MODELLING & STRENGTH ANALYSIS OF TWO DISTINCT JOINTS USING FINITE ELEMENT ANALYSIS

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Abstract: - Joints represent one of the greatest challenges in the design of structures in general and in composite structures in particular. Type of joining to be used requires careful consideration of several parameters with a knowledge of the service that the joint is expected to provide. Modelling and static analysis of 3D models of two different joints were carried out using NX Nastran and ANSYS software. The results were interpreted in terms of Vonmises stress. The work was focused on the behaviour of single lap Riveted and Adhesive joints subjected to tensile load. Finite element analysis tool was used to analyse the stress – strain behaviour, deformation and to predict the properties like working stress, ultimate strength and rupture stress numerically for service conditions.

Keywords: FEA, stress – strain behaviour, deformation, working stress and ultimate strength.

I. INTRODUCTION

Fiber reinforced plastic (FRP) materials have proven to be very successful in structural applications. They are widely used in the aerospace, automotive and marine industries. A typical composite contains layers of aligned fibers oriented at different angles held together by a resin matrix, giving high strength and stiffness in different directions. This anisotropy can cause difficulties when joining two parts together, especially if the two pieces have different stiffness and strength characteristics. The joint can potentially become the weakest link in the structure due to the large amount of load it must transfer. There are wide varieties of ways to join different parts together. Two major methods include mechanical fastening and adhesive bonding. Adhesive bonding of structures has significant advantages over conventional fastening systems. Bonded joints are considerably more fatigue resistant than mechanically fastened structures because of the absence of stress concentrations that occur at fasteners.

II. DATA COLLECTION

The design of structures with advanced polymer composites proceeds through the application of classical lamination theory. Designers are used to working with materials such as plastics and metals that are described as homogeneous and isotropic. Polymer composites have developed into important structural materials due to the wide variety of reinforcing fibers that are available. Carbon is generally a combination of graphite. Graphite has a tensile strength three to five times stronger than steel and has a density that is one-fourth that of steel. Other fiber materials such as aramid, quartz, boron, ceramic, or polyethylene are also available and provide unique properties.

OBJECTIVE: Two plates were subjected to the static tensile test aluminium one from the 6061 alloy and the CFRP (carbon- fibre-reinforced plastic) joined with the steel rivet. The aluminium plate was fixed and the tensile load was applied to the plate made from CFRP.

Geometry of plates are:

Width: 22.5 mm, Length: 100 mm, CFRP thickness: 1.8 mm,
Arrangement of fibres in the CFRP plate 0°, Thickness of the aluminium plate: 2 mm,
Plate overlap: 20 mm, Diameter of the holes in plates: 4.8 mm,
Diameter of the steel rivet: 4.74 mm, Diameter of the rivet head: 12.6 mm,
Height of the rivet head: 2.32 mm, Diameter of the headed rivet part: 4.07 mm,
Height of the headed rivet part: 1.48 mm, Total rivet height: 11.63 mm.

Boundary conditions: Tensile load: 1770 [MPa], Removing all degrees of freedom in the joint location

Material Type	Young's Modulus (Gpa)	Density (Kg/mm3)	Poisson Ratio
STEEL	200	7.85X10-6	0.3
CFRP	170	1.61X10-6	0.3
EPOXY	4	1.08X10-6	0.4
6061 AA	75	2.7X10-6	0.33

Table 1: MECHANICAL PROPERTIES OF COMPOSITES

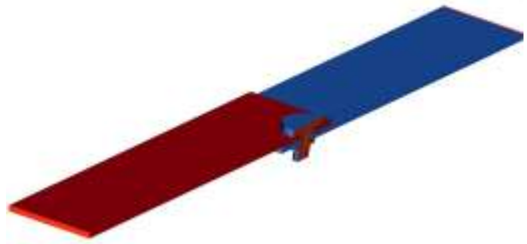

Fig: 1. Geometry of the riveted joint.

III. METHODOLOGY

Tsai-Wu Theory:

One of the first attempts to develop a general failure theory for anisotropic materials without the limitations of previous theories was discussed by Gol'denblat and kopnav. This theory is capable of predicting strength under general states of stress for which no experimental data are available. It uses the concept of strength tensor which allows for transformation from one coordinate system to another. It has the capability to account for the difference between tensile and compressive strengths. The theory satisfies the invariant requirements of coordinate transformation, following normal tensor transformation laws.

III.I GEOMETRY:

The geometry of single lap joint used for the analysis is taken as follows

4.3 DESIGN CALCULATIONS:

1. Diameter of rivet head = φ 1.75D = 1.75 X 4.74 = 8.295mm
2. Height of rivet head = 0.75D =0.75 X 4.74 = 3.555mm
3. Diameter of shank = D = 4.74mm
4. Diameter of post rivet head = φ1.6D = 1.6 X 4.74 = 7.584mm
5. Height of post rivet head = 0.7D = 0.7 X 4.74 = 3.318mm

III.II DESIGN PROCEDURE FOR Two Different JOINT USING FEM IN ANSYS FLOW CHART

- Analysis System Selection
- Engineering Data
- Importing Solid Model Of Joints
- Meshing
- Analysis Setting & Required Inputs
- Solution
- Results

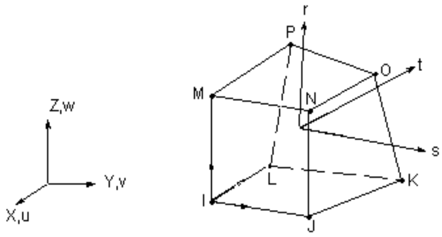

Fig 2: Solid 45 Element

The finite element mesh in the plates is generated using three dimensional hexagonal elements. The finite element mesh in the rivet is generated using a three-dimensional brick element 'SOLID 45' of ANSYS (Fig.:5.1) The element is defined by 8 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions.

TABLE 2: Elements and Nodes for Different Types of Joints

JOINTS	No. of nodes	No. of elements
BONDED JOINT	9979	1320
RIVETED JOINT	10526	2013

IV. RESULTS AND DISCUSSIONS

The first step in any design is to analyze how forces are applied to particular components, and the kinds of stresses which result from these applications. For the analysis of the nature of the stresses how they are caused knowledge of the strength of materials, metallurgy and other relate subjects is essential. The data obtained from these tests can then be directly related with varying degrees of simplicity and accuracy to any structural shape. The test methods outlined in this section merely represent a small selection available to the composites scientist.

IV.I MODELING OF JOINTS

Table 3: PREDICTED VALUES FOR ADHESIVE JOINT

Load (N)	Stress (N/mm^2)	Strain (mm/mm)	Deformation (mm)
100	373.15	0.004350	0.14486
200	747.02	0.008701	0.28972
300	1120.5	0.013052	0.43457
400	1402.6	0.017402	0.57943
500	1867	0.021753	0.72459
600	2241	0.026104	0.86915
700	2614	0.030454	1.014
800	2988	0.034805	1.1589
900	3361	0.039155	1.3037
1000	3352	0.040506	1.4486
1100	3346	0.041857	1.5934
1200	3335	0.043207	1.7383
1300	3328	0.045558	1.8832
1400	3296	0.045561	1.8836
1500	3290	0.045565	1.8841

Table 4: PREDICTED VALUES FOR RIVETED JOINT

Load (N)	Stress (N/mm^2)	Strain (mm/mm)	Deformation (mm)
100	350.66	0.0020627	0.13667
200	701.32	0.0041254	0.27334
300	1052	0.0061881	0.41001
400	1494	0.0082509	0.54668
500	1753.3	0.010314	0.68336
600	2104	0.012376	0.72356
700	2454.6	0.014439	0.9567
800	2805.3	0.016502	1.0934
900	3156	0.018564	1.23
1000	3150	0.020627	1.3666
1100	3131	0.02169	1.5034
1200	3128	0.022753	1.6401
1300	3120	0.023815	1.7767
1400	3109	0.024878	1.9133
1500	3089	0.025941	2.0499

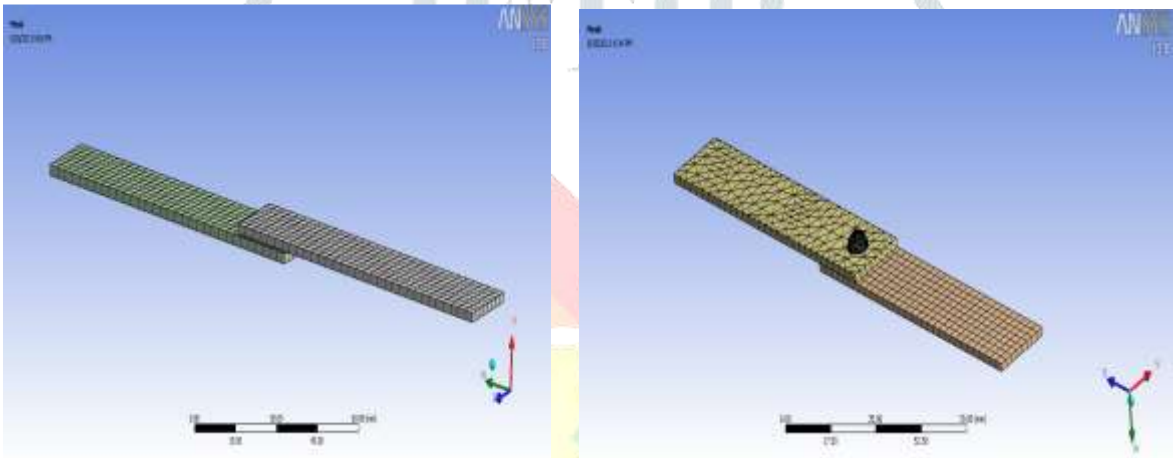

Fig: 2 Meshed model of adhesive joint & riveted joint

The prediction of stress, strain and deformation values are tabulated in the table 5.1from Ansys software are potriated with the following objective: Two plates were subjected to the static tensile test aluminum one from the 6061 alloy and the CFRP (carbon- fibre- reinforced plastic) joined with the steel rivet. The aluminum plate was fixed and the variable tensile load was applied to the plate made from CFRP.

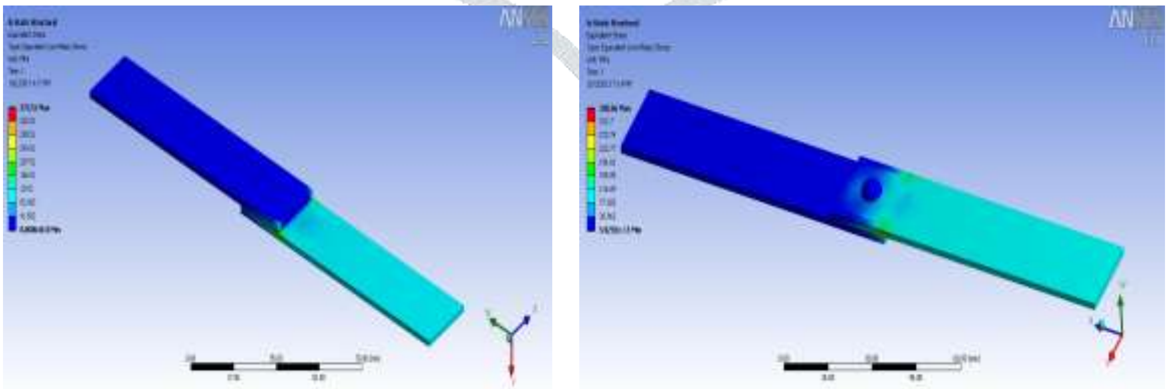

Fig: 3 Deformation adhesive joint and riveted joint of 100 pressures

The prediction of stress, strain and deformation values are tabulated in the table 3 & 4

ANALYSIS OF STRESS FOR ADHESIVE JOINT & RIVETED JOINT:

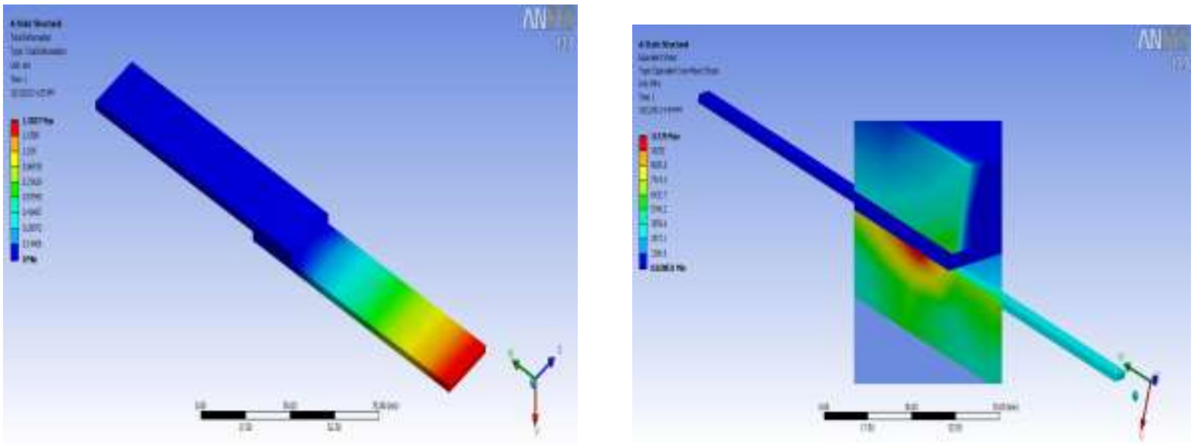

Fig 4: stress –strain & deformation design –analysis for adhesive joint.

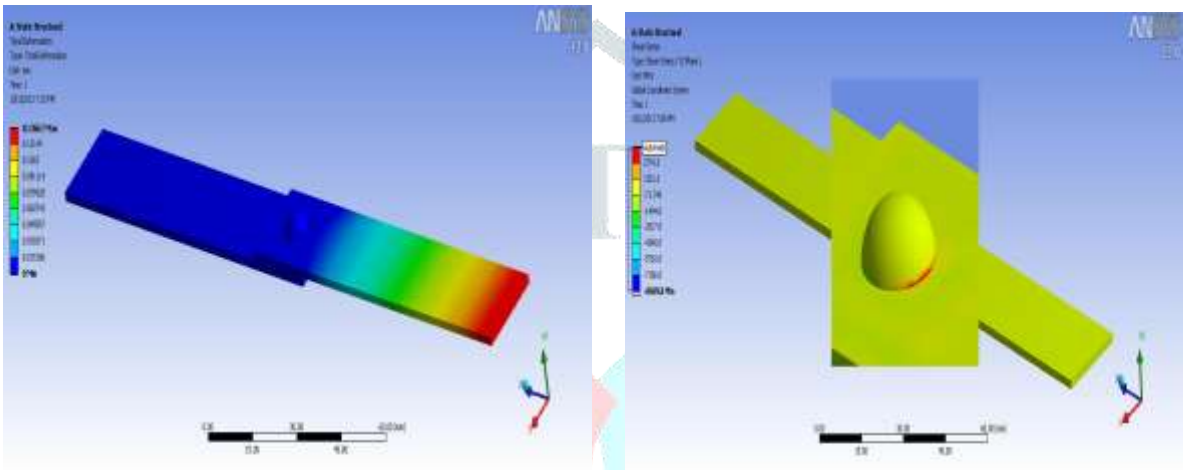

Fig 5: stress –strain & deformation design –analysis for riveted joint.

ADHESIVE JOINT:

To predict ultimate strength or tensile strength of Adhesive joint using ansys software is done through the methodology of stress and strain relationship. The horizontal line at which highest point of ordinate gives the ultimate strength 3361 Mpa of Adhesive joint subjected to variable tensile load. Fracture stress 3328 Mpa and fracture strain are considered from the rupture point. Working stress 2314 Mpa is the mean stress of stress- strain plot for adhesive joint are as shown in fig:6

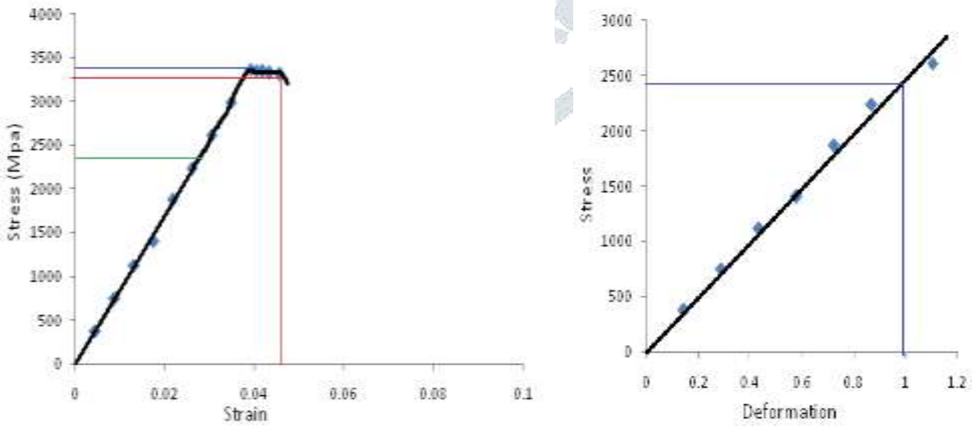

Fig 6: Stress Vs strain diagram & deformation for adhesive joint

Deformation (or) change in length of adhesive joint from stress-deformation plot is 0.045558 mm. Working stress is always below the elastic stress, so using this stress. we can find the deformation (delta- length) with variable stress values on ordinate and deformation values on abscissa.

Tensile strength = fracture stress / (1+fracture strain) = $\sigma/(1+e)$

Tensile strength = 3328/ (1+0.045558)

Tensile strength = 3182.98937 Mpa

Predicted Tensile Strength = 3361 Mpa and Calculated Tensile Strength = 3182 Mpa

RIVETED JOINT:

To predict ultimate strength or tensile strength of riveted joint using ansys software is done through the methodology of stress and strain relationship. The horizontal line at which highest point of ordinate gives the ultimate strenght 3156 Mpa of riveted joint subjected to variable tensile load. Fracture stress 3089 Mpa and fracture strain 0.025941are considered from the rupture point. Working stress 2306.4 Mpa is the mean stress of stress- strain plot for riveted joint are as shown in fig: 7

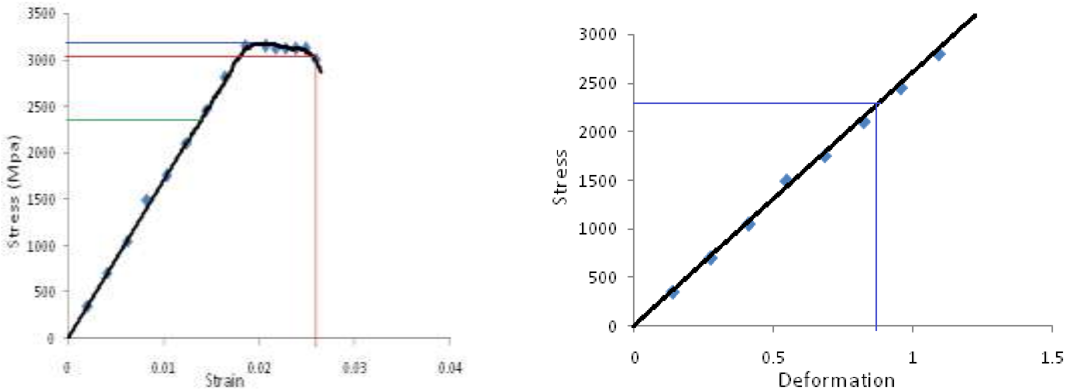

Fig 7: Stress- strain diagram & deformation for riveted joint

Deformation (or) change in length of riveted joint from stress-deformation plot is 0.86915 mm. Working stress is always below the elastic stress, so using this stress we can find the deformation (delta- length) with variable stress values on ordinate and deformation values on abscissa.

Tensile strength = fracture stress / (1+fracture strain) = σ/ (1+e)

Tensile strength = 3089/ (1+0.025941)

Tensile strength = 3010.894389 Mpa

Predicted Tensile Strength = 3156 Mpa and Calculated Tensile Strength = 3010 Mpa

FACTOR OF SAFETY:

Although designer takes care of all possible forces responsible for stressing a component, however, there is always a possibility of some unaccounted forces which may cause excessive stressing of components ultimately leading to failure. It is always desirable to introduce a factor of safety. F.O.S = (Ultimate stress) / (Working stress)

Factor of safety = 3156/2306.4 = 1.368 (Riveted)

Factor of safety = 3361/2314 = 1.45 (Adhesive)

V. CONCLUSIONS

The Engineer or designer is most interested in the way in which the materials will respond to external loads. Therefore, the result must be furnishing the information so as to predict the performance of a material in service.

The predicted tensile strength under the action of tensile load is 3156 Mpa for riveted joint & 3361 Mpa for adhesive joint. The change in linear dimensions 0.86915 mm & 0.9967 mm is considered as deformation with the working stress of both the joints. Also Factor of safety for both the joints under tensile load is 1.38 & 1.45. Riveted joint is a mechanical fastening joint. It is recommended where the material is reliable; loads are predictable and low weight to be maintained. However, the adhesive joint permits maximum tensile strength compared to riveted joint.

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