ISSN XXXX XXXX © 2018 IJESC

Research Article Volume 8 Issue No.7

Finite Element Analysis of Composite Material Nut-Bolt

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Abstract:
Bolted Joints have been extensively used in aircraft and automobile applications due to widespread introduction of composite materials. Work presents detailed study of finite element analysis of composite bolted joints under static load of 10000N.Finite Element Analysis will be done to identify correctly the critical locations in the joints and reproduce it with accuracy. Consequently, Modal Analysis will be performed on steel Nut-bolt and composite bolts to calculate the natural frequency. Stresses and strains results developed in the whole region are reported and discussed with the aim of improving the Bolted joint designs. Finite Element Analysis is performed to determine the stresses and strains distributions in a composite bolted joints loaded in tension with the aim to predict the ultimate failure of such joints.

Keywords: Bolted joints, Composite bolts, Finite element analysis, Stresses and Strains

1. INTRODUCTION

Composite structures are used widely in flying machine structures because of their outstanding mechanical properties united with low density. Fastener joining is the utmost important method of assembling structural elements in the aerospace industry, due to its ability to assemble, disassemble and repair, and its tolerance to environmental effects. For high accountability applications on composite structures bolted joints should be sensibly designed.

The improved stress intensity factor at the surrounding of the hole and the weakness of the composite under out of plane loads, make the designing and assembly process more critical in the case of composite joints than in those based on metallic components. Structural safety should be guaranteed in aeronautical industry, therefore the study of bolted joints in structural composite components have acknowledged significant attention in both scientific literature and aeronautical standards. Threaded structural fasteners are one of the most common methods used to join assemblies in mechanical components. They allow components to be disassembled and reassembled with greater ease, as compared to other methods like welding. However, there are several difficulties associated with using threaded structural fasteners (i.e., the ability to determine the preload applied to a bolt and the non-linear behavior of a bolted assembly). An example of a bolted assembly is shown in Figure 1.

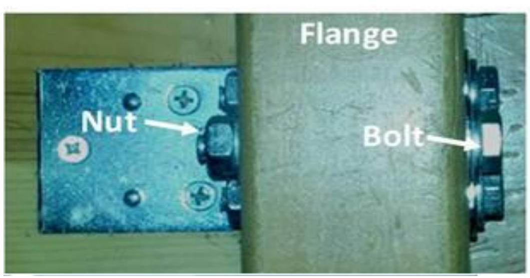


Fig1: Bolted Joints

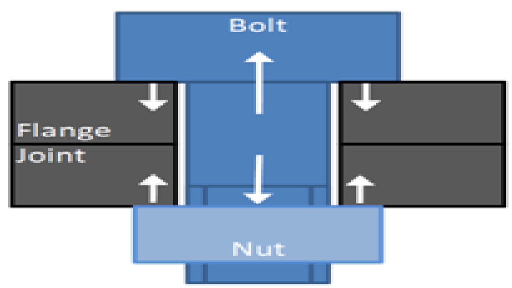


Fig 2: Bolted Joints Clamping Forces

The bolt preload is the clamping force that holds bolted assemblies together. Therefore, the bolt preload is an important factor used to determine the acceptability of a given joint. The amount of bolt preload at installation can be estimated by Equation 1 from:

Preload = T/K d.............................(1)

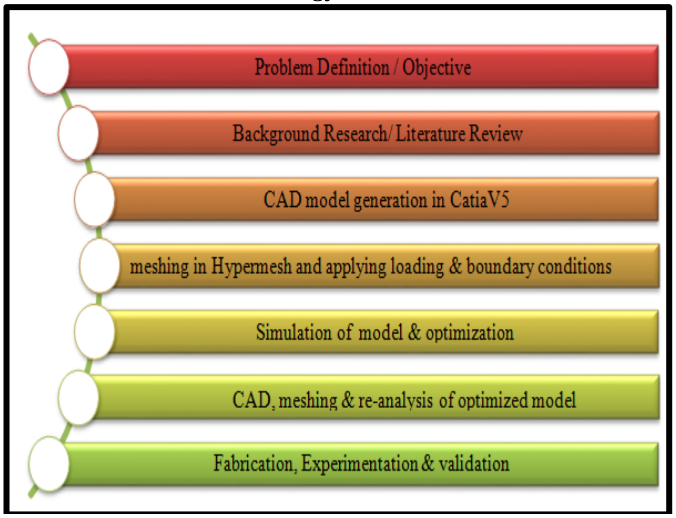
However, there can be significant scatter when determining the torque coefficient (K) and the applied torque (T). These values can be affected by the friction of the threads or bearing surfaces, thread geometry, and how the torque is applied to the bolt or nut.Various researchers have performed research who have worked in this area of bolting strength of composite nut-bolt and optimization worked on the Predictionof bolted single-lap composite joints.The model predictedthe effect of secondary bending and tightening torque showing an excellent agreement with experimental results. In addition, a parametric study was carried out to analyze the influence of friction coefficient and tightening torque. A new set of failure criteria is proposed to predict composite failure in bolted joints. The present failure criteria include out of plane shear stresses in the formulations of the four failure criteria proposed by Chang Lessard and the consideration of two new failure modes: out of plane matrix cracking and delamination. The advantages of the present failure criteria with respect to Chang Lessard criteria are the consideration of a 3D stress field and the prediction of out of plane failure modes as delamination.

II. PROBLEM IDENTIFICATION

Metal Bolts and Nut cannot be used in Plastic parent components as they wear and damage the parent part, And Plastic bolts are rarely available in market which has low strength and durability, hence a composite bolt can be a solution to this problem which has high tensile strength and can do no harm to plastic parent material.

III. METHODOLOGY

The methodology for the research:



DESIGN OF COMPOSITE NUT AND BOLT

Design and Analysis of composite nut and bolt of dissertation includes design and analysis of existing nut and bolt. Dimensions of the existing nut and bolt have been measured from market and CAD model of a nut and bolt have been prepared in CATIA V5. The finite element analysis is carried out by using Hypermesh and ANSYS as post-processor.

CAD (Computer-Aided Design)

Computer-aided design (CAD), also known as computer aided design and drafting (CADD), is the use of computer technology for the process of design and design documentation. Computer Aided Drafting describes the process of drafting with a computer. CADD software, or environments, provides the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CAD is mainly used for detailed engineering of 3D models and/or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components. It can also be used to design objects.

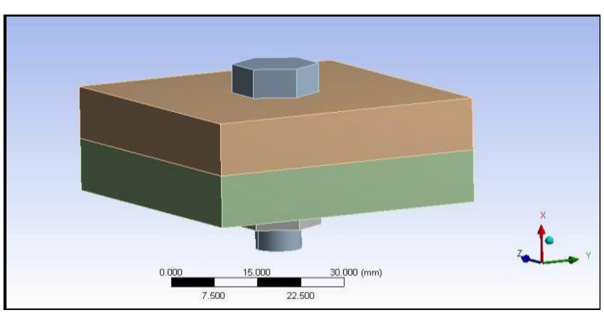


Fig 3: Bolted lap joint

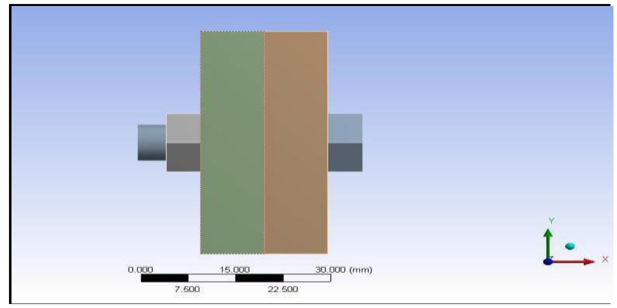


Fig 4: Bolted lap joint

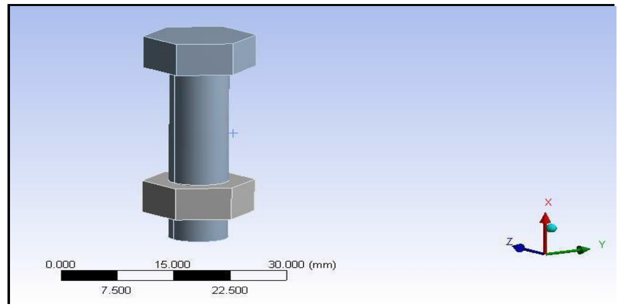


Fig 5: Nut and bolt considered for analysis

Table 1: Meshing Details

Number of Nodes	33939
Number of Elements	7868
Element size	2 mm
Type of element	3D (Hexahedral, Tetrahedral)

A structure or component consists of infinite number of particles or points hence they must be divided in to some finite number of parts. In meshing we divide these components into finite numbers. Dividing helps us to carry out calculations on the meshed part. We divide the component by nodes and elements. We are going to mesh the component using 2D elements. We will be using the shell elements for meshing. While meshing mesh size of an element is to be taken into consideration because all software's have some limits for the number of elements. Less the mesh size more will be the number of elements and coarse the mesh size less will be the number of elements. As the number of elements increases the run time increases. After meshing elements are to be checked for Quality elements have some definite quality criteria which should be met by all elements. A quality criterion consists of minimum and maximum angles of the elements, jacobian, warpage etc.

IV.FEA ANALYSIS

Finite Element Analysis Of Existing (Steel) Nut And Bolt

To perform the FEA of the Existing steel nut and bolt, continuum (model) is discretized into finite number of elements through meshing process and then boundary conditions are applied to the system. The assembly of lap joint is coupled with the help of M8nut and bolting. Each M8 bolt is capable of sustaining a pre tension of 13000N load. Assembly of bolted lap joint has been simulated considering the effect of nut and bolt

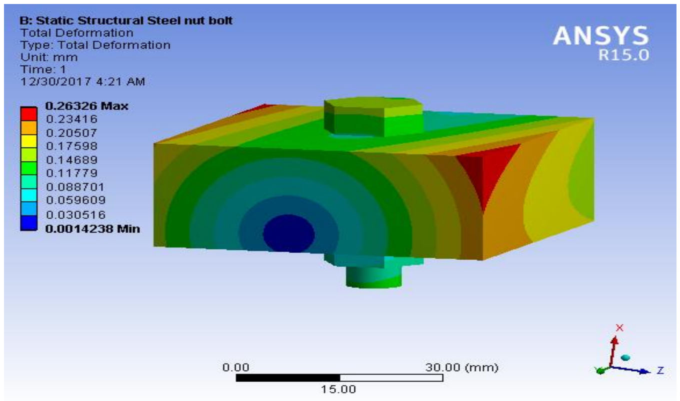


Fig 6:Displacement in whole assembly(Steel)

Finite Element Analysis Of Composite Nut And Bolt

Carbon Fiber

Carbon Fiber>Constant

Density -1.6e-006kgmm^-3

Table: 2 Carbon Fiber>Orthotropic Elasticity[3]

Temperature C	Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MP
	1.269 +005	11000	1.269 +005	0.2	0.2	0.2	6600	4230	4880

Carbon fiber material data

Deformation and stress plots for whole assembly (Carbon Fiber)

For above considered loads and boundary conditions as in case of existing steel nut and bolt following deformation and stresses are observed in composites

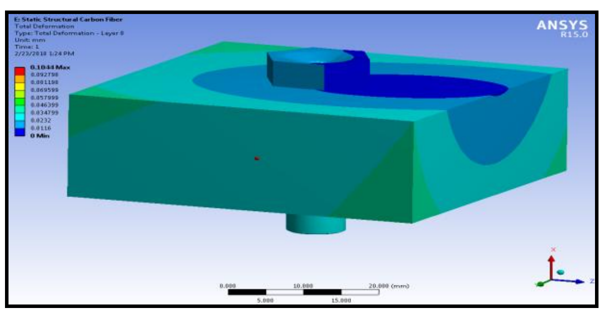


Fig 7:Displacement in whole assembly(Carbon Fiber)

Glass Fiber

Glass Fiber > Constant

Density – 1.9e-006 kgmm^-3

Table: 3 Glass Fiber>Orthotropic Elasticity[3]

Temperature C	Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MP
	40300	6210	40300	0.2	0.2	0.2	3070	2390	1550

Glass fiber material data**:** By following the same procedure as considered in case of carbon fiber, Glass fiber layer are generated for nut and bolt and analyzed for the above considered boundary conditions. Following are the results observed for glass fiber.

Deformation and stress plots for whole assembly (Glass Fiber)

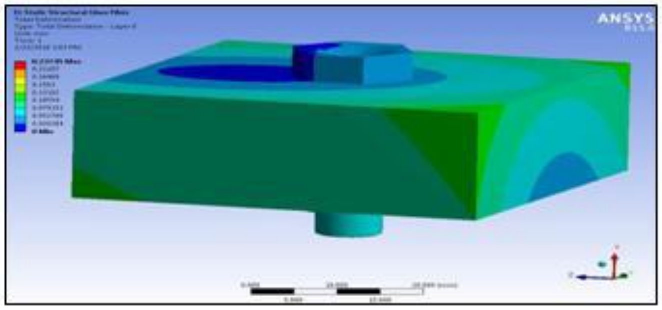


Fig8:Maximum displacement in whole assembly(Glass Fiber)

V. VIBRATIONAL (MODAL) ANALYSIS OF NUT ANDBOLT

What is modal analysis?

Physically "The mode shape" is the shape of the deformed structure when it is excited by a dynamic force. Mode shapes gives idea about how the given structure will vibrate with respect to six degrees of freedom and the respective magnitude of frequency of vibration and maximum deformation value. By considering above applied lodes and boundary conditions following vibrational results are observed for nut and bolt. The mode shape has no unit. In finite element analysis infinite degrees of freedom of a Continuum is restricted to 6 degrees of freedom that is 3 translations and 3 rotations with respect to global X, Y and Z axis. In this modal analysis we get the mode/shape of vibration of the given component with respect to these 6 degrees of freedom.

Modal analysis results for Composite Nut Bolt(Glass Fiber):

Mode 1:

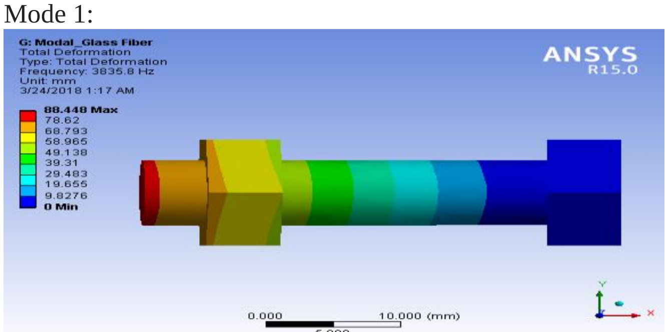


Fig 9:1st Mode shape of Glass Fiber nut and bolt

Mode 2:

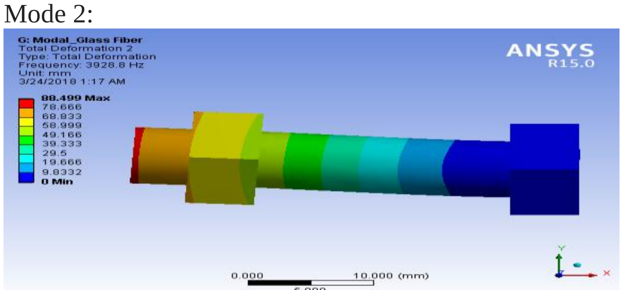


Fig10: 2nd mode shape of Glass Fiber nut and bolt

Mode 3:

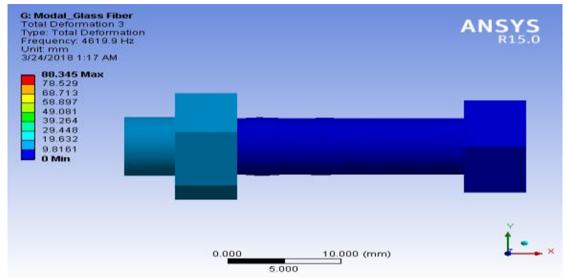


Fig 11: 3rd mode shape of steel nut and bolt

Mode 4:

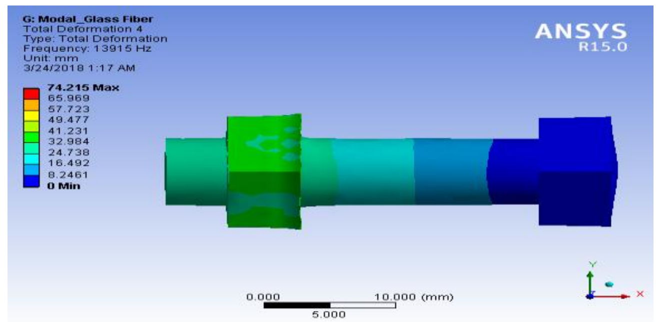


Fig 12:4th mode shape of Glass Fiber nut and bolt

Mode 5:

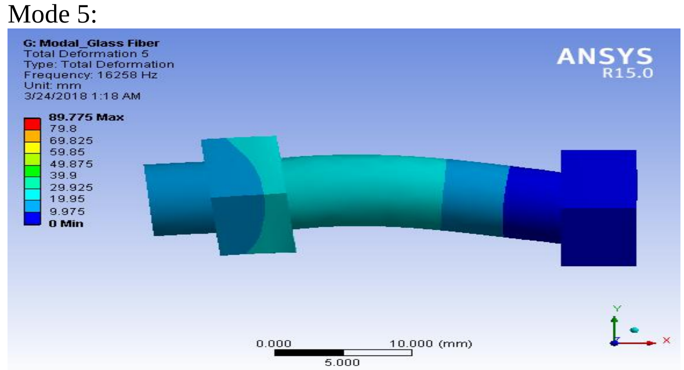


Fig 13: 5th mode shape of Glass Fiber nut and bolt

Mode 6:

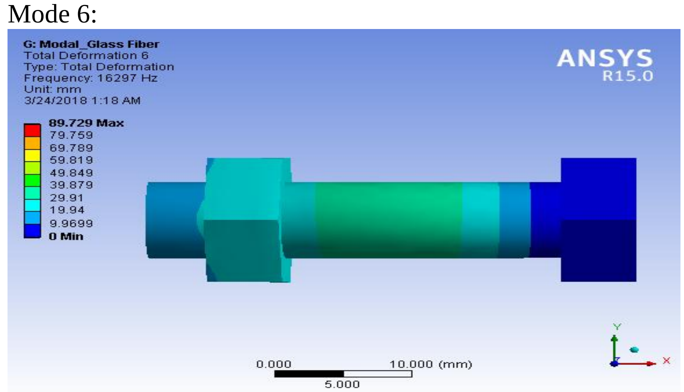


Fig 14: 6th mode of Glass Fiber nut and bolt

VI.EXPERIMEMTAL RESULTS

Fabrication of composite nut and bolt

Following are the Steps considered for fabrication:

Preparation of glass fiber components

Preparation of Resin Mixer

Including Cobalt, Hardener, epoxy Resin

1 litre. mixer is been made for applying on each layer of glass fiber

The glass fiber is been cut according to the size best fit inside

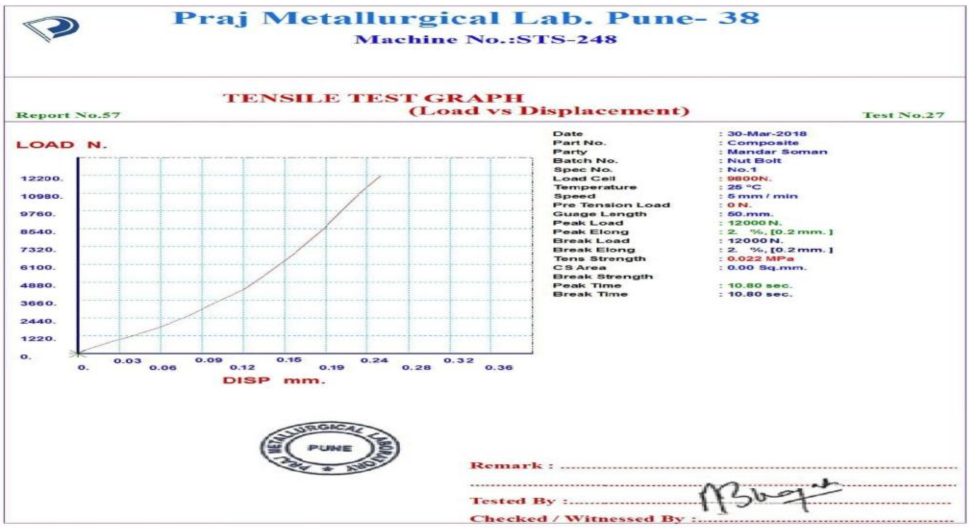
The two sheets which are compressed together in between GF is been applied with epoxy resin mixer

The component is kept for 48Hrs. for drying and solidification of Glass Fiber resin

After drying finishing operation is been performed like grinding, cutting, deburring turning etc.

The Glass fiber nut-bolt is ready

TEST REPORT



Results and Discussions

1. Comparison of Experimental and FEA results for force of 10000N on composite nut-bolt

Table 4: Comparison of Experimental and FEA

S.No.	Type of Analysis	Max. Displacement	% Error
	FEA	0.237 mm	7.17%
	Experimental	0.22 mm	

2. Comparison of Mass and Topology Optimization

Table 5: Comparison of Mass and Topology Optimization

Cases	Existing Nut-bolt	Glass Fiber Nut-bolt	% of mass reduction
Mass of nut bolt	0.022kg	0.007kg	68.18%

VII. RESULT ANALYSIS & VALIDATION

*Comparison of Modal Analysis Results***:**

Analyzing with respect to practical working sense of nut and bolt are much stiffer for above considered loading conditions there are very less atmosphere for vibration. At extreme case to make nut and bolt assembly to vibrate there will be a requirement of very high exiting dynamics forces at that condition we will come can induce and observe vibrations in nut and bolts with the following frequency ranges listed below for respective materials.

Table 6: Modal Analysis Results

Sr. No.	**Mode**	**Frequency (Hz)**		
		Steel	**Carbon Fiber**	**Glass Fiber**
1	1	4010	4029.4	3835.8
2	2	4123.3	4086.7	3928.8
3	3	4778.9	4759.9	4619.9
4	4	14483	14287	13915
5	5	16552	16539	16258
6	6	16582	16575	16297

COMPARISION OF RESULTS

Table 7: Comparison of Results

Material	**In Total Assembly**		**In Bolt**		**In Nut**	
	Deformation (mm)	Stress (Mpa)	Deformation (mm)	Stress (M pa)	Deformation (mm)	Stress (Mpa)
Steel	**0.263**	**509.19**	**0.112**	**442.14**	**0.164**	**322.45**
Carbon Fiber	**0.104**	**575.49**	**0.104**	**305.83**	**0.031**	**141.29**
Glass Fiber	**0.234**	**602.26**	**0.237**	**272.51**	**0.077**	**123.19**

VIII. CONCLUSIONS

Experimental results are in well arrangement with FEA results with error of 7.17%

Weight has been reduced approximately by 68.18% since density of glass fiber is less than steel

Mechanical strength has been increased considerably

Rust free operation

The natural frequencies of existing glass fiber nut-bold are analyzed using FEA.

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