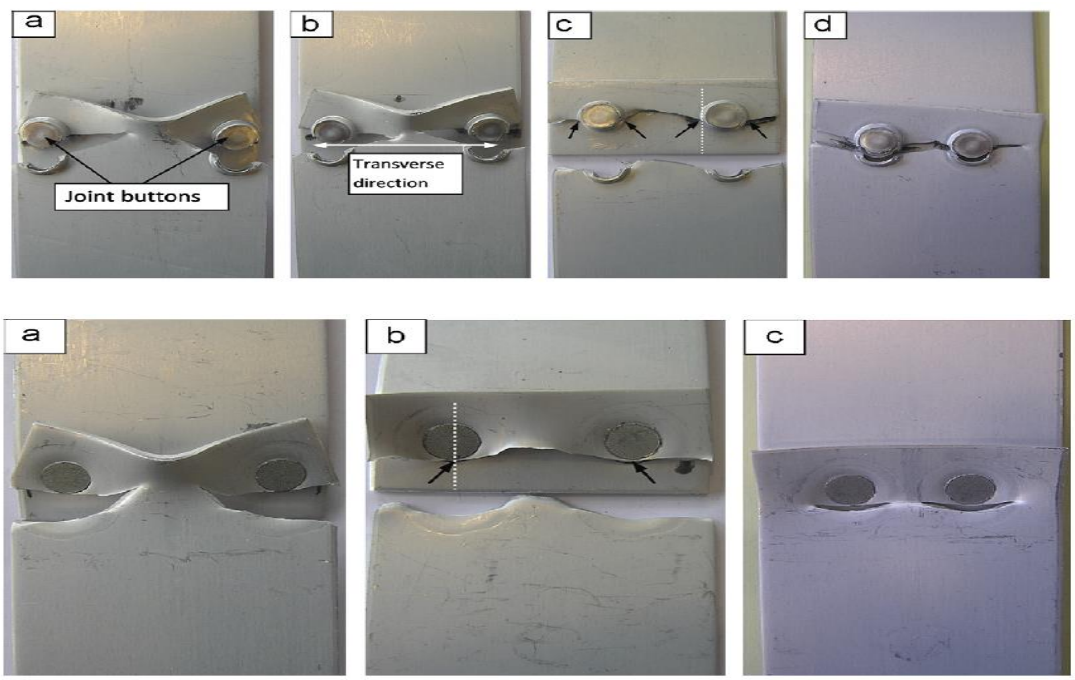


Figure 1. Image of Lap shear fatigue fracture

1.2. Objective of Project

The Main Task of the project are:

- Investigation of SIF for a single and multiple cracks in a rectangular bar located in opposite direction and subjected to far field tensile loading

- Inspect the effect of crack depth (a/d) and aspect ratios (a/c) on SIF of multiple cracks in rectangular bar.
- Decison of interaction behavior of opposite cracks located in a rectangular bar.

2. Materials and Methods

2.1. Description of The Finite Element Model

The arithmatical estimation of SIF for cracks located in inverse direction in a rectangular bar subjected to tensile loading condition was accomplish using ABAQUS Finite Element software. A 3-D rectangular bar with surface cracks of same size located in inverse direction was considered for the reasoning.. The dimensions of the rectangular bar are listed below. Two aspect ratios (a/c) and four crack depth ratios (a/d) were considered in the present work to understand the effect of these variables on SIF. The meshed model of the rectangular bar is shown in Fig.1b. Semi minor and major axis 'a' and 'c' correspond to the crack depth and transverse length of the crack.

Length of the bar	:	100 mm
Width of the bar	:	50 mm
Height of the bar	:	50 mm
Crack depth ratio (a/t)	:	0.1, 0.2, 0.3,0.4 and 0.5
Diameter of the revert	:	3mm
Material used	:	ALLUMINIUM

2.2. Specification of crack front and crack extension direction

The rectangular bar subjected to multiple cracks located in opposite direction. The crack front is the region which defines the first contour. The crack front in the rectangular bar can be considered to be equivalent to the crack line in three dimensional problems. The direction of the virtual crack extension can be specified at each node along the crack front by specifying either the normal to the crack plane (n) or by specifying the crack extension direction. Since the present problem is 3-Dimensional in nature the crack propagation direction can not be predicted and thus, normal to the crack plane approach was used to define the crack extension direction.

In most of the fracture problems, the singularity at the crack tip should be considered for small strain analysis since it improves the accuracy of SIF values. To obtain a square root singularity, collapsed second order elements are used. To create a 3D crack tip singularity, 20-node brick and 27-node brick elements can be used with a collapsed face. If all the midface nodes are moved to their quarter points closest to the crack line, $\frac{1}{\sqrt{r}}$ singularity can be modeled. In the present work several contours have been considered around the crack front region and the top surface of the bar is constrained for all degrees of freedom and a tensile load is applied at the bottom surface.

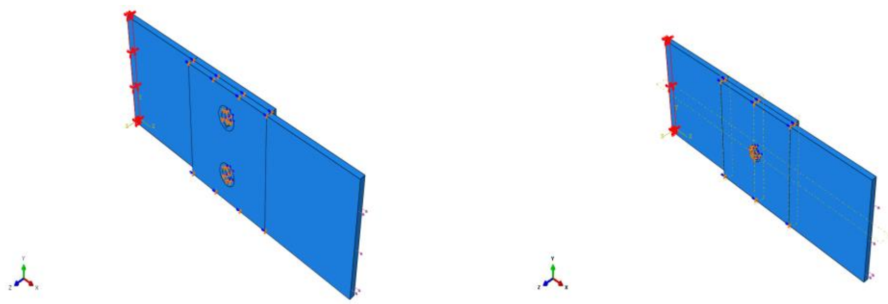


Figure 2. FE model with boundary condition

2.3. Finite Element Mesh

Twenty-node brick isoperimetric elements (C3D20) were used to model both plates. Each plate contains 3648 elements and has two elements through the thickness. These elements use quadratic interpolation (quadratic elements or second-order elements). The rivets were modeled with 8-node brick elements (C3D8). Each rivet contains 2448 elements. These elements use linear interpolation in each direction (linear elements or first-order elements). The joint was modelled with no interference (perfect fit joint). Friction between the lap joint components was not taken into account (LT = 100%).

A detail of the mesh used in the contact area is shown in Fig. 2. Several contact surfaces were modelled using 27-node brick elements (C3D27): contact between the two plates to avoid the interpenetration due to bending; contact between the rivet and plates; and contact between rivet head and each plate. A total of 13 contact pair surfaces were created. The boundary conditions used in the model are shown in Fig.The load eccentricity effect is evident in this figure, where displacements were enlarged in post-processing of the FEM analysis, to highlight this effect. A detail of the plate's separation is shown in fig.

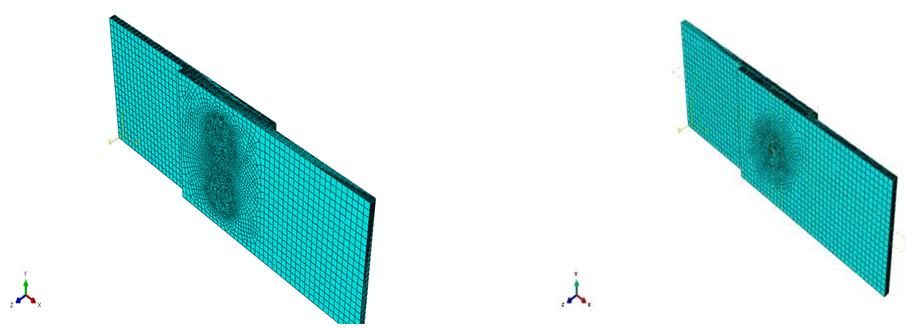


Figure 3. FE model with meshing

2.4. Determination OfSIF Using Fe Method

The present paper intends to give an overview of different types of problems with different levels of complexity which have to be addressed by aircraft stress analysts:
(i) In the first part, the influence of residual stresses due to the cold-working process on the fatigue behaviour of 2024-T3 Al open hole specimens is discussed. The residual stress field due to a standard cold-expansion technique was quantified by X-ray measurements and finite element analysis (FEA) modelling. The effect of the residual stresses on the specimens fatigue lives and on the fatigue striation spacing was quantified and discussed.

(ii) The second part discusses the fatigue behaviour of a single rivet lap joint. This specimen can be regarded as a slice of a riveted lap joint with various columns of rivets, for a specific pitch. Problems such as the stress intensity fac- tor calibration of symmetrical/asymmetrical cracks and the load transfer between the rivets and plates was quantified using three-dimensional FEA. The estimation of rates of crack propagation based on fatigue striation measurements is also presented.

(iii) The third part consists of the analysis of a riveted lap joint panel with 3 rivet rows and 15 rivet columns. At this stage, the problem ofMSDis discussed and an approximate predictive model for fatigue crack propagation, initially proposed by Silva et al. and based on the FRANC2D/L finite element programme is presented. Each one of the three parts initiates with a concise reference to relevant previous work. The main features of the experimental work are then presented followed by a discussion of the experimental and numerical results obtained. The emphasis is on the present authors' own experimental or modelling work. It is outside the scope of this paper to present a general review of the subject, and because of space limitations just a few results and procedures proposed by other authors are mentioned.Hence the various crack propagation will be mentioned in the following fig.

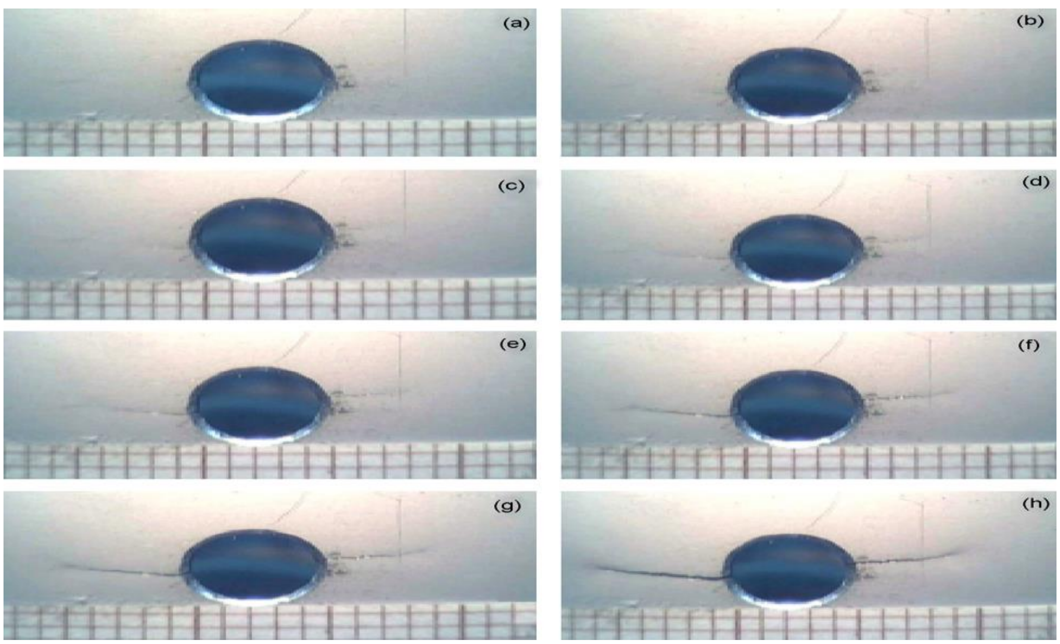


Figure 4. crack propagation in plates

3. Results And Discussion

3.1. Von Mises Stress

SIF evaluation of a rectangular plate chances to multiple cracks located in opposite direction has been carried out using 3-D finite element analysis. Figure shows a good agreement between present SIF values with results of Raju and Newman. The available SIF solution of Raju and Newman is limited to single crack model subjected to far field tension loading condition whereas, in the present work SIF solution several cracks located in opposite direction has been treated.

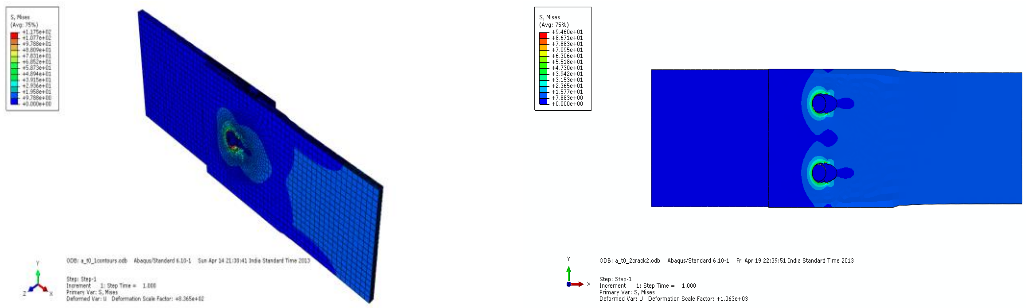
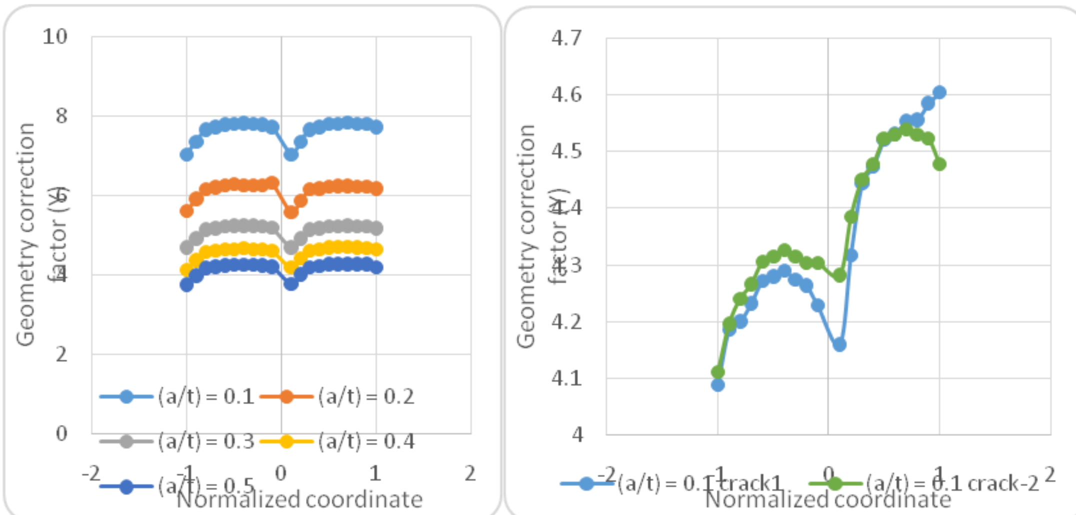
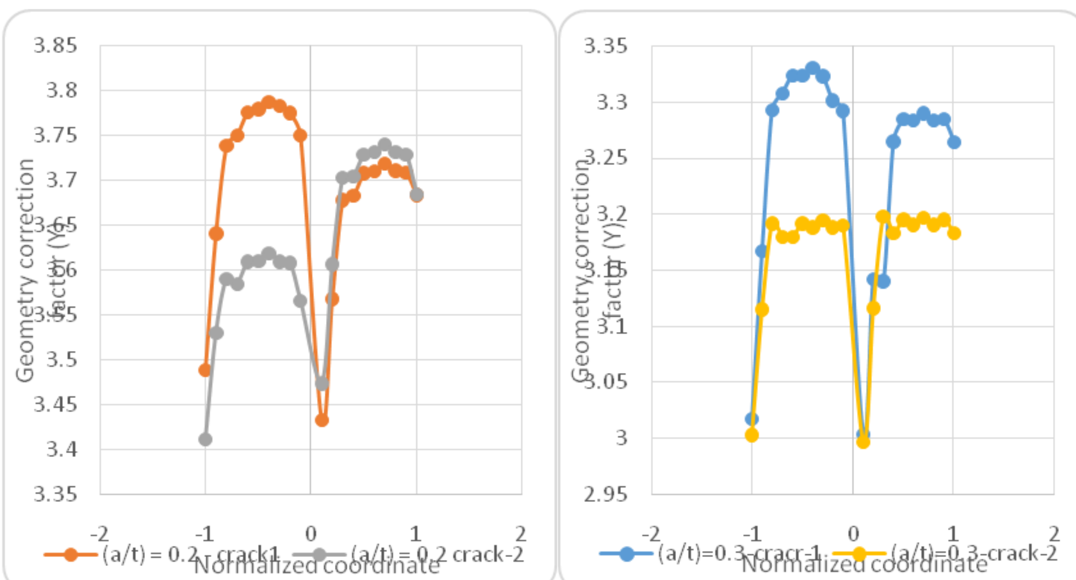


Figure 5. Result of von mises stress in single rivet& double rivet



F

igure 6. Variation of geomentry correction factor (a/t) = 0.1 in single riveted plate



F

igure 7. Variation of geomentry correction factor (a/t) = 0.2& 0.3

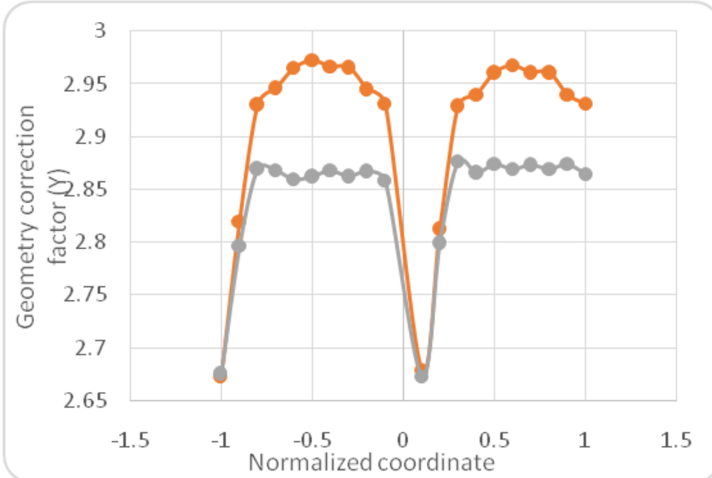


Figure 8.Variation of geomentry correction factor (a/t) = 0.4

3.2. Effect of Crack Interaction on SIF

the reciprocal effect of opposite cracks in a rectangular plate subjected to triangular cracks for various crack depth ratios. The reciprocal factor is calculated by the relation

Interaction factor = $K_{1,1} / K_{1,2}$

Where

$K_{1,1}$– mode I SIF for the front face crack

$K_{1,2}$ _ mode I SIF for the rear face crack

It is detected that the interaction effect is more pronounced at higher crack depth ratios.

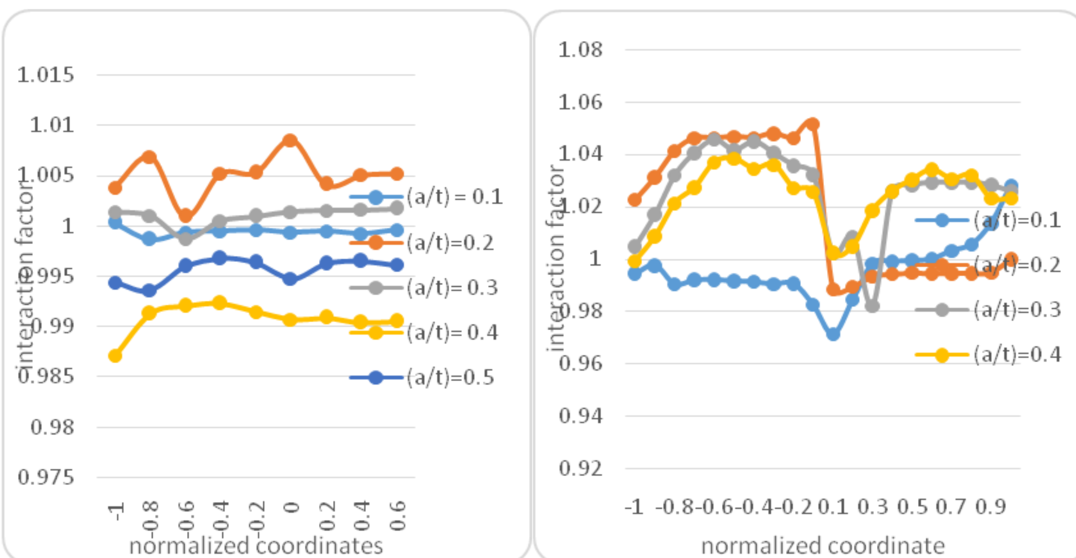


Figure 9. Effect of crack interaction on SIF in single Double rivet

The interaction factors of triangular cracks for various crack depths are listed provides the interaction factors for a triangular crack. Thus one can use the interaction table while determining the SIF for a multiple cracked bodies.

Table 1.Values of crack interactin in single rivet

	(a/t)=0.1	(a/t)=0.2	(a/t)=0.3	(a/t)=0.4	(a/t)=0.5
-1	1.000292	1.003788	1.001395	0.987069	0.994393
-0.8	0.998604	1.006827	1.000968	0.991251	0.993574
-0.6	0.999329	1.000947	0.998728	0.991997	0.995939
-0.4	0.999468	1.005197	1.000459	0.992272	0.996729
-0.2	0.999604	1.005273	1.000911	0.991463	0.996328
0	0.999342	1.008523	1.001365	0.990704	0.994722
0.2	0.999475	1.004087	1.001476	0.990835	0.996233
0.4	0.99921	1.005032	1.001593	0.990373	0.996439
0.6	0.999604	1.005155	1.001709	0.990473	0.996112
1	0.999601	1.023503	1.001264	0.990056	1.002632

The interaction factors of triangular cracks for various crack depths are listed provides the interaction factors for a triangular crack. Thus one can use the interaction table while determining the SIF for a various cracked bodies.

Table 2.Values of crack interactin in double rivet

	(a/t) = 0.1	(a/t) = 0.2	(a/t) = 0.3	(a/t) = 0.4
-1	0.994488	1.022625	1.004655	0.999134
-0.9	0.997545	1.031253	1.016902	1.008564
-0.8	0.990404	1.041384	1.031873	1.021265
-0.7	0.992031	1.046221	1.040412	1.027294
-0.6	0.992105	1.046211	1.045463	1.03701
-0.5	0.991645	1.046803	1.041473	1.03832
-0.4	0.99131	1.046388	1.044784	1.03448
-0.3	0.990451	1.048023	1.04041	1.036071
-0.2	0.990665	1.046331	1.035641	1.027209
-0.1	0.982528	1.051573	1.032171	1.025495
0.1	0.971374	0.988365	1.002183	1.002312
0.2	0.984496	0.989397	1.0084	1.004783
0.3	0.998264	0.993215	0.98214	1.018442
0.4	0.99908	0.994102	1.02579	1.025876
0.5	0.999431	0.994531	1.028114	1.030284
0.6	1	0.99434	1.029275	1.034192
0.7	1.003177	0.994449	1.029215	1.030558
0.8	1.005571	0.994437	1.029275	1.032038
0.9	1.013664	0.994726	1.028114	1.023027
1	1.028065	0.999842	1.025794	1.023191

Thus this chapter describes the various graphs and tabulation of the crack interaction and geometry correction . And gives us the sif and crack propagation path.

4. Conclusion

This chapter discusses on the overall results presented in the earlier chapters. Base on the overall results, it can be improved further and include several recommendations for future research especially in structural behaviour to any system.

SIF of numerous cracks placed in opposite direction in a rectangular plate subjected to far field loading condition has been determined numerically. The comparison of SIF values for a single and multiple cracks reveals the following conclusions.

1. SIF values are greater for semi-elliptic crack than semi-circular crack irrespective of the crack depth ratios considered. Thus one can expect higher crack growth rate at the middle region of a semi-elliptic crack compared with semi-circular crack
2. As the aspect ratio increases SIF values decreases considerably along the crack front. This is due to curvature effect of the surface cracks with increasing aspect ratios
3. The interaction effect of opposite cracks is marginal at the middle region of the crack front whereas at the crack surface region the interaction effect is more significant.
4. The effect of interaction effect increases with crack depth ratio and it is higher for the deep cracks.

References

[1]. Schijve J. Fatigue of structures and materials. Boston, MA: Kluwer Academic, Dordrecht; 2001.
[2]. Schijve J. The significance of flight-simulation fatigue tests. In: 13th Symposium of the international committee on aeronautical fatigue (ICAF), Pisa, Italy; 1985.
[3]. Segerfrojd G. Fatigue of mechanically fastened joints. Doctoral thesis, KunglTekniskaHogskolan. Stockholm: Royal Institute of Technology; 1999.
[4]. Segerfrojd G, Blom AF. Fatigue behavior of mechanical joints: a state of the art overview. In: 7th International fatigue congress,FATIGUE 99, Beijing, China; 1999.
[5]. KarlsonHibbitt and Sorensen Inc. Abaqus, Fracture Mechanics (course notes); 1991.
[6]. Harris Charles E, Piascik Robert S, Neman Jr James C. A practicalengineering approach to predicting fatigue crack growth in riveted lap joints. In: International Conference on Aeronautical Fatigue (ICAF). W.A.: Seattle; 1999.
[7]. Owen DRJ, Fawkes AJ. Engineering fracture mechanics: numerical methods and applications. Swansea, UK: Pineridge Press; 1983.Henshell RD, Shaw KG. Crack tip finite elements are unnecessary. Int J Numer Meth Eng 1975;9:495–507.
[8]. Barsoum RS. On the use of isoparametric finite-elements in linear fracture mechanics. Int J Numer Meth Eng 1976;10(1):25–37.
[9]. David Broek. Elementary engineering fracture mechanics. MartinusNijhoff; Distributed by Kluwer, Dordrecht, The Netherlands; Boston Hingham, MA, 4th rev. edition; 1986.
[10]. Couroneau, N. and J. Royer (1998) Simplified model for the fatigue growth analysis of surface cracks in round bars under mode I. International Journal of Fatigue, 20, 711-718.
[11]. Dragoni, E. (1996) Effect of pitch on the fatigue strength of steel bolts. International Journal of IMechE, 211, 591-599.
[12]. Guo, W., H. Shen, and H. Li (2003). Stress Intensity Factors for elliptical surface cracks in round Bars with different Stress concentration coefficient. International Journal of Fatigue, 25, 733-741.
[13]. Mackay, T.L. and B. J. Alperin, (1985) Stress intensity factors for fatigue cracking in high strength bolts. International Journal of Engineering Fracture mechanics, 21, 391-397.
[14]. Majzoobi, G.H., G.H. Farrahi, and N. Habibi (2005a) Experimental evaluation of the effect of thread pitch on fatigue life of bolts. International Journal of Fatigue, 27, 189-196.
[15]. Noda, N.A., and Y. Takase (2003). Generalized Stress Intensity Factors of V-shaped notch in a round bar under torsion, tension, and bending. International Journal of Engineering Fracture Mechanics, 70, 1447-1466.
[16]. Raju, S., and J.C. Newman (1979) Stress intensity factors for a wide range of semi-elliptical surface cracks in finite thickness plates. International journal of Engineering Fracture Mechanics, 11, 817-829.
[17]. Shih, Yan-Shin., and Jien-Jong Chen (2002). The stress intensity factor study of an elliptical cracked shaft. International Journal of Nuclear Engineering and Design, 214, 137-145.
[18]. Shin, C.S., K.C. Man and C.M. Wang (1993). A practical method to estimate the stress concentration of notches. International Journal of Fatigue, 16, 242-256.
[19]. Shivakumar, K.N., and J.C. Newman (1991) Stress intensity factors for large aspect ratio surface and corner cracks at a semicircular notch in tension specimen. International Journal of Engineering Fracture Mechanics, 38, 467-473.
[20]. Toribio, J., J.C Matos, B. Gonzalez, and J. Escuadra (2009) Numerical modeling of crack shape evolution for surface flaws in round bars under tensile loading. International Journal of Engineering Failure Analysis, 16, 618-630.