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Bolting Strength of Composite Nut-Bolt FEA Analysis

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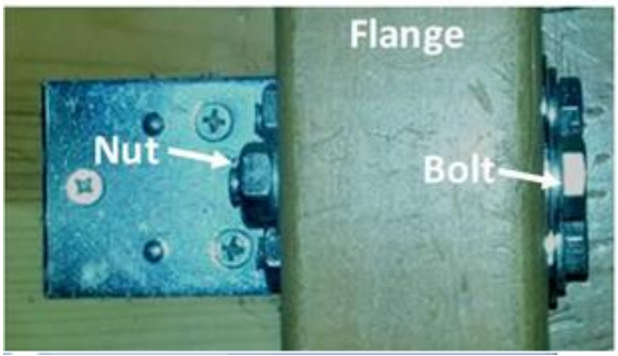
Abstract:
Bolted joints have been extensively used on aircraft since the dawn of aviation and, even with the recent and widespread introduction of composite materials, still play a key role in aeronautical structures. This work presents a very detailed FE model of a single lap composite bolted joint, under static tensile load. The stress states of the composite bolts are discussed, the evolution of the contact between the bolts and the holes is analyzed, and the numerical results are compared to experimental data. Parametric studies have been performed to study the influence of bolt clamping force, coefficient of friction and bolt–hole clearance on the joint behavior. Finite element analysis will be done to identify correctly the critical locations in the joint (head–shank transition and first thread in bolts and edges of the holes at the faying surface for the plates) and reproduce with accuracy the experimental load–displacement test curves (including an unloading–reloading loop) up to the point where bearing damage occurs. A correlation between the joint stiffness and the contact status between bolts and holes willbe found.

Keywords: Bolted joints, FEA

I. 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.



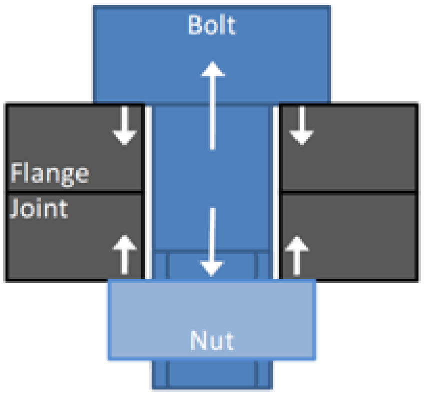


Figure 2: Bolted Joint Clamping Forces

Figure.1. Bolted joints

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.

II. PROBLEM IDENTIFICATION:

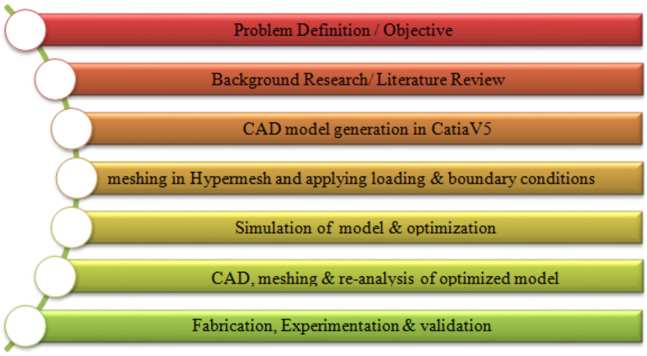
Metal Bolts and Nut cannot be used in Plastic parent components as they wear and damage the parent part, And Plastic bolts are rarely available in market which has low strength and durability, hence a composite bolt can be a solution to this problem which has high tensile strength and can do no harm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

OBJECTIVES:

The main purpose of the present study is to

- Determine the stress and strain distributions in an composite bolted joint loaded in tension with the aim to predict the ultimate failure of such joints.
- Appropriate finite element models were generated and developed to simulate the bolt clamping force and subsequent tensile load applied remotely at the plates end.
- Stress and strain results developed in the whole region are reported and discussed with the aim of improving the bolted joints design in composite structures.
- The main objective of the project is to analyze the strength of nut bolt by using composite material.

METHODOLOGY:



III. LITERATURE REVIEW

Following is a list of researchers who has worked in this area of bolting strength of composite nut-bolt and optimization. Álvaro Olmedo, Carlos Santiuste worked On the **Prediction of bolted single-lap composite joints.** The model predicted the 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. Rashmi Gill, Veerendra Kumar ,Anshul Choudhary done **A Review of Failure Analysis of Bolted Composite Joint** A review of publications associated with the failure of bolted composite joints in this paper has been carried out. The study covered the work done from 2005 to 2012. Mechanical fasteners often cause a reduction of load capacity of the composite structure because of the complicated stress field near the hole area. Consequently, special attention must be given to design of fasteners. The design of efficient structural attachments represents one of the major challenges in the development of composite structures. Because of its generic nature, the joint design deserves a separate treatment as a case study. Characterization of joint failure in bolted composite laminates is complicated because of the large number of parameters involved. A large part of the research, done on mechanically fastened joints so far, has been concerned with the experimental determination of the influence of geometric factors on the joint strength C. Stocchi, P. Robinson, S.T. Pinho[3], **Detailed finite element investigation of composite bolted joints with countersunk fasteners** This paper presents a very detailed FEM model of a single lap shear composite bolted joint, with countersunk fasteners, under static tensile load. Parametric studies have been performed to study the influence of clamping force, coefficient of friction and clearance on the joint behaviour. Numerical and experimental data, the joint behaviour can be divided in 5 stages: (i) No-Slip, (ii) Slip, (iii) Full Contact, (iv) Bearing Damage and (v), Final failure. The stiffness of the No-Slip stage seems to depend only on the plate stiffness while clamping force and coefficient of friction define the maximum load carried out only by friction. The full contact stage is influenced by the clearance which seems to modify the stiffness of the joint.

DESIGN OF COMPSITE NUT AND BOLT

The chapter 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.

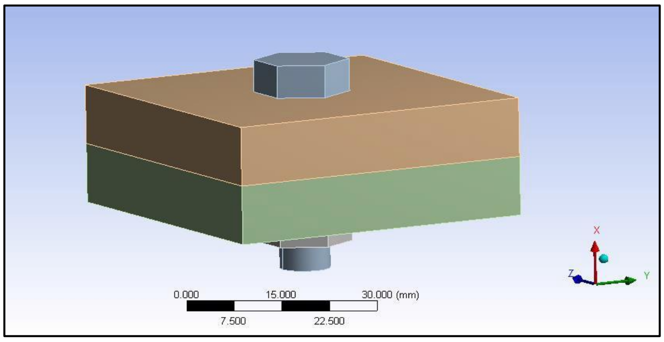


Figure.2. Bolted lap joint

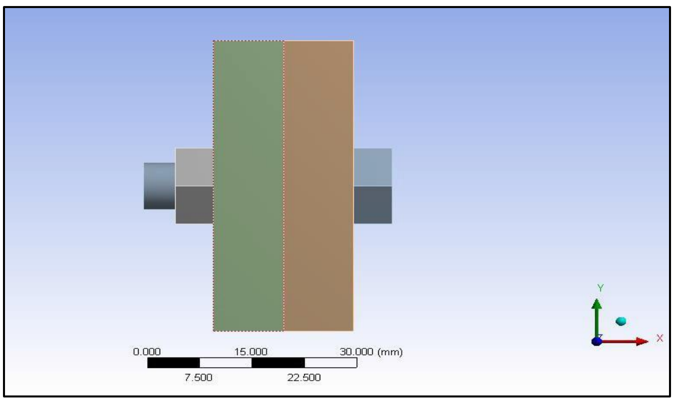


Figure.3. Bolted lap joint

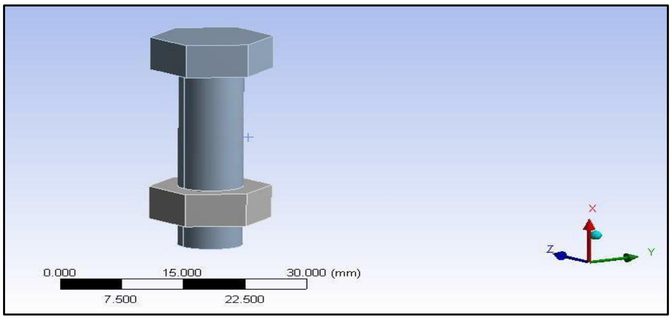


Figure. 4. Nut and bolt considered for analysis

MESHING

Initially the igs file is imported to the computer aided engineering (CAE) software like ANSYS. The CAD data of the nut and bolt is converted to meshed model.

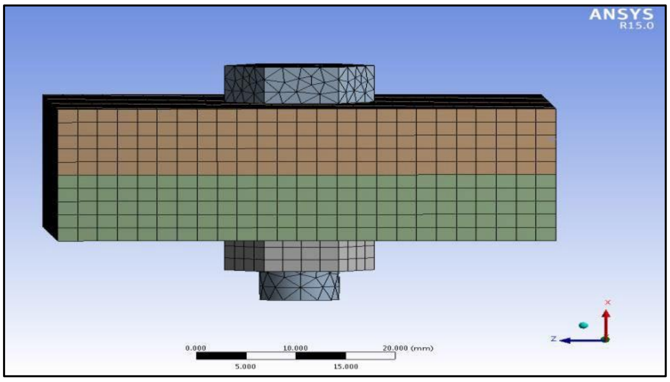


Figure.5. Meshing of Nut and bolt

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.

FINITE ELEMENT ANALYSIS OF EXISTING (STEEL) NUT AND BOLT

To perform the FEA of the Existing steel nut and bolt, continuum (model) isdiscretized 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 boltedlap joint has been simulated considering the effect of nut and bolt.

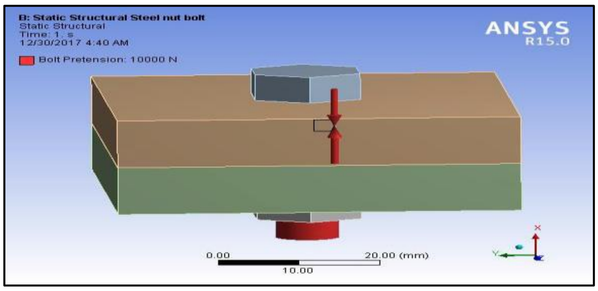


Figure.6. Bolted lap joint assembly with applied forces and boundary conditions

Closure:

The finite element analysis of the existing steel nut and bolt given maximum stress (von- mises) `of 322.45 and 442.14 Mpa and deflection of and 0.1641 and0.1123 mm in bolt and nut respectively. By observing these stress and deflection plots, it can be concluded that since steel nut and bolt will be under continuous stressed condition because of tight bolting. Because of continuous work cycles there are many chances of failure and permanent setting of the above deformation. Hence there is a need for optimization of existing steel nut and bolt. This can be effectively achieved by replacing steel material with composites (Carbon Fiber and Glass fiber).

FINITE ELEMENT ANALYSIS OF COMPOSITE NUT AND BOLT

Carbon Fiber

Carbon Fiber > Constants

Density	1.6e-006 kg mm^-3

TABLE 14

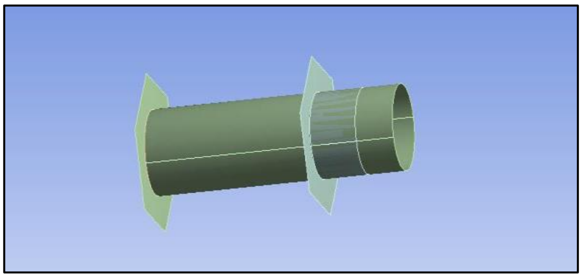
Carbon Fiber > Orthotropic Elasticity

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 MPa
	1.269e+005	11000	1.269e+005	0.2	0.2	0.2	6600	4230	4880

Carbon fiber material data

Layer Details

Modeling of composite nut and bolt is done by consider thin layered section of nut and bolt structure then composite class fiber layers are applied as per required dimensions as shown below



Figur.7. Nut and bolt section model used for application of composite layers

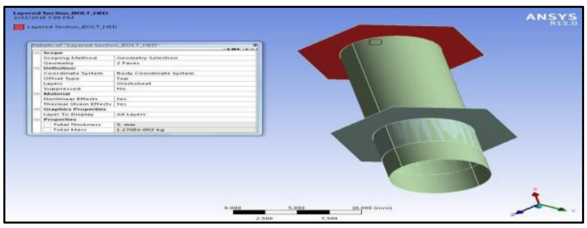


Figure.8. Application of carbon fiber layers to bolt head

GLASS FIBER

Glass Fiber > Constants

Density	1.9e-006 kg mm^-3

TABLE 14

Glass Fiber > Orthotropic Elasticity

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 MPa
	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)

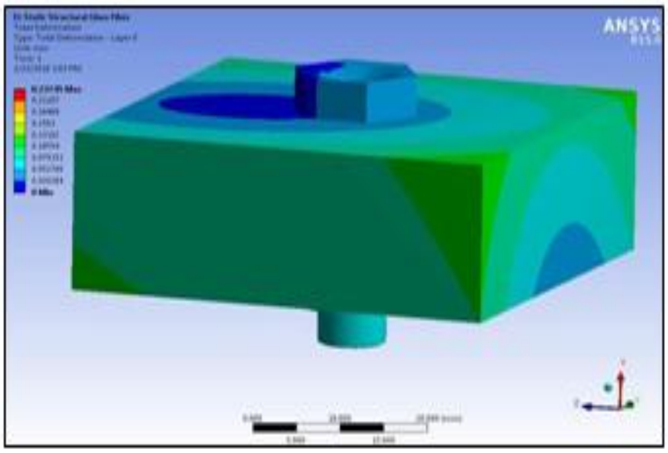


Figure.9.: Maximum displacement in whole assembly of 0.2374 is observed

IV. COMPRESSION OF RESULTS

Material	In Total Assembly		In Bolt		In Nut	
	Deformation (mm)	Stress (Mpa)	Deformation (mm)	Stress (Mpa)	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**

From above compression table it's clear that glass fiber material is more feasible CONCLUSION

- 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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