Computation Method in Failure Analysis of Mechanically Fastened Joints at Layered Composites

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Abstract

In this paper, a computation method in failure analysis of layered composites containing pin-loaded holes. The investigation is focusedon developing a reliable computation procedure to analyze initial failure load for pin-loaded holes at with layeredand without layered composite structures. Finiteelement analysis (FEA) is used to determine stress distribution around the fastener hole. Combining soderberg curvemodel and Tsai-Wu initial failure criterion are used to determine joint failure. Special attention in this work is paid to pin-load distributions andits effect on the load level of failure and its location. In previous work initial failure analysis was carried out using cosine distribution betweenpin/lug mechanically fastened joint. Here contact finite element pin/lug model is analyzed. The influence of stacking sequences of layeredcomposites containing pin-loaded holes is also investigated. Special attention is paid to failure load and mode analyses in composites withstacking sequence [0/ ± 90]s.

Introduction

Joining by mechanical fasteners is one of the common practices in the assembly of structural components. However, mechanical fasteners introduce complicated stress field near the bolt hole area in the structures. As a consequence, mechanical fastened joints are frequent sources of failure in aircraft and spacecraft structures. It is well known that they can severely reduce the load carrying capability of the components by more than fifty percent. Optimal design of joints improves not only structural integrity and performance, but more importantly, it considerably minimizes the weight of the structures and hence, can increase the load-carrying capability. Fiber reinforced laminated composite materials have been widely used in aircraft and spacecraft structures because of their high strength and stiffness to weight ratios. Due to the complex failure modes of composite materials, the mechanical joining of structures made of composite materials demands much more rigorous design knowledge and techniques than those currently available in the traditional methodology for metallic joints. Damage in bolted composite joints can initiate at an early loading stage and accumulate inside the laminates as the load increases. The accumulation of damage and the mode of failure strongly depend upon the material, ply orientation, laminate thickness, joint geometry, and loading condition, etc. Considerable analyses and experiments on bolted composite joints have been performed to evaluate the effect of material properties and ply orientation as well as layup on the joint response and failure in the literature. There are in general three basic failure modes in bolted composite joints: net-tension, shear-out, and bearing. Net-tension failure is associated with fiber and matrix tension failures, due to stress concentrations, while shear-out and bearing failures result primarily from the shear and compression failures of fiber and matrix. The first two failure types tend toail catastrophically. The bearing failure is more progressive and may not result in total reduction of the load-carrying capability of the joints.

A combination of any of the three modes may also occur in the joint.

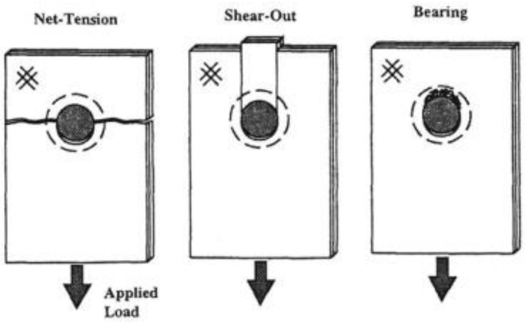

Fig: Illustration of the three failure types in mechanically fastened composite joints

1.1 Failures of Fasteners

Failure because of Overload : Many accidents can be characterized as an impact with a non-compliant object such as a truck impacting a concrete bridge support. The fine, grey appearance of the fracture surface is consistent with a sudden overload failure. **Failure from lack of Locking Mechanism:**To prevent bolts from loosening over time, various locking mechanisms are employed. They include lockWashers, locking nuts, jam nuts, mechanical deformations, wire wrap, cotter pins, metal locks, and expansion Anchors, helical coils and polymer locking compounds. Machinery that is subject to vibratory environments usually is equipped with some sort of locking mechanism. If the locking mechanism is not applied to the Machinery during manufacture, a catastrophic event may result.

Metal Fatigue: Metal fatigue is the phenomenon characterized by progressive crack growth during cyclic loading. A crack isoften initiated at a flaw or stress riser (sharp notch) in a part. Cyclic forces such as vibrations or repeated impactcause the crack to increase in size until the part can no longer sustain the load, and a final fracture occurs.

Failure from Improper Torque: When threaded fasteners are utilized, the amount of tightening or bolt torque is often important. Motor vehiclewheel studs require torques ranging from about 100 ft-lbs for smaller vehicles to over 400 ft-lbs for large trucks.

The appropriate torque is required in order to prevent relative flexing of the two parts being fastened and toassure an acceptable mechanical connection. Bolt failures as a result of improper torque have occurred inautomobile applications.

Corrosion Failure: Corrosion of metals can be disastrous to threaded fasteners. Surface and pitting corrosion attacks threadedFasteners as a result of contact with moisture or other corroding media. Since bolts often carry high loads, stresscorrosion cracking is another corrosion related failure mode. Corrosion, coupled with forces in a bolt, tends toaccelerate cracking.

Hydrogen Embrittlement (HE): A permanent loss of ductility in a metal or alloy caused by hydrogen in combination with stress, eitherexternally applied or internal residual stress.

Galling: If you've ever had the pleasure of installing or removing stainless steel fasteners, you've more than likelyexperienced galling. Galling is a cold-welding processesthose results when the threads are in contact under heavypressure and friction. Or in other words, when fasteners are assembled or disassembled.

Fig: Fasteners

1.2 Application of Fasteners

Some of applications of fasteners are as follows:

Military – Fasteners specially designed to withstand the stress of high temperature, high wear and corrosive environments such as engines, motors, heat exchangers and process equipment. We offer a wide range of diameters, lengths and thread configurations using stainless steel, copper alloys, alloy steels, nickel alloys and exotic alloys.

Oilfield – Fasteners manufactured using stainless steel, tool alloys, nickel alloys and exotic metals that will perform well in the high stress, corrosive environment found in oilfield and mining applications. Our fasteners are used in drilling rigs, tanks and pumping equipment.

Turbine & Power Generation – Fasteners used in electrical equipment, turbines, motors, exhaust systems, pumping systems and storage vessels. Nickel alloys, aluminum, steel alloys and stainless steel are used for their strength, high wear and anti-corrosive properties. Copper alloys are used for their conductive properties.

Chemical Refining – Fasteners manufactured using stainless steel, tool alloys, nickel alloys and exotic metals that will perform well in the high stress, corrosive environment found in chemical processing applications. Our fasteners are used in heat exchangers; exhaust systems, tanks and vessels, and processing equipment.

2. LITERATURE REVIEW

Okutan and Karakuzu [1] studied on the response of pin loaded laminated E/glass-epoxy composites for two different ply orientations such as [0/ ± 45]s and [90/ ± 45]s. The objective of this work is to study the behavior of graphite-epoxy pin loaded joints numerically, with particular attention paid to the sensitivity of the model to different geometric dimensions. The twodimensional finite element methods was used to obtain stress distribution at the composite lugs. To determine the failure load and failure mode initial damage prediction model was selected with Tsai-Wu failure criteria.

In this analysis, based on the Chang et al. strength prediction model, [2], the point stress failure criterion will be used to evaluate the characteristic lengths in tension and compression and a two-dimensional contact pin/lug finite element analysis used to evaluate the stress distribution in the vicinity of the joint. In many previous investigations Yamada-Sun failure criterionwas then used. In this paper Tsai Wu failure criterion was used to evaluate joint failure and the results compared with available experimental data and correlation observed.

This method was proposed by Whitney and Nuismer , and has been developed by Chang et al. and . It is still used for thefailure analysis of composite joints, [3]. In the characteristic length method, two parameters, i.e. compressive and tensile characteristic length should be determined by the stress analysis associated with the results of bearing and tensile tests on the laminates with and without hole. Once the characteristic lengths are determined, an artificial curve connecting the compressive and tensile characteristic lengths named characteristic curve is assumed, Failure of a joint is evaluated on the characteristic curve and not on the edge of the fastener hole. In this method the joint is taken to have failed when certain combined stresses have exceeded a prescribed value in any of the plies along the characteristic curve.The strategy for the finite element modeling of the joints is the same as in the finite element model of the laminate for bearing tests shown in Fig. Nonlinear finite element analysis for the joints composite structural components [4] is conducted by MSC/NASTRAN. Interface between fasteners and laminates is modeled by the slide line contact element provided by the software. The slide line element in MSC/NASTRAN was adopted to simulate the contact between the pins and the laminates. The pin and the laminate were modeled using CQUAD4 shell elements.In present study an attempt made to understand the behavior of the bolted joints and the stress concentration factor when loaded statically with uni-axial external loads [5]. Also an attempt has been made to minimize the error between experimental results and FEM simulated results by selecting the exact number of element and selecting suitable yield criteria. Linear finite element analysis method is used to determine the stress concentration factor of the threads in bolted connection.

3. METHODOLOGY

- Study the literature review.
- Create the 3Dsurface model of fastenerhole with help of CATIA parametric software.
- Selection of material and layer staking.
- Perform linear layer static analysis on fastener hole with number of layer stacking.

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3.1 MATERIALS AND METHODS

Carbon Fiber: In fiber reinforced composites, fiberglass is the "workhorse" of the industry. It is used in many applications and is very competitive with traditional materials such as wood, metal, and concrete. Fiberglass products are strong, lightweight, non-conductive, and the raw material costs of fiberglass are very low.In applications where there is a premium for increased strength, lower weight, or for cosmetics, then other more expensive reinforcing fibers are used in the FRP composite.

Table: mechanical properties of carbon fiber

Young’s modulus(Mpa)	70000
Tensile strength(Mpa)	3900
Poisson’s ratio	0.30
Density(kg/mm3)	0.00000020

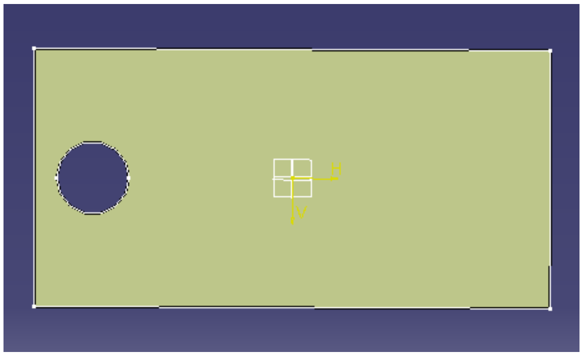
4.Finite element analysis

Finite element analysis is a method of solving, usually approximately, certain problems in engineering and science. It is used mainly for problems for which no exact solution, expressible in some mathematical form, is available. As such, it is a numerical rather than an analytical method. Methods of this type are needed because analytical methods cannot cope with the real, complicated problems that are met with in engineering. For example, engineering strength of materials or the mathematical theory of elasticity can be used to calculate analytically the stresses and strains in a bent beam, but neither will be very successful in finding out what is happening in part of a car suspension system during cornering.

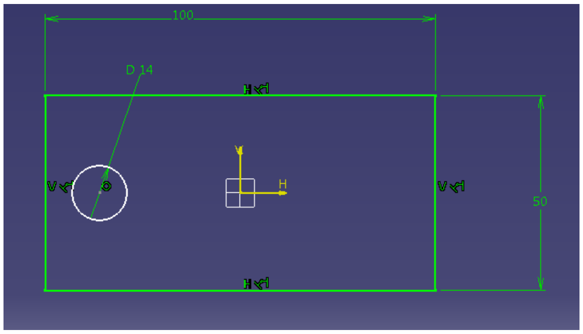
4.1CATIA PARAMETRIC SOFTWARE

Computer Aided Design (CAD) is the use of computer software to design a product or an object.Computer Aided Manufacturing (CAM) is the use of computer software and hardware to plan, manage and control the operations of a manufacturing plant.Computer Aided Engineering is the use of computer software to solve engineering problems and analyze products created using CAD.CATIA is an acronym for Computer Aided Three-dimensional Interactive Application. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, automobile to consumer products.CATIA is a multi platform 3D software suite developed by Dassault Systems, encompassing CAD, CAM as well as CAE.

3D surface model



2D drawing

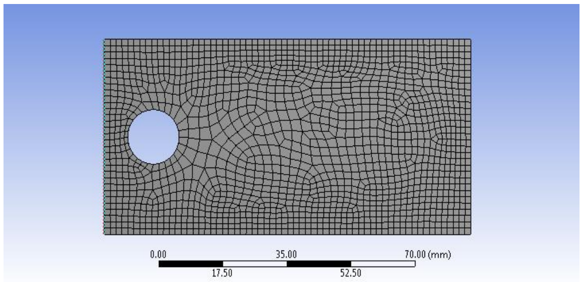


5. RESULTS AND DISCUSSION

Static Analysis of Fastener Hole

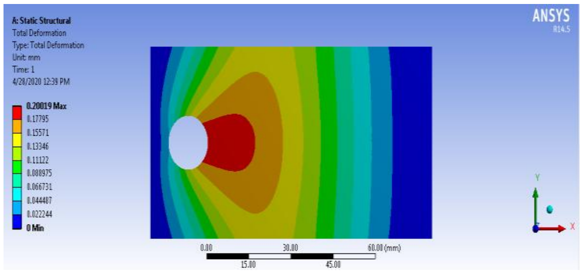
Case: 1 without layered composite

Meshed model



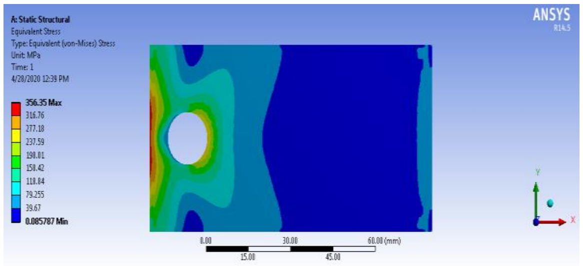
The model is designed with the help of CATIA and then import on ANSYS for Meshing and analysis. The analysis by static approach is used in order to calculating stress profile and damage. For meshing, the fluid ring is divided into two connected volumes. Then all thickness edges are meshed with 360 intervals. A tetrahedral structure mesh is used. So the total number of nodes and elements is 3631 and 13595.

Total deformation



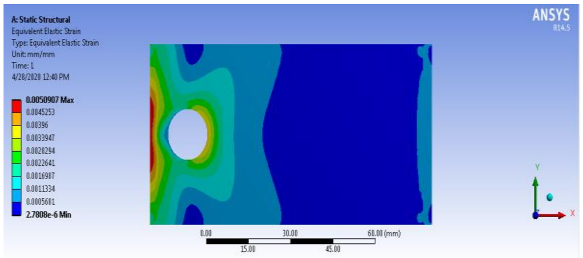
According to the contour plot, the maximum deformation at fastener hole due to applied the loads.The maximum deformation is 0.20019mm and minimum is 0.022244 mm

Stress



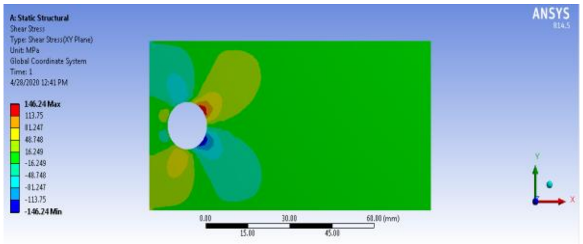
According to the contour plot, the maximum stress at fastener hole due to applied the loads.The maximum stress is 356.35N/mm^2 and minimum is 0.085787N/mm^2

Strain



According to the contour plot, the maximum strain at fastener hole due to applied the loads.The maximum stress is 0.005090 and minimum is 2.70e-6.

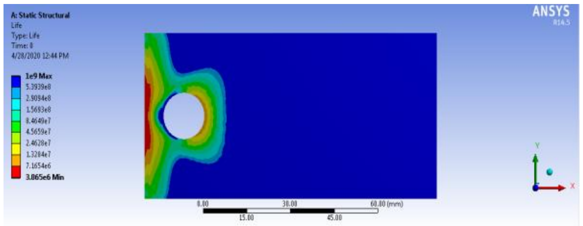
Shear stress



According to the contour plot, the maximum shear stress at fastener hole due to applied the loads.The maximum shear stress is 146.24N/mm^2 andminimum is1.24 N/mm^2.

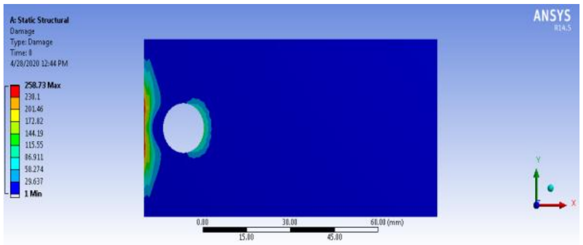
Fatigue analysis of fastener hole

Life



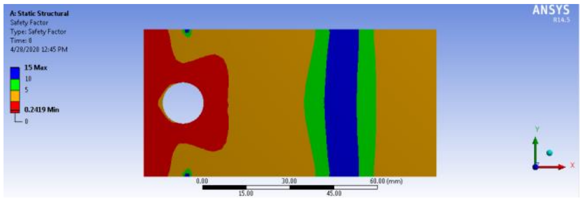
According to the plot, the maximum life at fastener hole and minimum at end of the specimen.

Damage



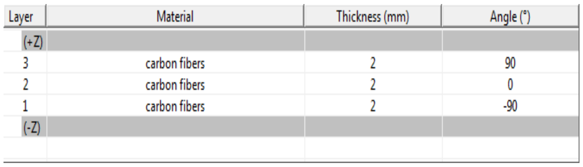
According to the plot, the maximum damage at end of the specimen and minimum at fastener hole.

Safety factor



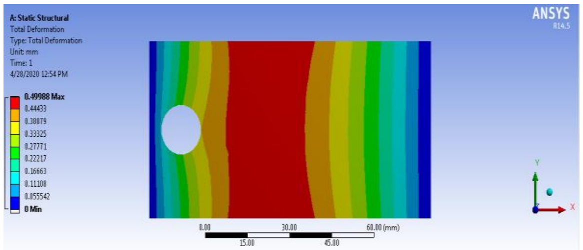
Case: 2 with layered composite

At -3 layers

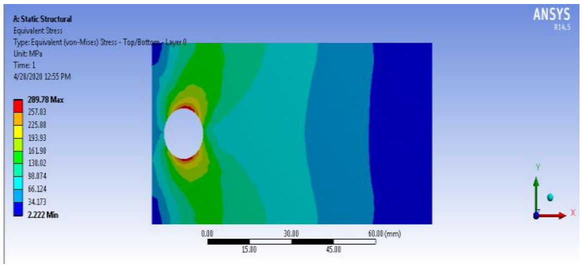


Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
3	carbon fibers	2	90
2	carbon fibers	2	0
1	carbon fibers	2	-90
(-Z)			

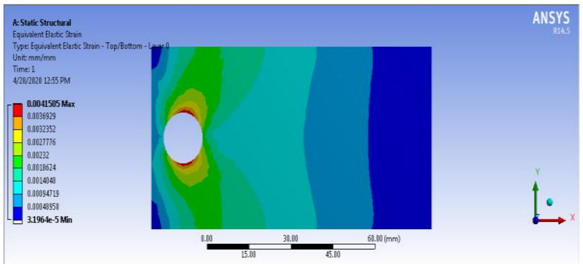
Total deformation



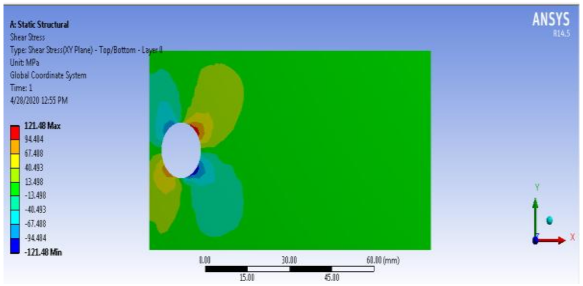
Stress



Strain

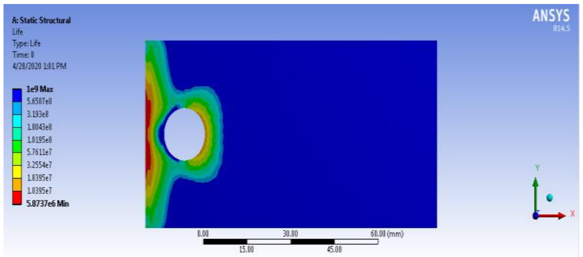


Shear stress

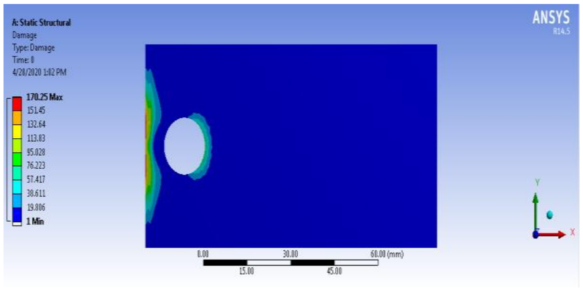


Fatigue analysis of fastener hole

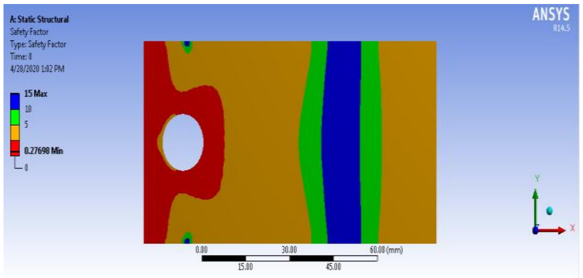
Life



Damage



Safety factor



Results tables

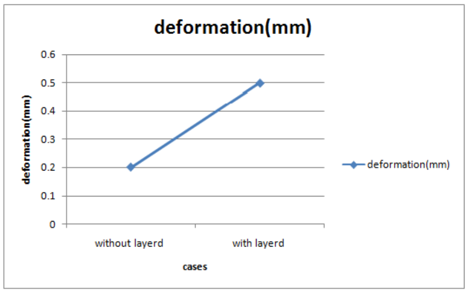
Table: 2 Static Analysis Results

Cases	Deformation (mm)	Stress (N/mm^2)	Strain	Shear strain
Without Layered	0.20019	366.35	0.00509	146.24
With layered	0.49988	289.78	0.27698	121.48

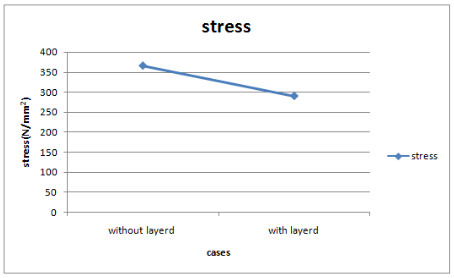
Table: 3 Fatigue Analysis Results

Cases	Life	Damage	Safety factor	
			Min	Max
Without Layered	$1e^9$	258.73	0.241	15
With layered	$1e^9$	170.25	0.276	15

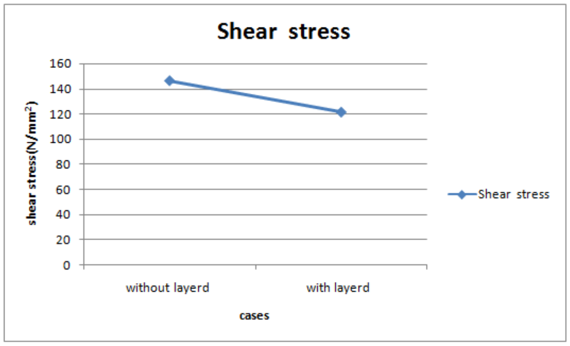
Graphs



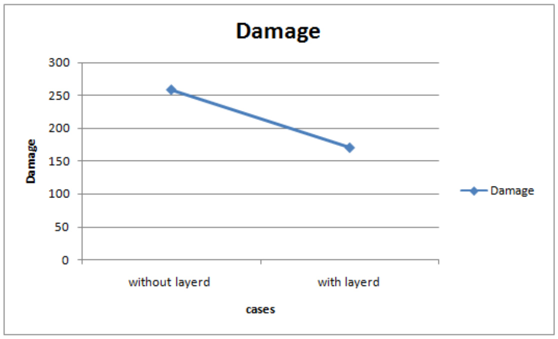
Above plot shows, the maximum deformation versus cases such as without layered and with layered.



Above plot shows, the maximum stress versus cases such as without layered and with layered.



Above plot shows, the maximum shear stress versus cases such as without layered and with layered.



Above plot shows, the maximum damage versus cases such as without layered and with layered.

6. CONCLUSION

In this work a numerical study on the failure load and failure mode investigations of pin loaded composite joints are presented. Special attention is paid to failure load and mode analyses in composites with stacking sequence [0/ ± 90]s. For the verification of the proposed FEA, composite laminated joints with layered and without layered composite structure. It can be seen that the results obtained analytically.

By observing the static analysis results, the stress and shear values are less at layered composite structure fastener hole.

By observing the fatigue analysis results, the damage values are less at layered composite structure fastener hole.

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