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"analysis of bolted joint in composite laminate"

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Abstract: - Mechanical fastening is a common method used to join composite materials. Mechanically fastened joints commonly adopted in aerospace structures are characterized by tight tolerances on both the fasteners and on the machined holes. Joints are the potential weakest point in the structure in order to make useful structure. The main objective of the bolted joint is to transfer the applied load from one part of the joint structure to the other through the fastener element. However, the presence of bolt holes induces high stress concentration which has thus recognized to be a source of damage developed during fatigue loading. The proposed work involves modeling of single bolted joint with the help of PRO/E for mild steel and E-glass fiber and analyzed with the ANSYS Workbench 14.5. Different stresses are evaluated theoretically and compared with that observed analytically for both the materials and it is found that maximum stresses are observed in E-glass fiber.

I. INTRODUCTION

Until early 1990s, the use of fiber-reinforced polymer (FRP) composites was almost limited to only aerospace and military applications. By the mid-1990s, civil engineers started to realize the advantages of such materials especially in the structural repair and rehabilitation of existing reinforced concrete bridges and buildings. In structural applications such as in aircraft, spacecraft and civil engineering structures, composite components are often fastened to other structural members by bolted joints. Since bolted joints require holes to be drilled in the structure, large stress concentration tends to develop round the hole, which can severely reduce the overall strength of the structure. The introduction of composite materials in the automotive industry, places new demands on the materials and manufacturing processes in terms of cost, cycle time and automation. Manufacture and assembly of composite structures require knowledge of reliable joining techniques. Mechanical fastening is a common method used to join composite materials. Mechanically fastened joints commonly adopted in aerospace structures are characterized by tight tolerances on both the fasteners and on the machined holes. Joints are the potential weakest point in the structure in order to make useful structure. Consideration is given to the ways of joining the various components of the structure. In structural application such as in aircraft, space craft and in civil engineering structures the components are often fasten to the structural members by bolted joints. Since bolted joint is to be required to drill hole in the structures, large stress concentration developed around the hole, which can reduce the overall strength of the structure. The usage of composite is increasing in aerospace and other engineering industries and the study of joining methods for composite materials became an important research area. The composite materials are widely used because they have high strength to weight ratio, good fatigue resistance and high damping properties. The main objective of the bolted joint is to transfer the applied load from one part of the joint structure to the other through the fastener element. However, the presence of bolt holes induces high stress concentration which has thus recognized to be a source of damage developed during fatigue loading.

The objective of this work is to determine the various types of stress induced in bolted joints by using ANSYS 14.5 and finally comparison is made between the metal plate and FRP plate with bolted joint.

II. LITERATURE REVIEW

Marie-Laure Dano, et al. [1], proposed a model to determine the influence of the failure criteria, the inclusion of a non-linear shear behavior on the strength prediction and the load-pin displacement curve and good agreement between experimental results and numerical predictions is observed.

Tae Seong Lim, et al. [2], was worked to increase the efficiency of whole structures with the composite bolted joints. From the results of this study, it was concluded that the laminate whose major plies are stacked in the axial direction could be used for the bolted joint structures under fatigue load when an appropriate clamping pressure was applied to the bolted joint.

Murat Pakdil [3], performed failure analysis of composite single bolted joint to determine the effect of joint geometry and stacking sequence of laminated composite plates on bearing strength and failure mode. He conclude that bearing strength increased with an increase in edge distance to hole diameter ratio (E/D) and an increase in bolt pretensions appeared to be rather suitable for a safe bolted joint owing to its provision of bearing mode and high bearing strengths.

Marie-Laure Dano, et al. [4], studied the influence of failure criteria by using the model at the pin–hole interface, progressive damage, large deformation theory, and a nonlinear shear stress–strain relationship. Better agreement between experimental results and numerical predictions was observed with the maximum stress criterion.

K.I. Tserpes, et al. [5], developed a PDM model to investigate the effect of failure criteria and material property degradation rules on the tensile behavior and strength of bolted joints in graphite/epoxy composite laminates and concluded that the strength prediction of the joint was governed by the combination of failure criteria and material property degradation rules.

Gordon Kelly, Stefan Hallstrom [6], investigated the bearing strength of carbon fiber epoxy laminates manufactured from non-crimp fabric from heavy tow yarn experimentally together with the effect of initial bolt-hole clearance on the bearing strength at 4% hole deformation and at ultimate load. It was concluded that the effect of bolt-hole clearance is significant with regard to the design bearing strength of mechanically fastened joints.

A. Nanda Kishore, et al. [7], worked to obtain failure modes and failure loads for multi-pin joints in uni-directional glass fiber/epoxy composite laminates by finite element analysis and validating the results with the experimental work. The results from experimental and finite element analysis showed that the failure modes observed in three- and four-pin joints from experiments and FEA were similar and the error obtained in failure loads were less than 10%.

Roman Starikov, Joakim Schon [8], worked related to the Measurements of the local strain between two bolts were made by using strain gauges on composite joints with different configurations. Observation showed that bolted joints tested at high loads sustained severe damage around the bolt holes.

M.A. McCarthy, C.T. McCarthy [9], presented finite element analysis on the effects of bolt-hole clearance in composite bolted joints. The models showed excellent capability to quantify the effects of increasing clearance, which included reduced contact area and overall stiffness in the single-bolt case, and substantially changed load distribution in the multi bolt case. It was found that increasing clearance had the effect of reducing the stiffness of single-bolt joints and changing the load distribution in multi-bolt joints.

J. Kratochvil, W. Becker [10], presented an approach to provide an efficient method for the calculation of stresses and displacements in the neighbourhood of the hole where failure is likely to occur and method appears to be much more computationally efficient.

A. Atas, et al. [11], suggested that the Clamping force was a key element that alters the mechanism and sequence of failure in bolted joints of composite laminates. It was showed that without modeling the in-plane failure modes, the effect of component is insignificant on the onset and growth of de-lamination; of course in the case of a bolted joint with a certain clamping force fracture was also restrained.

P.J. Gray, C.T. McCarthy [12], presents the development of an analytical model for replicating the through-thickness stiffness of single-bolt, single-lap composite joints subjected to bending. The method was validated against detailed three-dimensional finite element models of bolted composite plates and good agreement was obtained.

F.-X. Irisarri, et al. [13], presented a methodology to compute the failure of large-scale bolted joints in composite structures and it was important to notice that this work was not intended to promote fully numerical methods, but rather a balanced compromise between the use of actual experiments and virtual ones.

Luciano Feo, et al. [14], the results of a numerical analysis performed on different types of bolted composite joints with different geometry and subjected to tensile loads are reported. The results of this study showed that in multi-bolt joints, the load is not distributed equally due to varying bolt position, bolt-hole clearance, bolt-torque or tightening of the bolt, friction between member plates and at washer-plate interface.

Objective of the present work

- To detect “tensile stress” and “crushing stress”
- Modeling by using PRO/E
- Finite Element Analysis by ANSYS 14.5

Methodology:

- Design of rectangular plates of mild steel and FRP material using CAD modeling software Pro/E.
- Analysis of mild steel and FRP material using ANSYS Workbench 14.5.

CAD modeling:

CAD/CAE Software for Design

Pro/ENGINEER is a parametric, feature based, solid modeling System. It is the only menu driven higher end software. Pro/ENGINEER provides mechanical engineers with an approach to mechanical design automation based on solid modeling technology.

- ***Modeling:***

The essential difference between Pro/ENGINEER and traditional CAD systems is that models created in Pro/ENGINEER exist as three-dimensional solids. Other 3-D modelers represent only the surface boundaries of the model. Pro/ENGINEER models the complete solid. This not only facilitates the creation of realistic geometry, but also allows for accurate model calculations, such as those for mass properties.

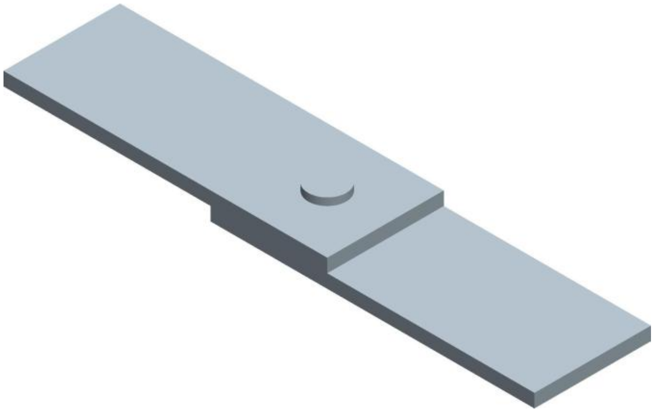


Fig: Assembly of single bolted joint.

III. DESIGN CALCULATIONS

DESIGN OF BOLTED JOINT:

Consider the Tensile Stresses induced in Single Bolted Joint made of E-Glass Fiber,

$F_t = 155$ KN

Now,

$$F_t = (b \times t) \times (\sigma_t)_{theoretical}$$
$$155 \times 10^3 = (b \times 4.16) \times 1025$$
$$b = 36.35 \text{ mm}$$

Let, b = 37 mm

Then,

$$155 \times 10^3 = (37 \times 4.16) \times (\sigma_t)_{Cal.}$$

$(\sigma_t)_{Cal.} = 1007.016$ MPa

As,

$$(\sigma_t)_{Cal.} < (\sigma_t)_{theoretical}$$

The obtained Dimensions are safe for the Design, so the Design is safe.

1. Consider the Crushing Stresses induced in Single Bolted Joint made of E-Glass Fiber, $F_c = 155$ kN

Now,

$$F_c = (d \times t) \times (\sigma_c)_{theoretical}$$
$$155 \times 10^3 = (d \times 4.16) \times 5000$$
$$d = 7.45 \text{ mm}$$

Let, d = 8 mm

Then,

$$155 \times 10^3 = (8 \times 4.16) \times (\sigma_c)_{Ca}$$

$(\sigma_c)_{Cal.} = 4567.45$ MPa

As,

$$(\sigma_c)_{Cal.} < (\sigma_c)_{theoretical}$$

The obtained Dimensions are safe for the Design, so the Design is safe.

Now, Consider Tensile Force on Plate, $F_t = 620 \times 10^3$ kN

$$F_t = n \times (b \times t) \times (\sigma_t)_{\text{ theoretical}}$$
$$620 \times 10^3 = n \times 37 \times 4.16 \times 1025$$
$$n = 3.92$$

i.e. $n = 4$

Therefore, Four Bolts are required for this force.

For Four Bolts ($n = 4$)

$620 \times 10^3 = 4 \times 37 \times 4.16 \times (\sigma_t)_{cal.}$

$(\sigma_t)_{cal.} = 1007.01$ MPa

Which is less than $(\sigma_t)_{theoretical}$. therefore, the Design is safe.

Consider the Tensile Stresses induced in Single Bolted Joint made of Mild Steel, $F_t = 27$ kN

Now,

$F_t = (b \times t) \times (\sigma_t)_{theoretical}$

$27 \times 10^3 = (b \times 4.16) \times 175$

$b = 37.08$ mm

Let, $b = 37$ mm

Then,

$27 \times 10^3 = (38 \times 4.16) \times (\sigma_t)_{Cal.}$

$(\sigma_t)_{Cal.} = 170.79$ MPa

As,

$(\sigma_t)_{Cal.} < (\sigma_t)_{theoretical}$

The obtained Dimensions are safe for the Design, so the Design is safe.

1. Consider the Crushing Stresses induced in Single Bolted Joint made of Mild Steel, $F_c = 27$ kN

   Now,

   $F_c = (d \times t) \times (\sigma_t)_{theoretical}$

   $27 \times 10^3 = (d \times 4.16) \times 207$

   $d = 6.96$ mm

   Let,

   $d = 8$ mm

Then,

$27 \times 10^3 = (8 \times 4.16) \times (\sigma_c)_{Ca}$

$(\sigma_c)_{Cal.} = 180.28$ MPa

As,

$(\sigma_c)_{Cal.} < (\sigma_c)_{theoretical}$

The obtained Dimensions are safe for the Design, so the Design is safe.

Now, Consider Tensile Force on Plate, $F_t = 105 \times 10^3$ kN

$F_t = n \times (b \times t) \times (\sigma_t)_{theoretical}$

$105 \times 10^3 = n \times 38 \times 4.16 \times 175$

$n = 3.79$

i.e. $n = 4$

Therefore, Four Bolts are required for this force.

For Four Bolts ($n = 4$)

$105 \times 10^3 = 4 \times 38 \times 4.16 \times (\sigma_t)_{cal.}$

$(\sigma_t)_{cal.} = 166.05$ MPa

Which is less than $(\sigma_t)_{theoretical}$. Therefore, the Design is safe.

FEA analysis of Bolted joint mild steel and E-glass Fiber:

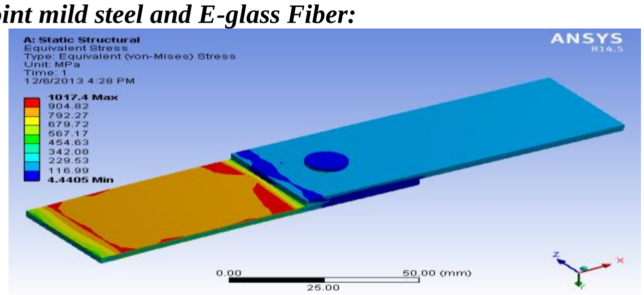
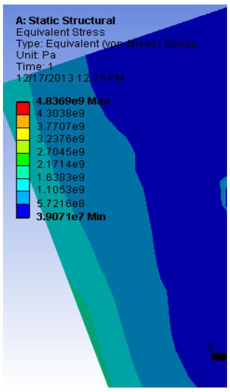


Fig: FEA analysis of single bolted joint in E-glass fiber

- Maximum tensile stress obtained is 1017.4MPa.



No. of	Materia	Theoretical	Analytical

Fig: FEA analysis of single bolted joint in E-glass fiber

- Maximum crushing stress obtained is 483.63MPa.

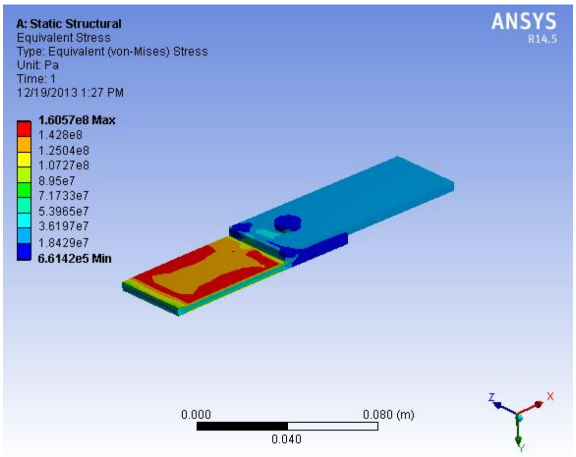


Fig: FEA analysis of single bolted joint in mild steel fiber

- Maximum tensile stress obtained is 160.4MPa.

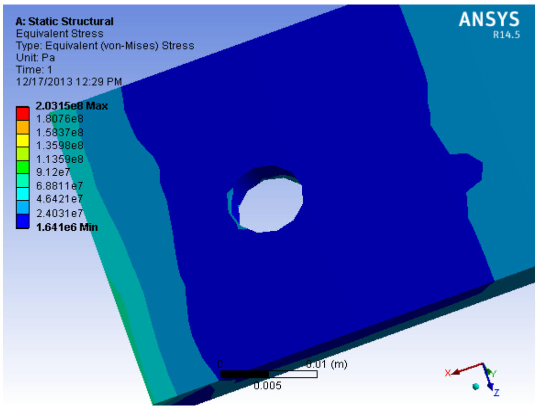


Fig: FEA analysis of single bolted joint in mild steel

- Maximum crushing stress obtained is 203.15MPa.

IV. RESULTS AND DISCUSSION:

According to the calculation and the values of stresses obtained analytically following results are obtained.

		σ_t (MPa)	σ_c (MPa)	σ_t (MPa)	σ_c (MPa)
Single Bolted Joint	E-Glass Fiber	1025	5000	1017.4	4836
	Mild Steel	175	207	177.72	203.1
Four Bolted Joint	E-Glass Fiber	1025	5000	1069.2	4736
	Mild Steel	175	207	172.20	203.15

- From results obtained from design calculation and FEA it is observed that the tensile stress and shear stress of E-glass fiber is more than mild steel.

V. CONCLUSION

- From, the results it is observed that the tensile and crushing stresses are more in case of E-glass fiber than mild steel. Thus it can be concluded that E-glass fiber is better replacement material to mild steel.

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