Crack Growth Analysis of Lug Joint

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Abstract: In this paper, an examination of crack growth in a lug joint is introduced. This component is widely utilized in various industries like aerospace and automotive. This study aims to examine how a lug joint reacts to varying loads and sizes of crack as it propagates. The finite element method is utilized for the analysis and the progression of the crack is assessed via the Paris law. We investigate how material properties, geometry and loading conditions impact crack growth behavior and identify the critical crack size in various loading situations. This finding offer significant understanding of how lug joints progress and develop cracks

I. INTRODUCTION

In aircraft structures, lugs are connector type elements used as structural supports for pin connections. Prior to the 1950's, lugs were overdesigned as weight and space were not design driving factors. With the tightening of weight, cost, and space requirements in the aerospace industry, a more precise method of lug analysis was required. Fatigue as a complex process, could be dangerous and even cause failure of lug and hence components which are connected by lug joint. Due to previous reason it is very important to assess, analyze and to predict the crack initiation and crack growth behavior of attachment lugs.

Landing gear is a vital structural unit of an aircraft which enables to take off and land safely on the ground. A variety of landing gear arrangements are used depending on the type and size of an aircraft. The most common type is the tri-cycle arrangement with one nose landing gear unit and two main landing gear units. Even during a normal landing operation heavy loads (equal to the weight of an aircraft) are to be absorbed by the landing gear. In turn joints are to be provided such that such heavy concentrated loads are first received by the airframe and subsequently diffused to the surrounding areas. Normally heavy concentrated loads are received through a lug joint. Therefore, design of a lug joint against failure under static and fatigue loading conditions assumes importance in the development of an aircraft structure. This project deals with the design and analysis of a typical lug joint representative of a landing gear attachment of a small transport airplane. The design will provide safety against 1) failure of the lug, 2) failure of the pin. The types of loadings to be considered are a) axial, b) transverse or drag load. Aircraft design practices will be used.

1.1 GEOMETRICAL CONFIGURATION

ATTACHMENT LUG

The attachment lug configuration in the present work is shown in figure 1. The attachment lug dimensions are length 'L', width 'W', outer to inner radius ratio R_0/R_i are shown in the figure. The pin is assumed to be rigid which nearly corresponds to a steel pin in the aluminum lug, with the ratio of pin to lug modulus being three. Pin is assumed to be push fit and the pin plate interface is assumed to be smooth.

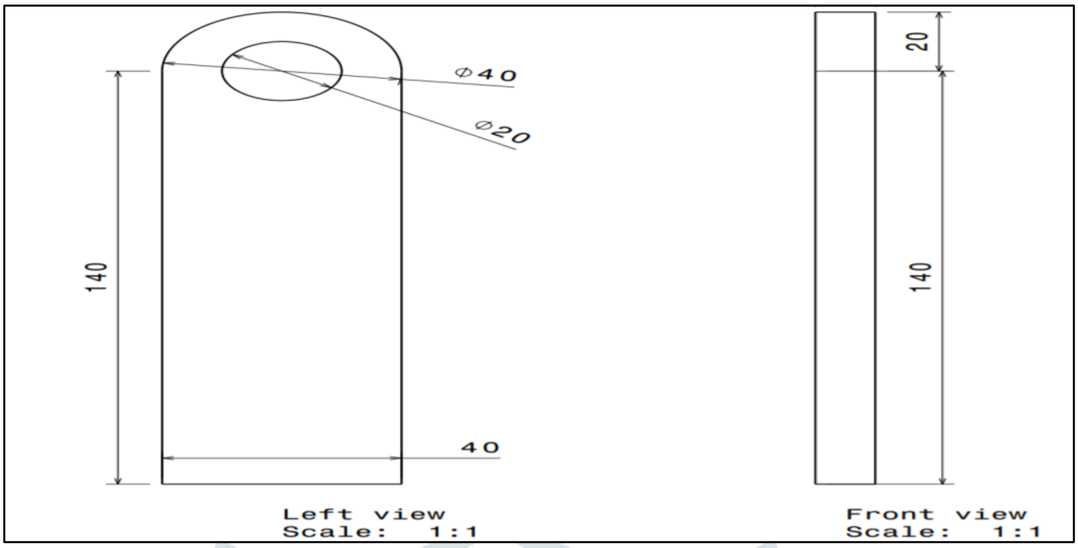

Figure 1: Full model of attachment lug

For Finite Element analysis, attachment lug has been modeled by using MSc PATRAN MSc NASTRAN software according to the assumed dimensions. The full model of lug can be considered as a symmetric boundary so by taking advantage of symmetry and the considering advantage of reduced time to model half of the attachment lug, instead of modeling the full model it can be reduced into half and hence the solution domain need only half of the geometry as shown in figure 2

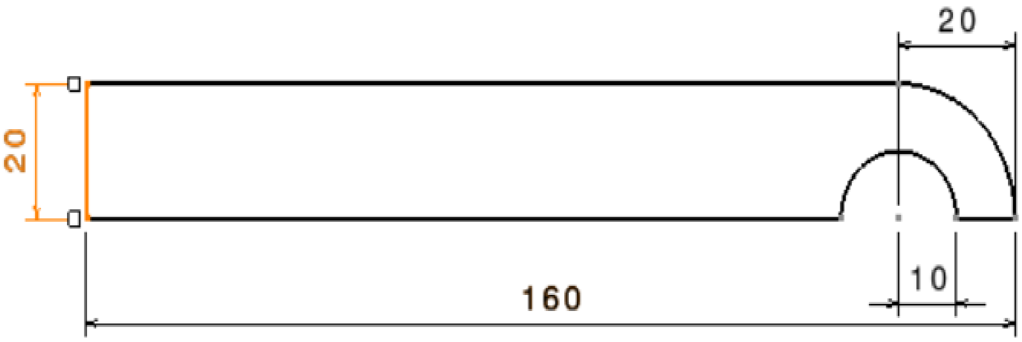

Figure 2: Half symmetric Model of Attachment Lug

1.2 MATERIAL SPECIFICATION

Selection of aircraft materials depends on many considerations, which can in general be categorized as cost and structural performance. Cost includes initial material cost, manufacturing cost and maintenance cost. The key material properties that are pertinent to maintenance cost and structural performance are

- Density (weight)
- Stiffness (young's modulus)
- Strength (ultimate and yield strengths)
- Durability (fatigue)
- Damage tolerance (fracture toughness and crack growth)
- Corrosion

1.3 ALLOYS

7075-T6 has higher strength than 2024, lower fracture toughness. uses for tension application where fatigue is not critical. it also has low short transverse properties and low stress corrosion resistance.

The tensile strength of aluminum 2024 is 140-210MPa where as for the aluminum 7075-T6 is 220mpa. The yield strength of the 7075-T6 is much higher than aluminum 2024 by 10MPa, i.e. the yield strength of 7075 is nearly 482MPa and that of 2024 is 472.6MPa.

Whereas, the Tensile Strength of Aluminum He30/6082 is 150-330 MPa and Yield Strength of the 6082-He30 is 280MPa. It is excellent Corrosion resistant material. It is the strongest aluminum alloy when compared to all the 6000 series alloys.

II. MODELING CONDITION

This project can be approximated as 2-dimensional since the load is applied in the plane of the attachment lug. In a Cartesian coordinate system, there are two possible assumptions to get in regard to the performance of the structure in the third dimension.

Configurations of attachment lug joints analyzed in this report are shown in figure. In the plane stress condition, the third dimension is appropriate for solids, which are thin in this case; in the plane strain condition, the third dimension is applicable for solids which are thick.

2.1. FINITE ELEMENT MODEL OF ATTACHMENT LUG

A finite element model of attachment lug is the complete idealization of the entire structural problem including the node location, the element, physical and material properties, loads and boundary conditions. The required model of tapered attachment lug has been modeled by using the advantage of symmetry in the software MSc Patran according to given dimensions.

2.2 MESHING

In finite elements libraries, for meshing the required model of Attachment lug we have selected 4 nodded QUADRILATERAL Shell Element (QUAD4) which is under both ISOMESH and HYBRIDMESH for the available surface area chosen for formulation of FE Model.

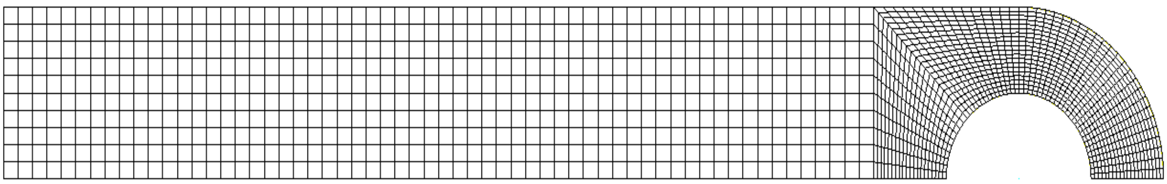

Figure 3: Half Symmetric Meshed Model of Attachment Lug.

The finite element mesh for the tapered attachment lug is generated by using QUAD 4 elements in the MSc Patran software as shown in figure below. A coarse mesh is applied to the lug geometry but near the hole of the lug where stress analysis is carried out progressively fine mesh is applied, as the mesh increases progressively, the accuracy of the result will increases.

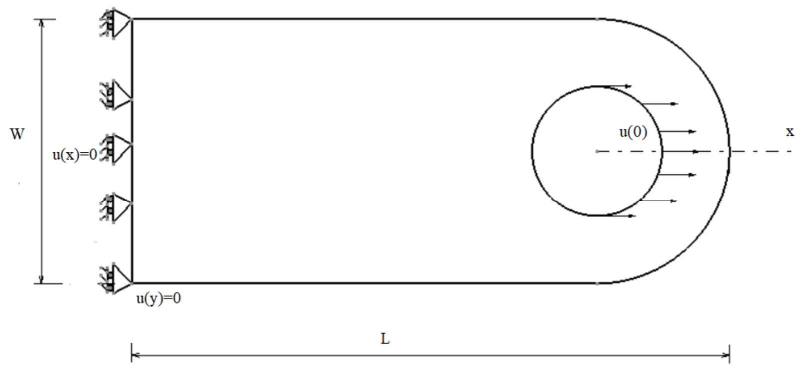

Figure 4: Displacement is given at circular hole(pull)

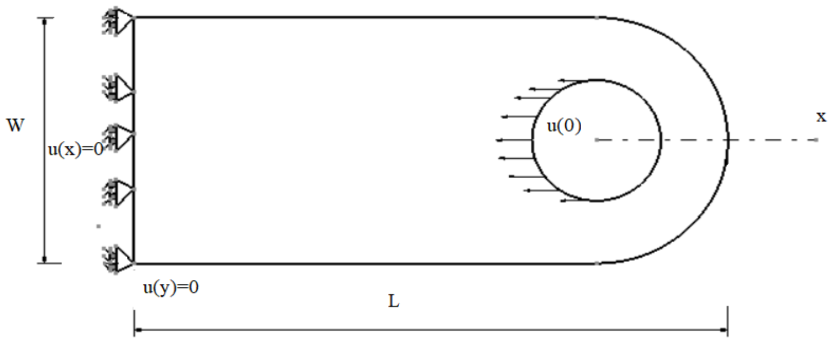

Figure 5: Displacement is given at circular hole(push)

III. STRESS ANALYSIS OF ATTACHMENT LUG

This report will analyze the structural integrity of lug. The stress distribution and stress concentration factors for various structures and loading complexities are determined for the lug. The attachment lug is considered to be a male lug and subjected to loading which is axially symmetric. Results of two dimensional stresses and fracture analysis of attachment lug has been carried out in the present work. Pin contact displacements and stress concentrations are discussed and using critical node location.

3.1 STRESS ANALYSIS

The attachment lug is subjected to stress analysis for a given loading conditions. The force is assumed to be rigid which nearly corresponds to steel pin in the aluminum lug. The force is assumed to be push fit$(\lambda = 0)$ and the pin lug interface is assumed to be smooth. The far end of the lug is supported on rollers and the rigid body displacement in y-direction is suppressed at one point. The force is transferring the load P and the pin-hole interface exhibits a contact over 180^0 and the force is applied on the inner radius of the lug acting outwards in Y-axis direction which is assumed to be steel pin. These results are calculated using MSc PATRAN and MSc NASTRAN software. The attachment lug model deformations when subjected to forces ranging from 0.2N to 1.0N with 0.2N difference is shown in figure. After applying the force the far field stresses and maximum stress have been found. The deformed and undeformed attachment lug is shown in the figure below. Which gives value of deformation for the forces applied on the attachment lug.

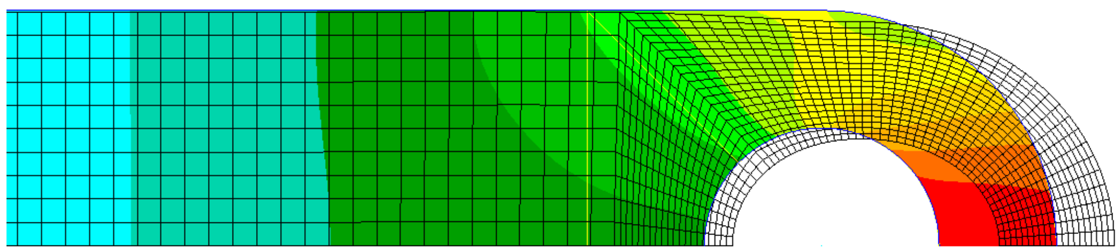

Figure 6: Attachment lug with deformation after applied force

The analysis part on the attachment lug can carried out with the help only one half of the lug because of its symmetric configuration in x direction. But the fabrication and testing of the same in Universal Testing Machine is not possible, so to be accurate we conducted the analysis of the same. The analysis on complete lug is conducted and the deformation is shown in the below image. We can also see the graph of DEFORMATION Vs LOAD and MAXIMUM STRESS Vs LOAD as shown in the below figure 9 and figure 10

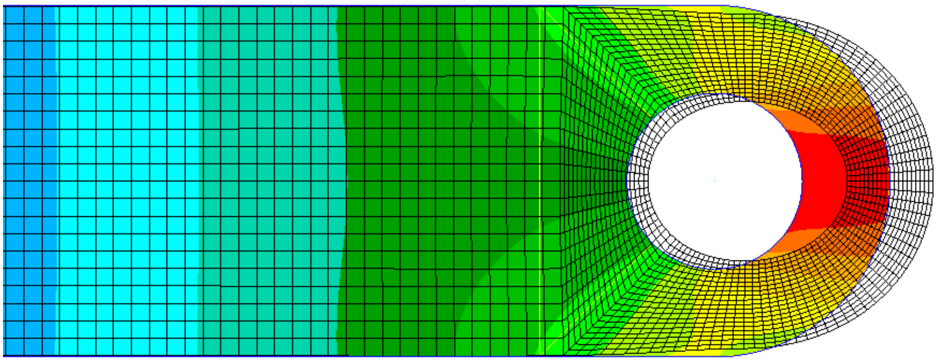

Figure 7: Deformed model of complete lug attachment(pull)

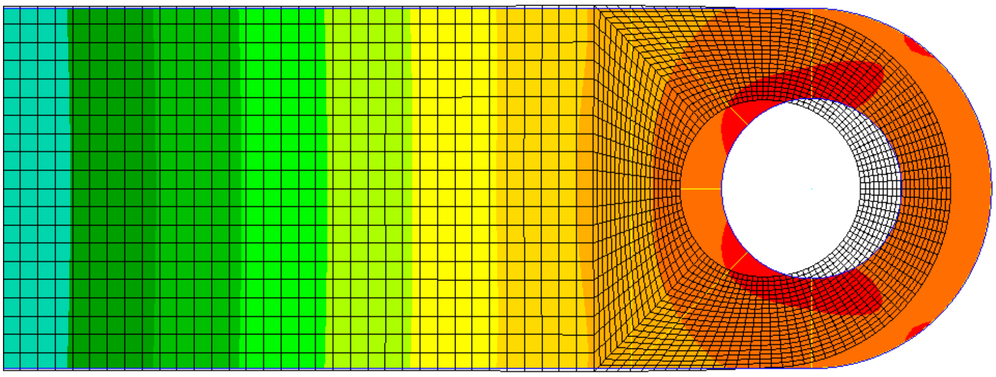

Figure 8: Deformed model of complete lug attachment(push)

3.2 Interpretation of results

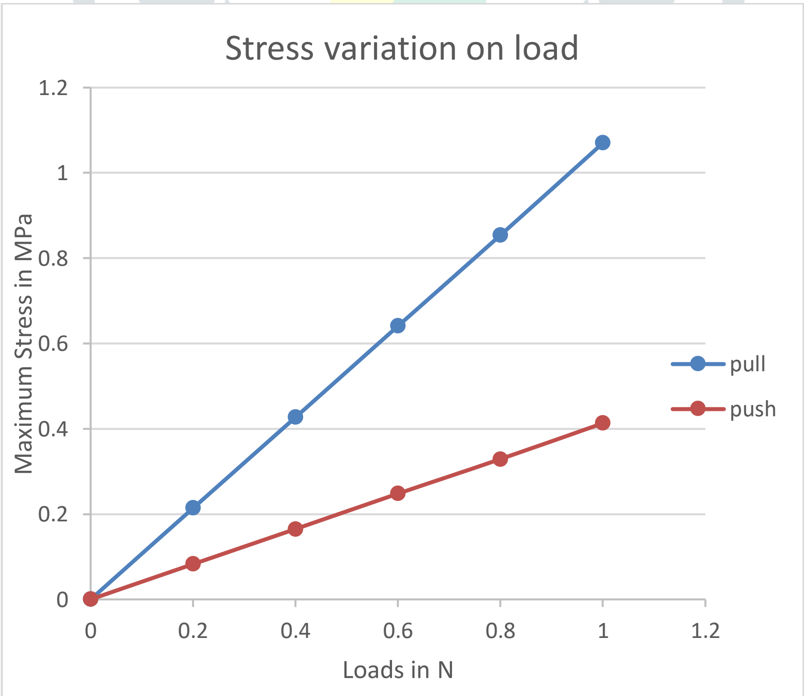

Figure 9: Graph showing maximum stress vs load

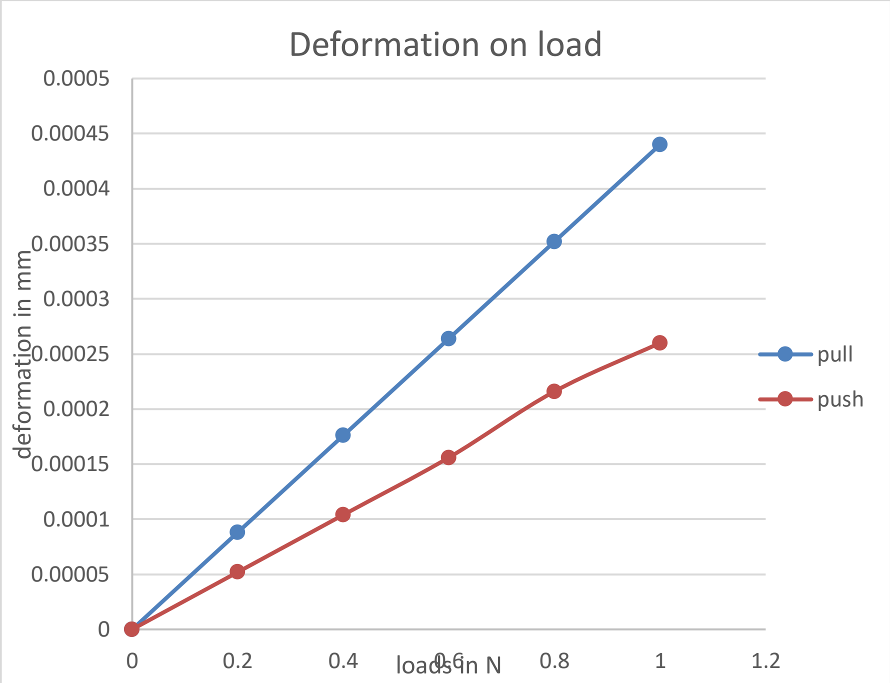

Figure 10: Graph showing deformation vs load

Stress analysis on the inner radius of the lug is conducted under both compression and tension, this was applied with the help of force (N). By conducting this process we came to know the exact location of the maximum stress generated and also the exact location of the particular node in which deformation takes place. The push and pull which is shown in the graph is compression and tension respectively. here the compression force applied is shown as red mark and blue mark represents tension. We can also notice that under tension there is more deformation taking place with increase in load when compared to compression.

IV. CRACK GROWTH ANALYSIS

4.1 INTRODUCTION

Developing an appropriate computational procedure for crack growth analysis is one of the key issues for the assessment of the reliability of components and structures.

In general, to accurately assess fatigue growth of crack in the lug it is necessary to analyze fatigue growth behavior at the point of maximum crack depth and at the point of surface crack interaction with the surface. Due to previous reason, the crack propagation process can be described by two coupled equations for crack growth rate as follows:

$$\frac{da}{dN} = C_A K_{ImaxA}^2 \Delta K_{IA}$$

Where C_A is a material constant experimentally obtained, ΔK_A, $\Delta K_,$ K_{maxA}, are the ranges and maximum values of stress intensity factor at the depth A respectively.

Final number of loading cycles for the lug with corner crack can be estimated for both directions if expressions for crack growth rate are integrated i.e.

For depth direction:

$$N = \int_{a_0}^{a_f} \frac{da}{C_A K_{ImaxA}^2 \Delta K_{IA}}$$

Since relationships for stress intensity factors are complex functions, numerical simulations have to be performed to compute fatigue life of attachment lugs up to failure for both directions.

4.2 STRESS INTENSITY FACTOR FOR THE ATTACHMENT LUG

The attachment lugs, due to the fact that they connect vital engineering components, demand careful crack growth analysis and a damage tolerance analysis to aid structural integrity. For structural safety, the evaluation of stresses in the vicinity of cracks is very important. In fracture mechanics, the stress analysis is based on knowledge of the stress intensity factor at the tip of the crack. The stress intensity factor is a primary parameter for crack growth analysis due to the fact that it employs geometry, material and loading conditions.

4.3 EVALUATION OF STRESS INTENSITY FACTOR

Numerical approach for calculating stress intensity factor based on finite element method is introduced in this report. The attachment lug with single through-the-thickness crack has been tackled as contact problem for different R_0/R_i ratios. For this purpose singular four-node finite elements are used. Actually, step-by-step, for each increment of crack length different meshes are modeled by using super-elements around crack tip.

Modified Virtual Crack Closure Integral (MVCCI) method is referred as a very powerful tool in calculating fracture parameters. This method is popular for 2-D and 3-D problems with cracks and in particular which involves mixed mode fracture. This method uses quad 4 and quad 8 shell elements. The parameters are evaluated using MVCCI approach where at any crack lengths, a virtual crack extension is assumed and the SERR is estimated as the work to be done to close the crack to the original shape. The method used to factor for different crack lengths. MVCCI method is based on the energy balance.

V. RESULTS AND DISCUSSIONS

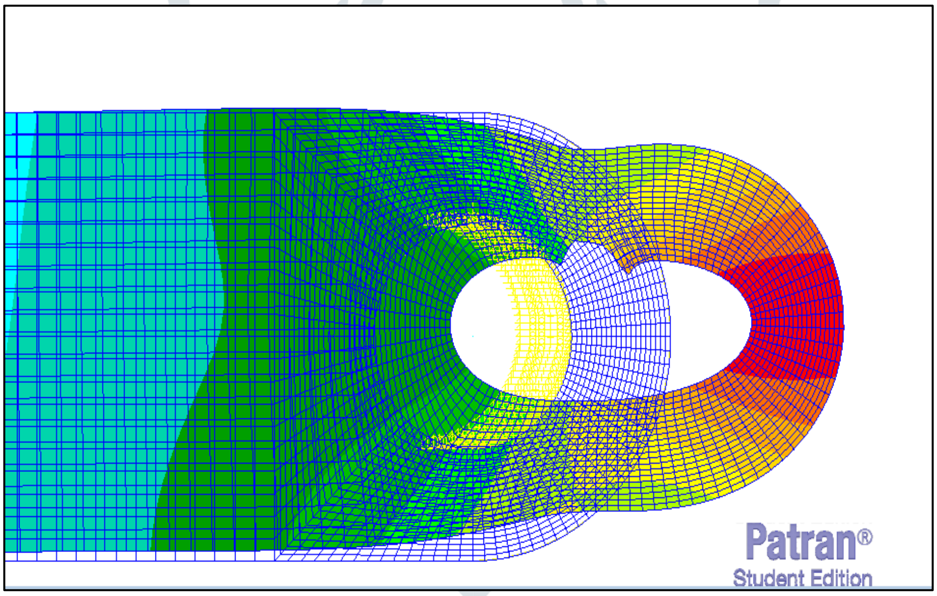

Figure 11. Deformed model of complete lug with crack

The stress intensity factor for attachment lug has been found out from Modified Virtual Crack Closure Integral (MVCCI) technique for the different forces applied and it is found from above variation is that as the normalized crack length increases the stress intensity factor decreases.

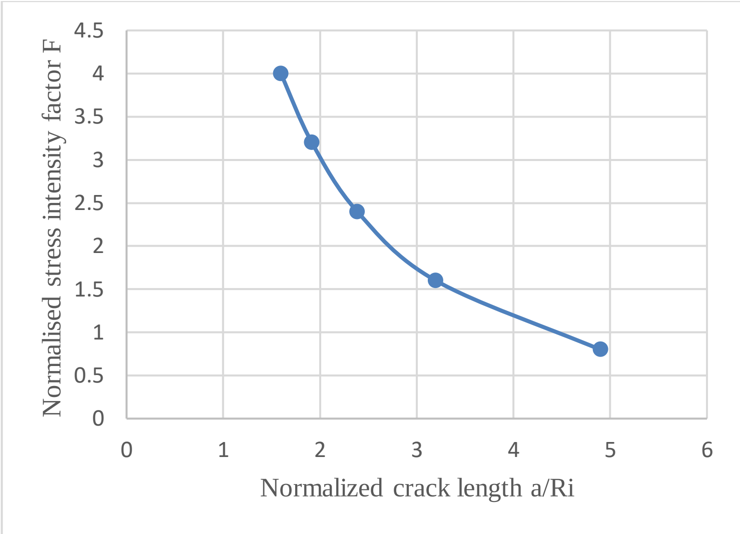

Figure 12: Graph of Stress Intensity Factor vs Normalized crack length

VI. Experimental Methodology

Methodology deals with the systematic representation of the methods used in the research or an analysis. With reference to our project it encompasses the theoretical analysis of the methods, principles used, quantitative or qualitative techniques to fabricate and test the Lug joint. It also includes a consideration of concepts and theories which underlie these methods. The whole methodology may be divided as fabrication of lug joint followed by testing. While fabrication of lug joint deals with machining process which includes Drilling, Milling, filing etc and testing is done to evaluate mechanical properties of the model. Machining method was used for the fabrication of the lug joint. Tensile test was conducted to evaluate the mechanical properties and depict the mechanical behavior.

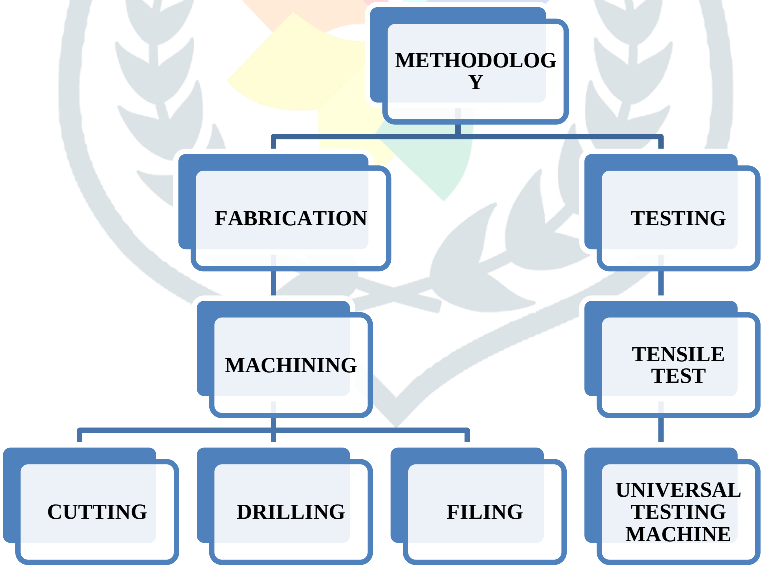

Figure 13: Flowchart of methodology

6.1 **FABRICATION**

Fabrication is a manufacturing process in which an item is fabricated from raw material to finished material. Fabrication of composite materials is totally different from the methods used to fabricate metal components. We specifically use metal fabrication. Metal fabrication is the creation of metal structures by cutting, bending, and assembling processes. It is a value-added process involving the creation of machines, parts, and structures from various raw materials.

Typically, a fabrication shop bids on a job, usually based on engineering drawings, and if awarded the contract, builds the product. Large fab shops employ a multitude of value-added processes, including welding, cutting, forming and machining.

Figure 14: Fabricated lug joint

metalworking, such as machining, metal stamping, forging, and casting, may be similar in shape and function, but those processes are not classified as fabrication.

In the fabrication work of lug model, we used Machining type of fabrication. Using the help of Certain machines like drilling, milling, filing and cutting we fabricate raw material to finished product. Our raw material was of 170 mm length, 40 mm width and 10mm thickness flat bar. In the process we first cut the material to specified length of 165 mm and then start filing the one end of a material until we get a semicircular end of 40mm diameter. We use straight file and round file for doing this job. As soon as the filing gets over, we measure the length to see it's 160 mm. Soon after this we use drilling machine. Drilling is the manufacturing process where a round hole is created within a work piece or enlarged by rotating an end cutting tool, a drill. We use this to drill a hole of 20mm diameter from a distance of 40mm from the semicircular end. Now our product is completely fabricated with one polishing against the surface.

6.2 TESTING

The mechanical testing of composite structures to obtain parameters such as tensile strength is an essential process and it involves a range of test types in a variety of different environments. Determination of bulk properties requires tension. The major tests to be done are tensile test only. Laboratories undertaking Metal testing for aerospace applications face a number of challenges. Four significant challenges are:

1. Ensuring all that tests are conducted in compliance with the wide range of Standards.
2. Achieving, maintaining, and being able to demonstrate accurate alignment of grips and fixtures.
3. Changing test fixtures quickly and efficiently in order to cover a wide range of tests while

   maintaining high productivity.
4. Maintaining the correct test environment.

6.3 UNIVERSAL TESTING MACHINE(UTM)

There are many types of testing machines. The most common are universal testing machines, which test materials in tension, compression or bending. There are two classes of testing machines, electromechanical and hydraulic. The electromechanical machine uses an electric motor, gear reduction system and one, two or four screws to move the crosshead up or down. A range of crosshead speeds can be achieved by changing the speed of the motor through the software control. A microprocessor based closed-loop servo system can be implemented to accurately control the speed of the crosshead. The hydraulic type uses high pressure of water to run the machine. The main components of the universal testing machine are as follows,

1. Actuator,

2. Attachment kit and

3. Measuring and safety devices

Digital UTM's give accurate reading and automatic graphs are plotted. This is stored in the digital computer connected to the machine. Figure 15 shows a common universal testing machine.

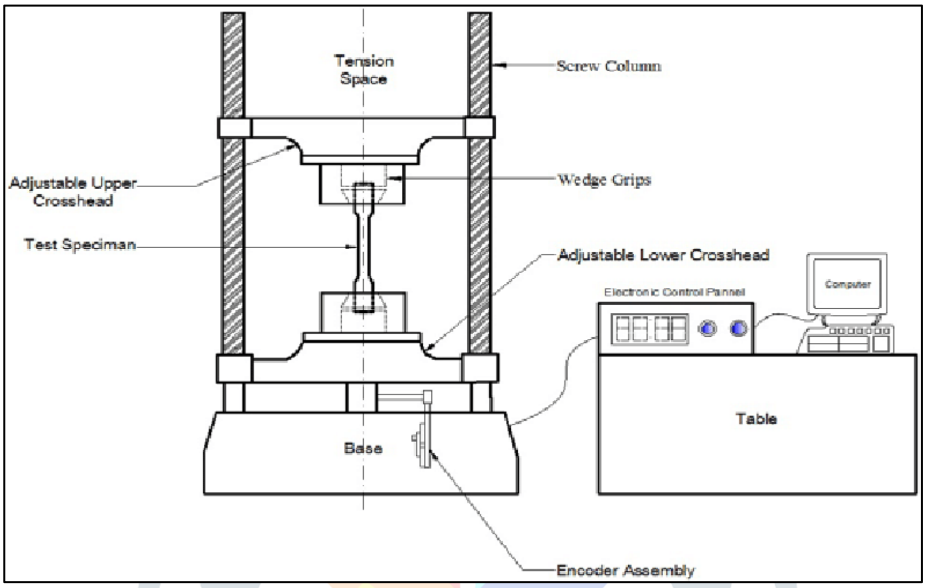

Figure 15: Schematic diagram of universal testing machine

Figure 16: Universal Testing Machine

6.4 TENSILE TEST

The primary use of the testing machine is to create the stress-strain diagram. Tensile test determines the strength of the material subjected to a simple stretching operation. Typically, standard dimension test samples are pulled slowly and at uniform rate in a testing machine while the strain and stress is defined as:

Engineering Strain = (change in length)/ (original length)

Engineering Stress = (applied force)/ (original area)

The aim of the test is to assess some mechanical characteristics of testing material: its elasticity, ductility, resilience and toughness. Examples of common standards for the tensile testing are ASTM D 3039, EN 2561, EN 2597, ISO 527-4, and ISO 527-5. The specimens are parallel sided with bonded tabs to prevent the grip jaws from damaging the material and causing premature failures. Gripping mechanisms include manual and hydraulic wedge grips. For demanding aerospace testing, hydraulic wedge gripping solutions are generally preferred because of their controllability and repeatability.

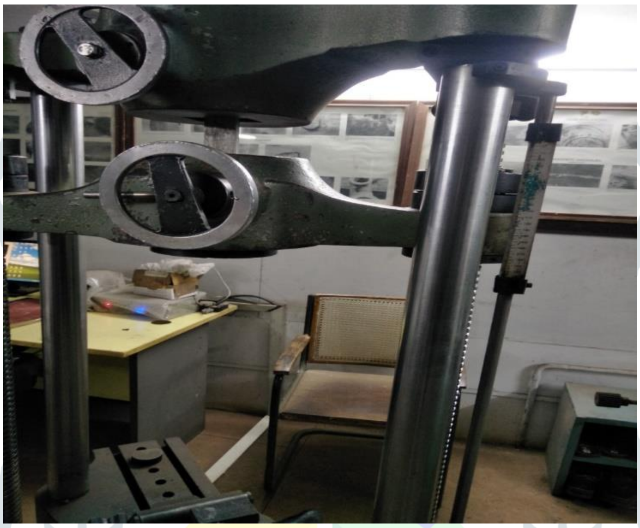

Figure 17 Lug clamped in between upper and middle cross head jaws

When using well-aligned grips, it is recommended that the grips are permanently left in place on the testing machine and that, when needed, test fixtures including compression platens and bend fixtures are mounted on the grips using adapters.

Figure 18: Fractured lug after tensile test

6.5 RESULT

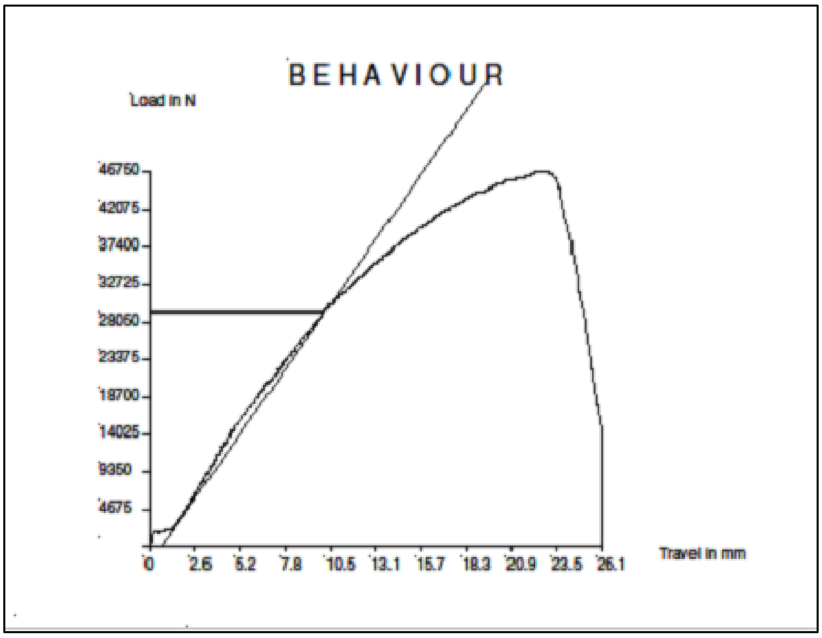

Figure 19: Graph of load Vs displacement

VII. CONCLUSION AND SCOPE FOR FUTURE WORK

7.1 CONCLUSION

The method of analysis is conducted in the present report where, stress and fatigue of attachment lugs has been analyzed with different parameters. MSc NASTRAN and MSc PATRAN for stress analysis and crack analysis, that is the initiation of the crack and the stress intensity factor is also found out, there are the software part in the thesis. The forces that was applied ranging from 0.2N to 1.0N with 0.2N difference and the deformation in the lug is found.

The graph of stress Vs load and deformation Vs load is drawn with the help of the values from the analysis. Then the crack is initiated and stress intensity factor is found out with help of the graph.

The fabrication of the attachment lug is done with help of machining, the material used was Aluminum He30/6082 and tensile test on the lug is conducted with the help of automated universal testing machine.

VIII. FUTURE WORK

Stress analysis can be carried out in 3D for more accurate values, number of different alloys of steel and aluminum testing can have carried out. Number of different software can have used for analysis and crack initiation in 3D. Even fatigue analysis can also be done in the future. As well as lug optimization can also be carried out to meet the appropriate factor of safety of the lug in the main landing gear.

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