International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 8, October - 2012

Experimental And Numerical Analysis Of Critical Stress Intensity Factor Of Pressure Vessel Material Used In Disc Shaped Compact Specimen

B. C. Patel[1], Bharat Gupta[2] and Abhishek Choubey[2]
[1]*M.Tech Student, Mech. Engg. Dept., O.I.S.T., Bhopal*
[2]*Professor, Mech. Engg. Dept., O.I.S.T., Bhopal*

Abstract

To predict the stress state ("stress intensity") more precisely near the tip of a crack caused by a inaccessible load or residual stresses Stress intensity factor (K) concept is widely used in fracture mechanics. The present work emphasis on the comparison between the experimental and numerical evaluation of the residual stresses Stress intensity factor (K). The work is carried out to test mechanical properties of pressure vessels materials IS 2062 and SA 516 Gr-70 with different thickness 12,16,18 and 20mm and critical stress intensity factor of disc shaped compact specimen DC(T) which have crack/width ratio 0.5 as suggested by ASTM E-399 using experimental and numerical techniques.

1. Introduction

Internal, surface, semi-elliptical cracks are occasionally found in pressure vessels and pipes during service or manufacturing. The crack may exist within a component due to manufacturing defect like slag inclusion, cracks in a weldment or heat affected zones due to uneven cooling and presence of foreign particles. Subsequent fatigue and fracture analyses of such cracks require determination of stress intensity factors for a wide range of encountered crack shapes and sizes. Fracture mechanics is based on the implicit assumption that there exists a crack in a work component. The crack can be prepared in different shapes i.e. a hole, a notch, a slot, a re-entrant corner etc. A dangerous crack may be generated and developed during the service of the component. Initially, the fluctuating load nucleates a crack, which then grows slowly and finally the crack growth rate per cycle picks up speed. Thereafter comes the stage when the crack length is long enough to be considered critical for a catastrophic fracture failure.

In the modern industrial world many components of are subjected to fluctuating loads and subsequently may fail through fatigue. In fact, failure through fatigue is so general that more than 80% failures are caused by fluctuating loads. Many researchers are currently working for the development in this field. However, suitable and effective methods to control fatigue failures are still not effectively developed. A critical structural component should be regularly checked to detect fatigue cracks through non-destructive tests. These has led to the development of excellent method of crack identification, such as ultrasonic crack detection, X-rays or radiation filming, detecting through monitoring acoustic emission, magnetic flux method, decoration of surface cracks through die-penetration, etc.

The present work standard disc shaped compact specimen DC(T) is considered as suggested by ASTM E-399 with various thicknesses. Using the UTM experiments are performed on the components. Subsequently the components are modelled in Pro-Engineer software and analysed in ANSYS 13.0 software with Westergaard method to validate the results. Following sections describe the work done in this area and the methodology in details.

2. Literature Review

Webster et al. investigated the failure of thick walled tubing subjected to internal pressure [1]. Thick-walled tubing is used for variety of applications in the chemical, nuclear and armaments industries where high internal pressure has to be withstood. If this pressure is cyclic, initiation and propagation of cracks by fatigue may take place with the ultimate risk of failure by fast fracture.

Usually fatigue crack in thick walled cylinders initiate at the bore and propagate in a radial plane in the manner illustrated (Figure.1).

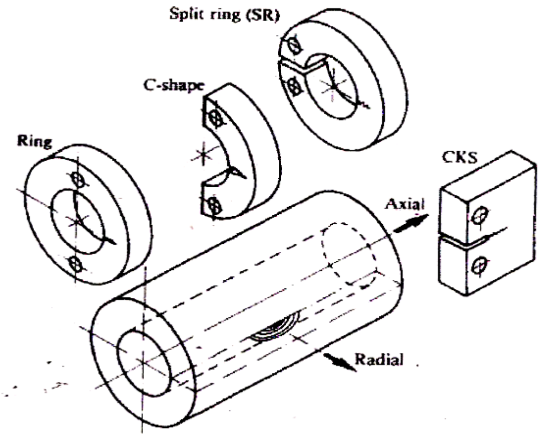


Figure.1 Test pieces for fatigue crack growth studies of thick walled tubing

Evans et al. [2] described a method of testing cylinder wall material based on the compact tension specimen design. The test requires the manufacture of a special loading fixture which can be used in a conventional testing machine. The test differs from the test using the well-known C-shape specimen because fracture propagating in the direction of the cylinder axis is simulated in the new test. With this geometry (Figure. 2) the specimen width is unrestricted but the specimen thickness is equal to the full wall thickness. Some examples of tests on specimens taken from an aluminum alloy cylinder were given. The authors have tested a number of specimens taken from the walls of aluminium alloy cylinders (158 mm internal diameter, 8 mm wall thickness).

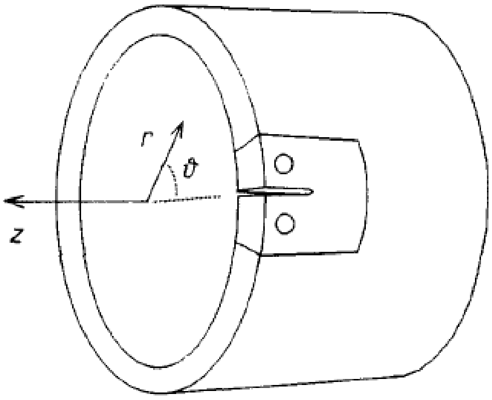


Figure 2 Specimen taken from a cylinder wall.

Guerrero et al. calculated the behaviour of a pressure vessel (PV) made of high strength steel(P500) subject to the designed loads and assuming the existence of the “worst case” crack allowed by the European standards in order to demonstrate the shape use of this steels and the too conservative design rules currently applied by the pressure vessel manufacture codes [3]. It was demonstrated that the presence of cracks on pressure vessels made of high strength P500 steel non-detected during non-destructive test do not endanger the safety of vessel.

The three principal stress distributions along the crack tip are presented in Figure. 3. The axial stress is normal to the surface of crack and the one that causes the crack to open.

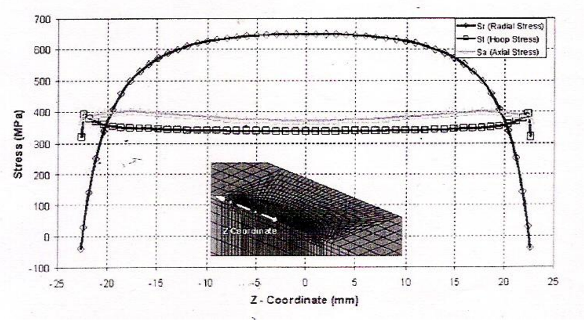


Figure 3 The three principal stress distributions along the crack tip

Zheng et al. has discussed method of calculating stress intensity factors for cracks subjected to complex stress[4]. The method is based on the use of generalized weight functions.

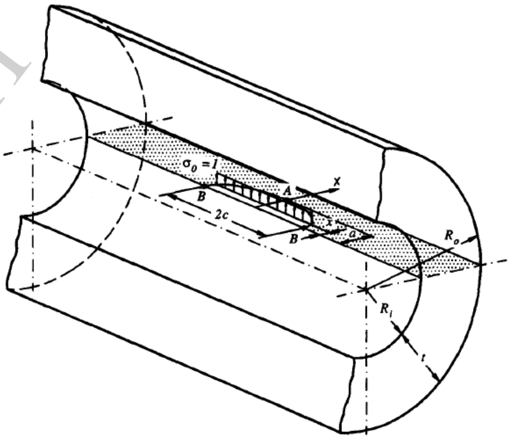


Figure.4 Internal, radial-longitudinal, surface, semi-elliptical crack in a cylinder

It has been shown that the weight function enable the determination of stress intensity factor for variety of geometrical and stress field configuration.

Ishio et al. in their paper, the results of fracture toughness and mechanical tests of pure niobium plates (3-mm-thick) and welded joints for superconducting cavities at 4K are reported (Figure 5) [5].

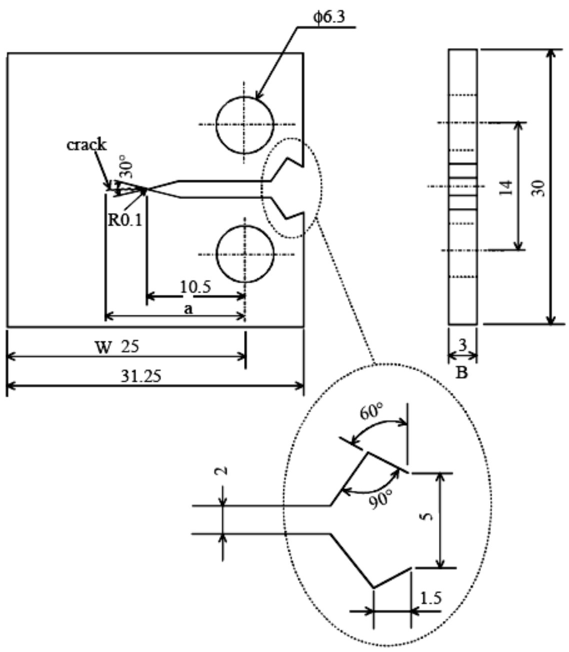


Figure 5. Shape of fracture toughness specimen (1/2 CT)

Shahani et al. have studied that steady state thermo elasticity problem in a thick-walled cylinder containing an internal axial semi-elliptical crack is solved analytically [6]. Thermal and mechanical boundary conditions are prescribed on the inner and outer surface of the cylinder. The steady state solution of the thermo elasticity problem is derived analytically and then, the stress intensity factors are extracted for the semi elliptical crack using the weight function method. The results show to be in accordance with that cited in the literature in the special cases. It is shown that the critical point of the crack front displaces from the deepest to the surface points at certain geometries for an internally pressurized cylinder, which can indicate the point of starting the crack growth.

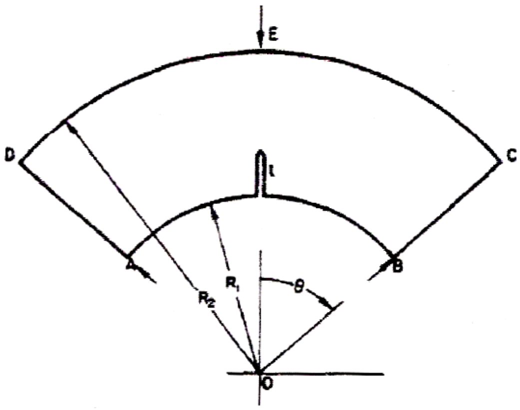


Figure.6 Circular ring section with crack

Peter et al. considered the problem in a circular ring segment with a radial crack emanating from a surface with the smaller radius [7]. Pure bending and three point loading are chosen for solution. The problem is solved using modified mapping technique and partitioning. This procedure is used to calculate stress intensity factor and displacement for primary loading system which is the bending couples applied at the ends BC and AD in Figure.6

3. Experimental Methodology

The K_{1C} test for DC[T] specimens is summarized as follows:

1. To begin with, K_{1C} of specimen is guessed. Then, the specimen is prepared following several dimensional constrains which are based on the guessed value of $K_{1C.}$ The crack tip is made very sharp with a fatigue growth.
2. The specimen is pulled in a tensile machine to obtain a relation between a load and a crack mouth opening displacement. This relation provides the critical load P.
3. Accounting for the crack length and geometry of specimen the stress intensity factor K corresponding to P is determined using LEFM. If K satisfies all the constrains on the geometry of the specimen and of, fatigue growth, it becomes K_{1C}.
4. Critical stress intensity factor indicates the upper limit of SIF which can be allowed in the component. In this work, critical stress intensity factor has been found experimentally for pressure vessel steel IS2062 and SA516 Gr.70.
5. Using disc shaped tension specimen as suggested in ASTM E399. Variation of critical stress intensity factor with thickness of specimen has been studied.
6. As suggested in ASTM E399, load V/s load line displacement is needed for the calculation of the force P_Q.

Hence, the UTM of suitable capacity is used. The data acquisition system was chosen such that required graph of load V/s load line displacement is obtained. The least count of machine is 0.1KN and 0.1mm in force and displacement respectively.

3.1 Disc shaped Compact specimens by ASTM:-

As per ASTM, various shaped of compact specimens are available for carrying out the experimental work [8]. Out of them, the following disc shaped compact specimen is selected for experimental work. The geometry is shown in Figure.7.

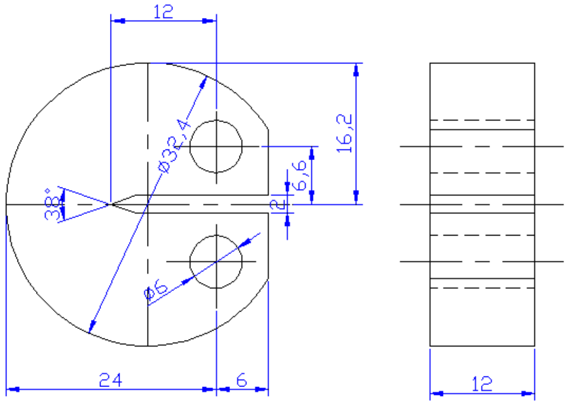


Figure 7. Geometry of disc shaped compact specimen for 12 mm thickness

Figure 8 DC[T] Specimen 12mm thick having wire-cutting notch of an angle 38^0.

Specimens are prepared from two materials IS2062 and SA516 Gr-70 for experiment. Specimens are prepared for the thickness of 12 mm, 16 mm, 18 mm & 20 mm from both the materials. Specimen for 12 mm thickness having wire-cutting notch of an angle 38^0 is shown in Figure 8.

The Specimens are then loaded one by one in the Universal Testing Machine TUE-CN-1000KN of Fine Spavy Associates make as shown in Figure 9 to carry out the experiment.

Figure 9. Experimental set-up showing crack propagation in loaded specimen

3.2 Experimental Result:-

Load vs. Cross head travel plots are obtained from the UTM. The plot for Load vs. Cross head travel for 12mm thickness specimen (SA516 Gr-70) is shown in Figure 10.

The graph generated is used for calculating the value of peak load P_Q considering 5% Secant line, which is then used for calculating critical stress intensity factor (K_{1C}).

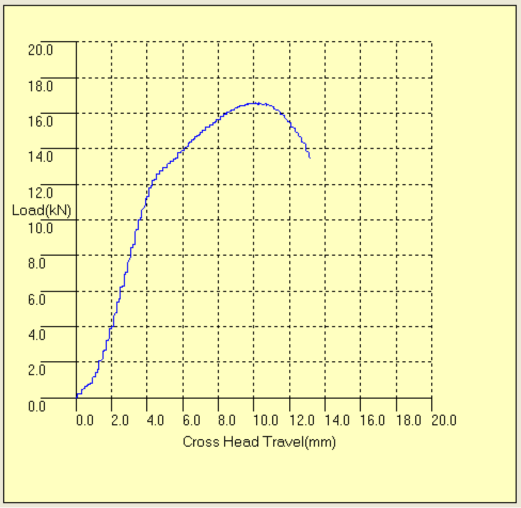


Figure 10. Load vs. Cross head travel for 12mm thickness specimen (SA516 Gr-70)

The experimental values for critical stress intensity factor are calculated using following equation and shown in Figure 11and Figure 12 (in red line).

$$K_{1C} = \frac{P}{BW^{1/2}} f\left(a/W\right) \text{ MPa.m}^{1/2}$$

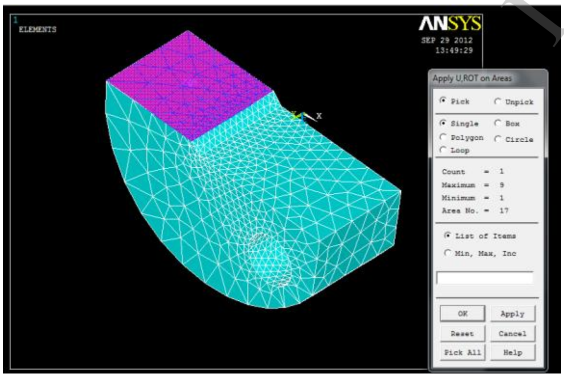
$$where,\ f(a/W)=\frac{(2+a/W)}{(1-a/W)^{1/2}}[0.76+4.8a/W$$
$$-11.58(a/W)^2+11.43(a/W)^3-4.08(a/W)^4]$$

4. Numerical Methodology

There exists several commercial finite element analysis software like ANSYS, ABAQUS, FRANC-3D, ZEN CRACK, ADINA etc. which can be employed to carry out finite element [FE] simulation disc shaped compact specimen. In the present study 3D FE analysis of disc shaped compact specimen is carried out to complete the Y component of stress intensity factor solution for SA516 FGr-70 and IS-2062 material. The obtained FE results are compared with experimental results.

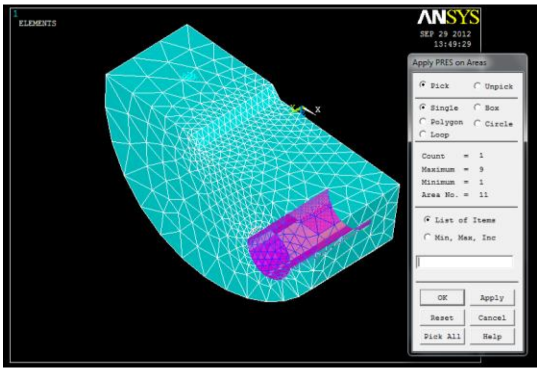
The present work includes numerical analysis to calculate the Y component of stress in Y direction for the cases at different applied loading conditions for 3D modelling. In the present work, component of stress in Y direction are obtained from simulation of DC [T] specimen in ANSYS using Westergaard method.

By looking at the symmetry of FE model, conditions only half the component tension specimen was modelled in 3D. Further the use of real constant in ANSYS for 3D model is not possible. Hence it is more complicated FE simulation. Following the step by step procedure as shown in the following Figures 11, 12 and 13, Y-component of stress can be obtained.



● Pick ○ Unpick
● Single ○ Box
○ Polygon ○ Circle
○ Loop
Count = 1
Maximum = 9
Minimum = 1
Area No. = 17
● List of Items
○ Min, Max, Inc

Figure. 11. Applying boundary condition



● Pick ○ Unpick
● Single ○ Box
○ Polygon ○ Circle
○ Loop
Count = 1
Maximum = 9
Minimum = 1
Area No. = 11
● List of Items
○ Min, Max, Inc

Figure. 12 Applying Load

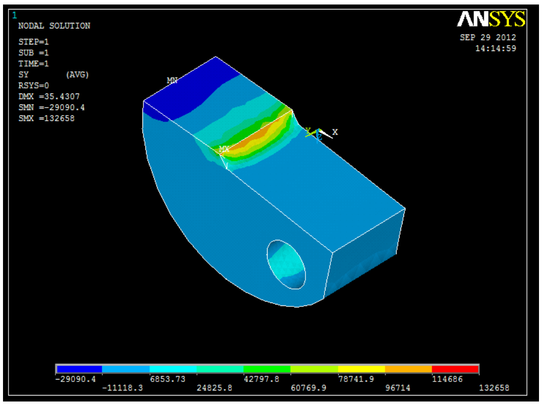


Figure. 13 Y-component of stress

After getting stress in Y- direction (σ_Y) Westergaard method is employed as under.

$$K_c=\frac{\sqrt{2\pi r}\sigma_Y}{\cos\frac{\theta}{2}(1+\sin\frac{\theta}{2}\sin\frac{3\theta}{2})}$$

From the above equation critical stress intensity factor have been found.

5. Results and Discussions

The Experimental and Numerical values of critical stress intensity factor are then compared with the corresponding values of specimen thickness (12mm. 16mm, 18mm and 20mm) for the two materials SA516 FGr-70 and IS-2062 respectively.

The comparison of critical stress intensity factor for SA516 Gr-70 and IS-2062 materials are shown in form of graphs in figures 14 and 15 respectively.

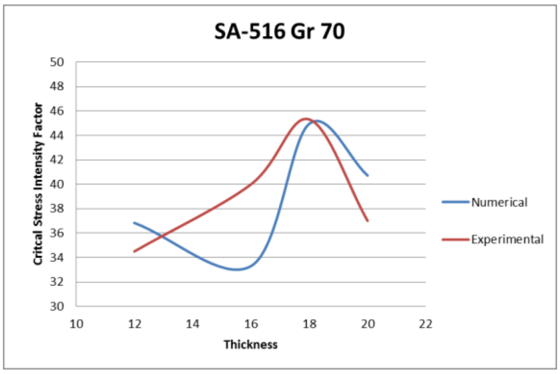


Figure 14. K_{IC} Vs. Specimen thickness for SA516 Gr-70 material

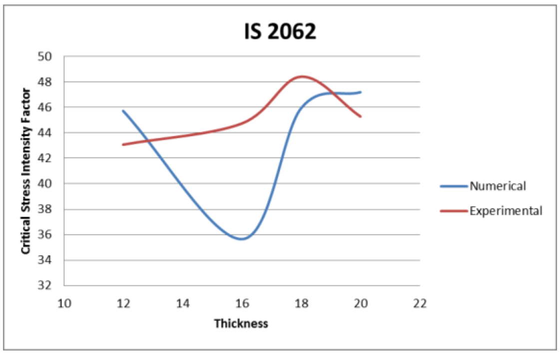


Figure 15. K_{IC} Vs. Specimen thickness for IS2062 material

Nomenclature:-

a	crack length
B	thickness of the specimen
K_{1C}	Critical stress intensity factor for Mode-I
K_Q	Critical stress intensity factor
P_Q	Load at peak
W	width of the specimen
DC[T]	Disc shaped compact specimen
LEFM	Linear elastic fracture mechanics
SIF	Stress Intensity Factor

Conclusion:-

The paper presents, experimental values of critical stress intensity factor are obtained by performing the test as per ASTM standard E-399. Also the numerical values of critical stress intensity factor are obtained by modelling in Pro-E and analysing in ANSYS 13.0.

From the calculated values for both the materials it is observed that for both IS 2062 and SA516 Gr-70 materials the experimental and numerical results have similar nature of variation and very less deviation except for 16 mm thickness.

References

[1]Webster G.A. ‘Stress intensity factor for cracked c-shaped and ring typed terst piece’

[2] Evans J.T., Kotsikos G. and Robey R.F., ‘A Method For Fracture Toughness Testing Cylinder Material.’ Engineering Fracture Mechanics Vol. 50, No. 2, pp. 295 31)0, 1995.

[3]Guerrero and Belzunce, ‘Fracture analysis of pressure vessel made of high strength steel HSS’ Engineering failure analysis, 2008

[4] Zheng x.j., kiciak a. And glinka, g. Weight functions and stress intensity factors For internal surface semi-elliptical crack in Thick-walled cylinder Engineering Fracture Mechanics,1997, Vol. 58, No. 3, pp. 207-221.

[5] Ishio K. Fracture Toughness And Mechanical Properties Of Pure Niobium And Welded Joints For Superconducting Cavities At 4 K.

[6] Shahani & Nabavi. ‘Closed Formed Stress Intensity Factors For A Semi Elliptical Cracked In A Thick Walled Under Thermal Stress’, International Journal Of Fatigue,(2006)

[7] Peter G. Tracy, ‘Analysis of a radial crack in a circular ring segments’, Engineering fracture mechanics, 1975.

[8]ASTM Standards E-399

[9] Anderson, T.L., ‘Fracture mechanics: Fundamentals and Applications, CRC’ Press Book, 2004.