International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 12, Issue 9 (September 2016), PP.12-16

Structural Durability Analysis of AL2024 T4

Vidyaprasad Desai[1], Parth Gunjal[2], Prateek Chougule[3]
[1]*Sinhgad College of Engineering, SCOE, Pune University, Pune*
[2]*Mahindra Vehicle Manufacturing LTD., MVML,Chakan.*
[3] *Flora Institute of Technology, Pune, Master of Engineering.*
[1]desai.vidyaprasad@gmail.com
[2]parth.gunjal@gmail.com
[3] *pratiknc22793@gmail.com*

Abstract:- This paper concerns the stress concentration due to the geometric discontinuity in the structure and its effect on durability. The typical aluminium 2024-T3 alloy sheet with the holes provided for the riveting purpose is considered as a specimen. The numerical investigation is carried out to predict the behaviour of a plate with multiple holes under the fatigue. The effect of manufacturing processes and other geometrical parameters on the fatigue life is studied to increase the fatigue life. The study is verified by experimentation

Keywords:- Fatigue Life, Durability, Stress concentration, Aluminium AL2024 T4, Fatigue life optimization

I. INTRODUCTION

Fatigue failure occurs due to the application of fluctuating stresses or varying stress. The fatigue failure occurs at much lower stress than the limiting static stress. It has been estimated that fatigue contributes to approximately 90% of all mechanical service failures. Fatigue failure is much pivotal in the case of Aluminium since unlike steel, it does not have any limiting stress for the infinite cycle fatigue. But the Aluminium sheets are preferred in the aerospace industry because of their high strength to weight ratio. So to confirm the safe working, it becomes necessary to ensure the safety under fatigue loading. Durability analysis plays a vital role to estimate the reliable life of a component. The modern numerical methods facilitate durability estimation in short period of time using various FEA packages.

Aircrafts are powered with jet engines which cause vibrations. It is the reason why riveting is preferred than the welding in the aircraft body. In the riveting process, the holes are blanked in the sheet. These holes cause stress concentration. The vibration due to the jet engine produces the cyclic loading effect in the sheet.

The stress concentration due to holes is investigated primarily using FEM software. The parametric study is done in the FEM software to estimate the effect of geometric dimensions on the stress concentration. For fatigue analysis, the loading conditions, S-N curve and other mechanical properties are elicited by literature review. The thickness of the sheet and the limiting dimensions related to holes are found by analyzing the sheet under specified conditions. Cumulative fatigue damage is also studied to evaluate the life. Manufacturing processes greatly affect the fatigue life of a metal. The various methods by which the fatigue life can be increased are also discussed in the paper.

II. STRESS CONCENTRATION

The distortion in stress line occurs due to the geometric discontinuities, causing stress concentration. Stress concentration plays an important role in fatigue failure. This stress concentration can be reduced by introducing other discontinuity also like notched or the extra holes. So it is required to find the effect of discontinuity on the plate arranged in different arrays on stress concentration factor and fatigue life. It is also required to find the optimum positions and size of holes to minimize the stress concentration factor and to maximize durability.

h – Horizontal distance between two holes centres in mm
v – Vertical distance between two holes centres in mm
r- Radius of a hole in mm

It is assumed that the geometric discontinuity will vary by changing these parameters-

I. v/h ratio
II. h/r ratio
III. v/r ratio

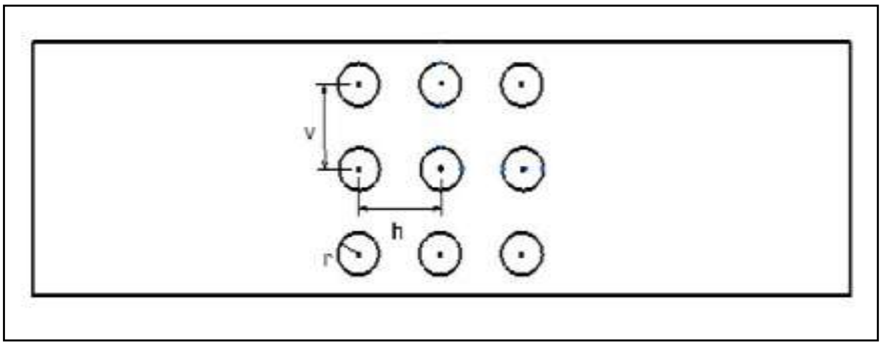

Fig 1: Geometric representation of a plate with multiple holes

III. NUMERICAL INVESTIGATION

It would be a much tedious task to simulate the real life scenario. So in order to simplify the process, a geometry of prototype was modelled using software package. The plate measured 65 cm X 20 cm with a thickness of 3mm .The 9 holes were pierced in the middle of the plate with maintaining the symmetry. The middle hole was observed as it would reflect the real time problem situation. The geometric dimensions namely ‘r’, ‘v’ & ‘h’ are ascribed to parametric simulation. Initially, the values are set to 3, 4, and 5 respectively.

The Hex-dominant meshing method is used, as the Hex elements have better skewness. The element size is varied to get the convergence by h-method. Convergence is achieved at 0.25 mm as shown in Fig 3.The meshing is as shown in Fig 2.The mesh quality is verified as per standard requirements.

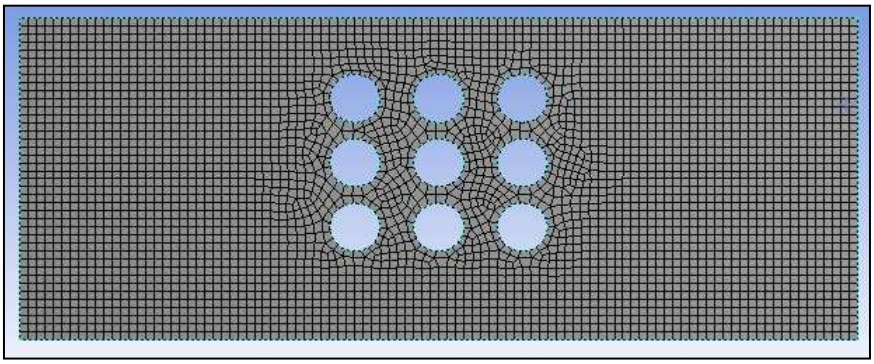

Fig 2: Meshing of plate

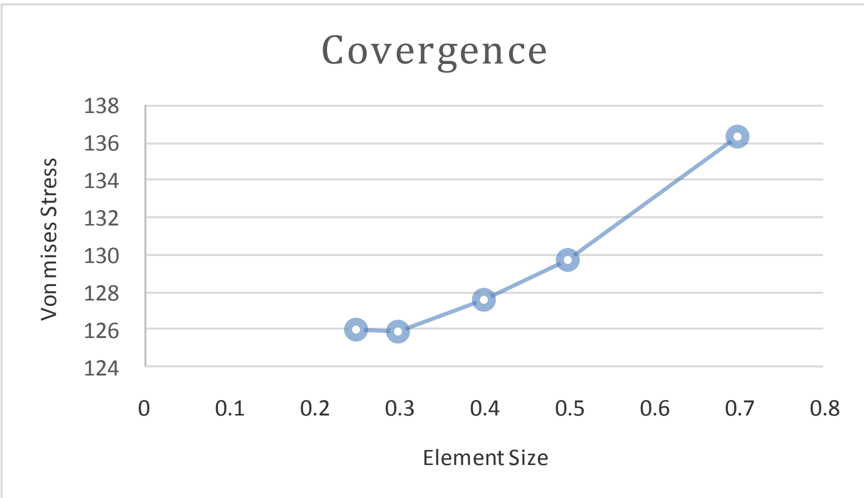

Fig 3: Convergence

The plate is fixed at one end and force of 2kN is applied on the another end. The cyclic load of fully reversed nature was applied. Material properties of Aluminium are assigned to the model. The model was solved using ANSYS solver .The parametric study was carried out for output parameter of equivalent stress and fatigue life of a component. The S-N approach is more accurate for high cycle fatigue, where the component is subject to cyclic stresses that are predominant within the elastic range.

The Soderberg line is used to calculate the fatigue life of a component. The advantages of using Soderberg line is, it also covers the failure point lying in the area having low mean stress. As no notch is considered in geometry, notch sensitivity is assumed to be 1. (K_f=1).

IV. EXPERIMENTAL VALIDATION

The finite element method, which originated in the field of structural analysis, was widely developed and exploited in the aerospace industry during the 1960s and 1970s. Due to lack of confidence in FEM models, the fatigue testing of structures has become standard procedure for model validation.

A specimen was installed in the fatigue machine, making sure that the specimen ends were tightened firmly within the grips as shown in Figure 4.1. Initially, the upper limit of the load was chosen and the lower limit of the load was set fully reversed. Then the operating frequency was set. In addition, the limit of maximum elongation was set, so that machine stops as soon as the elongation is beyond the limiting length. Thus the machine was protected from an extreme displacement, especially after a specimen fails. Thus the constant magnitude test was applied to a specimen in tension-compression fatigue mode. The fatigue loading was continued till the entire specimen fails as shown in Figure 4. Numbers of cycles required to cause the complete failure of the specimen were recorded.

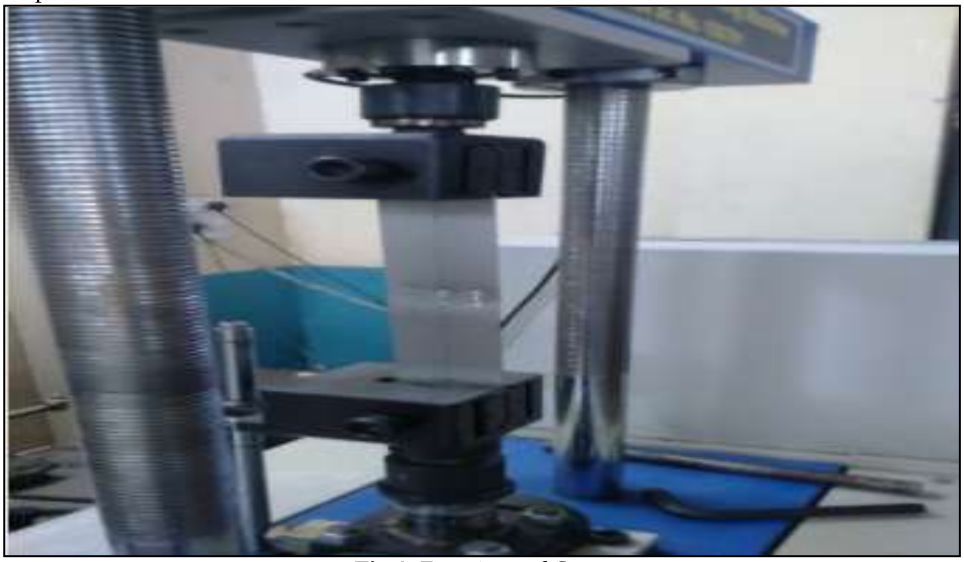

Fig 4: Experimental Setup

V. MATERIAL TREATMENT TO INCREASE FATIGUE LIFE

There are a number of techniques to improve the fatigue life of a product. Tempering process followed by short peenning induces compressive residual stresses on surface of the aluminium. The method of High Frequency Mechanical Impact (HFMI), in which hardened pin is hammered at the stressed part to induce compressive residual stresses, also help the cause. Abrasive Water Jet (AWJ) peenning is another method to increase the fatigue life. In AWJ peening surface roughness is decreased along with induction of compressive residual stresses. Ultrasonic impact treatment (UIT) is particularly used to improve fatigue life of steel and aluminium. The combined treatment of tempering followed by UIT gives highest improvement in fatigue life. These methods increase number of cycles before failure, resulting into improved fatigue life.

VI. RESULT AND DISCUSSION

The results from numerical investigation and experiments are illustrated below

A. Results for Numerical Investigation

By varying the 3 parameters (r, v, h) discussed above parametric study was done and results are illustrated in Table I.

Table I: Parametric Study Results

Sr No.	r (mm)	v (mm)	h (mm)	Von-mises Stress (MPa)	Fatigue Life (Cycles)
1.	3.5	4	5	147.27	78782
2.	3	4	5	126.1	1.3907E+05
3.	2.5	4	5	140.68	93180
4.	3	5	5	111.64	2.2565E+05
5.	3	5	4	110.37	2.57792E+05
6.	3	6	6	133.64	1.1234E+05
7.	3	4	4	111.30	2.12156E+05

The Fig 5 comply that the stress concentration in the optimized case is 3.3144 .The maximum stress occurs at the central hole bottom area. The life of the component is 2.5779E+05. The position of weak area is shown in Fig 6

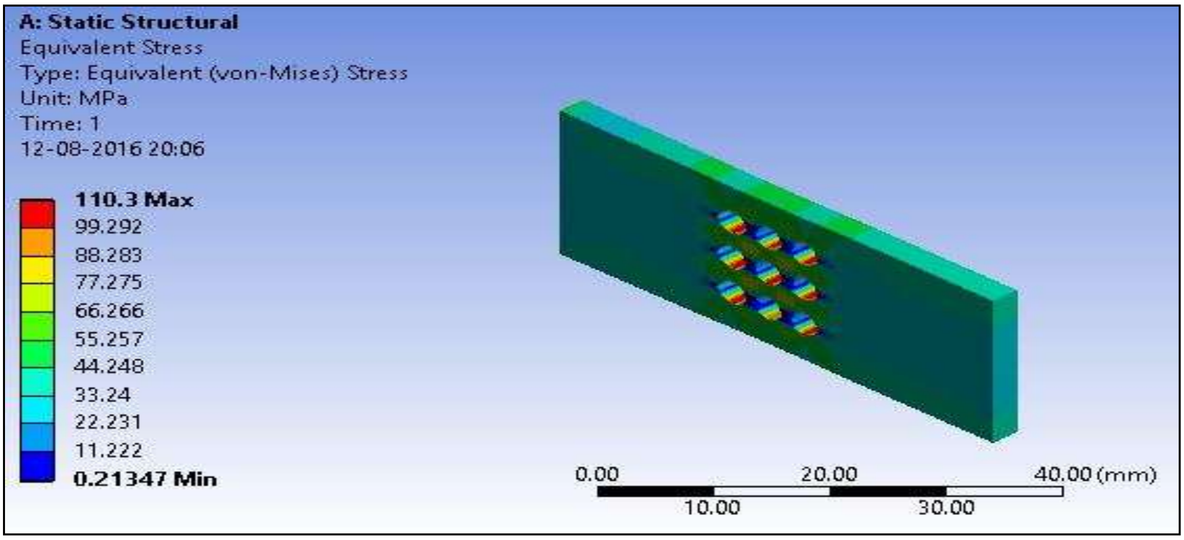

Fig 5: Von-mises Stress

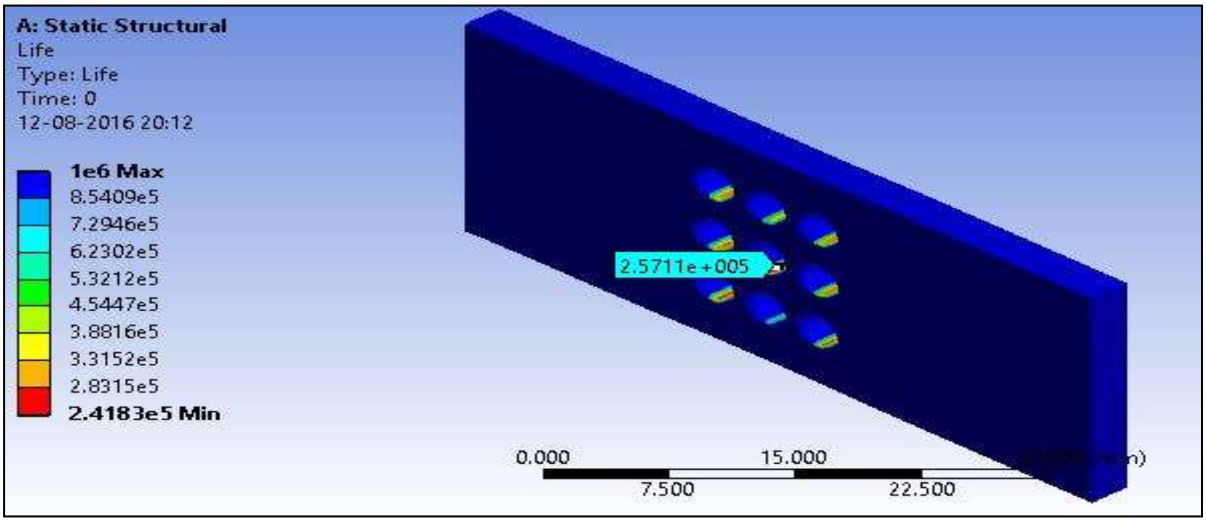

Fig 6: Fatigue Life of a Component

B. Experimental Results

The comparison between the numerical method and experimental method is illustrated in Table II

Table II: Comparison of Results

Sr.No.	Life by Numerical investigation (Cycles)	Life by Experiment (Cycles)	Percentage error (%)
1	2.57790E+05	2.70458E+05	4.683906559
2	2.57790E+05	2.72186E+05	5.289030295
3	2.57790E+05	2.71453E+05	5.033283847

VII. CONCLUSIONS

It can be analyzed from the parametric & experimental study that at design point 5 the component life is maximum. Effect of varying the geometric parameters was as follows:

1. Reducing the radius of hole, the life increased up to a certain point and plummeted afterward.
2. Fatigue life was maximum when v/h ratio is maintained 1.

When the Ratio h/r & v/r were 1.33 &1.66 respectively life was maximum

The Numerical and Experimental Investigation were carried out successfully. It was found that maximum fatigue life can be obtained by employing optimized design parameters.

ACKNOWLEDGMENT

We are grateful to the College of Engineering, Pune for the financial and infrastructural support. We also thank Dr. Nagesh Chougule for his valuable guidance for writing this paper.

REFERENCES

[1] Murlio Augusto ‘Three Dimensional Stress Concentration Factor in Finite Width Plates with Circular Holes’, World Journal of Mechanics, 3, 153-159**,**2013

[2] David Warren Whitely ‘Interacting stress concentration factors and their effect on fatigue metallic aero structures’ Doctoral Dissertations. Paper (2013)

[3] S.A.Meguid ‘Finite element analysis of a defence hole systems for the reduction of stress concentration factor in a uniaxial loaded plate with two coaxial holes’, engineering fracture mechanics Vol. 25. No. 4, pp. 403-413, (2000)

[4] C.R.Chiang ‘A numerical method for solving elasticity problems: Applications to the problems of an infinite plate containing two circular holes’, Computers and structures Vol. 30. No. 5, pp. 1199-1205, 2002

[5] A book on ‘Design of Machine Elements’ by V. B. Bhandari.

[6] K.T.Chen ‘Stress analysis of the multiple circular holes with the rhombic array using alternating method’, International Journal of Pressure Vessels and Piping 76, 503–514 (2007)

[7] Jamshid Aghazadeh‘ Stress concentration analysis between two neighbouring circular holes under internal pressure of a non-explosive expansion material’, Journal of the Earth Sciences Application and Research Centre of Hacettepe University, Vol. , NO.30 , PP.0 _ 0 , 30 January2010.

[8] Gary B. Marquis, Eeva Mikkola, Halid Can Yildirim, Zuheir Barsoum Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed fatigue assessment guidelines, Welding in the world, November 2013, Volume 57, Issue 6, pp 803–822.

[9] P. J. Haagensen, E.S. Statnikovand L. Lopez-Martinez Introductory fatigue tests on welded joints in high strength steel and aluminium improved by various methods including ultrasonic impact treatment (UIT), IIW Doc. XIII-1748-98.