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Design and Analysis of Hybrid Composite Lap Joint Using FEM

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ABSTRACT
In 1909 Ritz developed an effective method for the approximate solution of problems in the mechanics of deformable solids. It includes an approximation of energy functional by the known functions with unknown coefficients. Minimization of functional in relation to each unknown leads to the system of equations from which the unknown coefficients may be determined. One from the main restrictions in the Ritz method is that functions used should satisfy to the boundary conditions of the problem.
In 1943 Courant considerably increased possibilities of the Ritz method by introduction of the special linear functions defined over triangular regions and applied the method for the solution of torsion problems. As unknowns, the values of functions in the node points of triangular regions were chosen. Thus, the main restriction of the Ritz functions – a satisfaction to the boundary conditions was eliminated. The Ritz method together with the Courant modification is similar with FEM proposed independently by Clough many years later introducing for the first time in 1960 the term "finite element" in the paper "The finite element method in plane stress analysis". The main reason of wide spreading of FEM in 1960 is the possibility to use computers for the big volume of computations required by FEM. However, Courant did not have such possibility in 1943. An important contribution was brought into FEM development by the papers of Argyris, Turner, Martin, Hrennikov and many others. The first book on FEM, which can be examined as textbook, was published in 1967 by Zienkiewicz and Cheung and called "The finite element method in structural and continuum mechanics". This book presents the broad interpretation of the method and its applicability to any general field problems. Although the method has been extensively used previously in the field of structural mechanics, it has been successfully applied now for the solution of several other types of engineering problems like heat conduction, fluid dynamics, electric and magnetic fields, and others.
KEYWORDS: FEM, FEM development, Zienkiewicz. hybrid composite lap joint

I. INTRODUCTION

The common methods available for the solution of general field problems, like elasticity, fluid flow, heat transfer problems, etc., can be classified as presented in Fig. Below FEM will be compared with analytical solution of differential equation and Ritz method considering the shaft under tensile load.

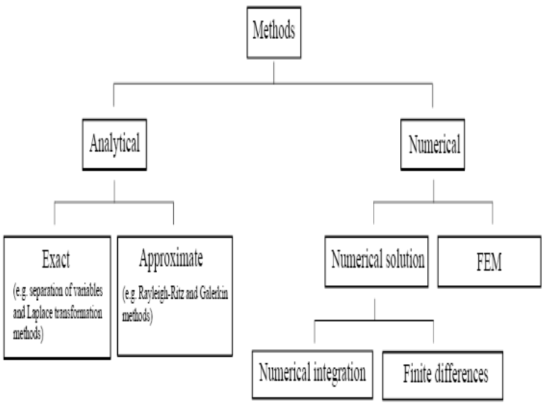

Fig. 1.1 Classification of Common Methods

FEM

FEM was treated previously as a generalization of the displacement method for shaft systems. For a computation of beams, plates, shells, etc. by FEM, a construction is presented in a view of element assembly. It is assumed that they are connected in a finite number of nodal points. Then it is considered that the nodal displacements determine the field of displacements of each finite element. That gives the possibility to use the principle of virtual displacements to write the equilibrium equations of element assembly so, as made for a calculation of shaft systems.

Introduction to Finite Element Method

There are two version of FEM
1. Flexibility Method or Force Method:
2. Stiffness Method or Displacement Method.
The set of equations in the stiffness method are the equilibrium equations relating displacements of points.

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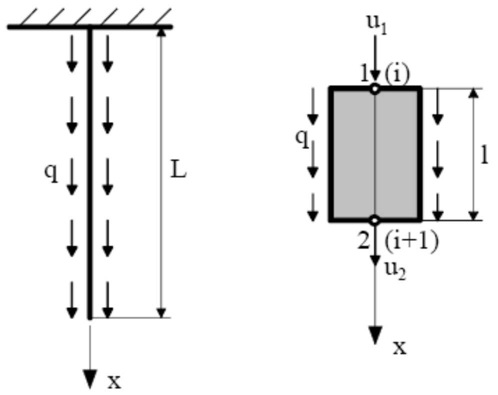
Rayleigh-Ritz is an approximate method based on energy principle by which we can obtain equilibrium equations in matrix form.

The learning objectives in this chapter is:

1.Understand Rayleigh-Ritz method and its application to axial members, torsion of circular shafts, and symmetric bending of beams.

2.Understand the perspective, the key issues, the terminology, and steps used in solving problems by finite element method.



Finite element of tensile shaft.

How the FEM works

To summarize in general terms how the finite element method works we list main steps of the finite element solution procedure below.

1. Discretize the continuum. The first step is to divide a solution region into finite elements. The finite element mesh is typically generated by a preprocessor program. The description of mesh consists of several arrays main of which are nodal coordinates and element connectivities.
2. Select interpolation functions. Interpolation functions are used to interpolate the field variables over the element. Often, polynomials are selected as interpolation functions. The degree of the polynomial depends on the number of nodes assigned to the element.
3. Find the element properties. The matrix equation for the finite element should be established which relates the nodal values of the unknown function to other parameters. For this task different approaches can be used; the most convenient are: the variational approach and the Galerkin method.
4. Assemble the element equations. To find the global equation system for the whole solution region we must assemble all the element equations. In other words we must combine local element equations for all elements used for discretization. Element connectivities are used for the assembly process. Before solution, boundary conditions (which are not accounted in element equations) should be imposed.

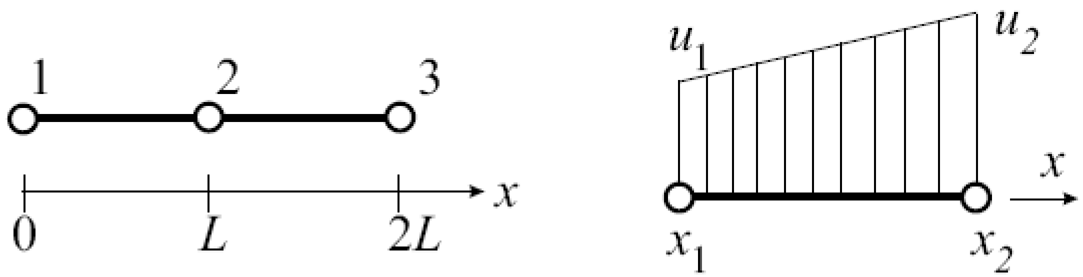


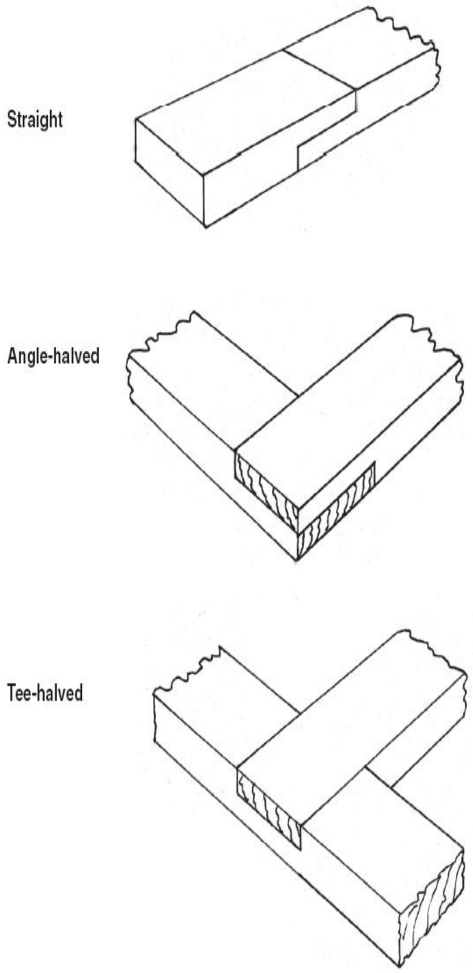
Figure 1.1: Two one-dimensional linear elements and function interpolation inside element.

5. Solve the global equation system. The finite element global equation system is typically sparse, symmetric and positive definite. Direct and iterative methods can be used for solution. The nodal values of the sought function are produced as a result of the solution.
6. Compute additional results. In many cases we need to calculate additional parameters. For example, in mechanical problems strains and stresses are of interest in addition to displacements, which are obtained after solution of the global equation system.

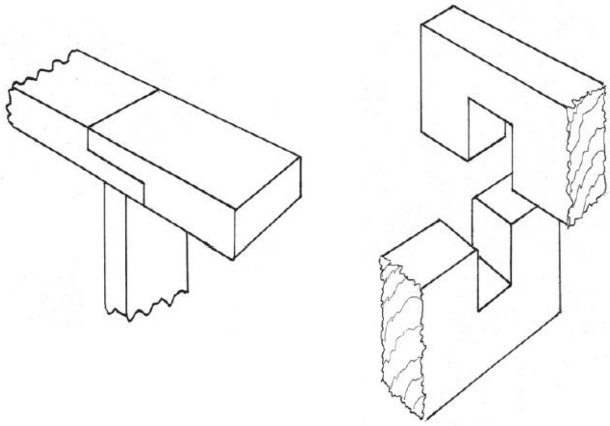
1.2 Formulation of finite element equations

Several approaches can be used to transform the physical formulation of the problem to its finite element discrete analogue. If the physical formulation of the problem is known as a differential equation then the most popular method of its finite element formulation is the Galerkin method. If the physical problem can be formulated as minimization of a functional then variational formulation of the finite element equations is usually used.

What is a lap joint?
Lap or halving joints are used for joining pieces of timber.
• It needs special cuts in the timber
• The joint is fixed with nails or screws
The two pieces of timber are cut so that they fit together at different angles. Usually half the timber thickness is cut away. That is why it can be called a halving joint.



What is a lap joint used for?
It is used for such things as
• joining long lengths of timber in a frame
• corner joints
• crossing one length of timber over another.



INTRODUCTION OF COMPOSITE

Nowadays the composite materials like plastics reinforced with carbon fibres (CFRP), glass fibres (GFRP), and aramid fibres (AFRP) are widely used in various industries such as automotive, chemical, electrical industry, aircraft and even in cryogenics.

Due to its superior properties, composites have been one of the materials used for repairing the existing structures in various applications and also for joining composite parts together, using adhesives or mechanical fasteners nowadays, a new method called hybrid joint is also being employed where a combination of both adhesive and mechanical fasteners are used.

In the present project, an attempt is made to analyze the stress distribution in 3D models of three configurations of double riveted Single lap joint namely bonded, riveted, hybrid. A major advantage of adhesive bonds with fastener may be designed and made in such a way that they can be stronger than the ultimate strength of many metals and it is broadly used in the fuselage panels in aircrafts structures etc.

II. Objective

In this attempt three joints were modeled using proE and analysis is done by using Ansys workbench. The stresses for two different materials were found such as vonmises, shear and normal stress.

III. Materials and Methods

Material of CFRP (carbon fibre reinforced plastic) composite with modeling and static analysis of 3D models of the joints (bonded, riveted, hybrid) were carried out using PROE (creoparametric) modeling and ANSYS FEA workbench software .

3.1 GENERAL

For understanding the seismic behaviour of precast concrete structures, the study of behaviour of joints is of great importance as the connections form the weakest link in the structure. Experimental studies are necessary as it gives the realistic response of the structure. But Finite Element Modelling as gained importance as experimental investigations though accurate can be time consuming and costly. The use of Finite Element packages to model the structural elements is faster and cost effective.

Hence, many parameters can be studied by modelling the structural elements using Finite Element packages. Several researchers worldwide have investigated the behaviour of precast beam-column connections under earthquake loading both experimentally and analytically. A detailed review of the literature has been carried out to understand the behaviour of precast beam column connections under cyclic loading. Among these the most significant literatures are briefly summarized in this chapter. The finite element modelling related to precast beam-column modelling related work are also reviewed.

OVERVIEW OF LITERATURE

3.2 Studies on Experimental Investigations of Precast Beam

Column joints under Seismic Loading

3.2.1 Wet Connections

Bull and Park (1986) investigated the performance of cast-in-place reinforced concrete moment resisting frames incorporating precast prestressed concrete U- beam shells subjected to seismic loading. The precast beams acted as permanent formwork and were not connected by steel to the cast-in-place concrete of the beam or column. Three full scale exterior beam column subassemblies were tested. It was concluded that the two specimens that were designed for seismic loading was satisfactory and can be used in ductile seismic resisting frame. The third specimen that was designed without special provisions for seismic loading was suitable for non seismic resisting frames where the seismic loads are carried by walls and other structural systems. Cheok and Lew (1991) attempted to develop moment resisting precast concrete connections in seismically active regions by testing four one third scale monolithic concrete beam-to-column connections.

Two were designed according to the 1985 Uniform Building Code (UBC) Seismic zone 2 criteria and two according to UBC zone 4 criteria. In addition, two precast post-tensioned concrete beam-to-column connection similar in design to the monolithic zone 4 specimens were tested. It was concluded that post tensioned precast concrete beam-column connections are strong and as ductile as the monolithic connections, for high seismic regions. However, the per cycle and cumulative energy.

MECHANICALLY FASTENED JOINTS

Mechanical joints are used when repeated disassembly and reassembly is required or when surface preparation is not practical. Mechanical joints require that bolt or rivet holes are drilled into the composite, that reduced the net cross sectional area of the structure and introduce localized stress concentration. These stress concentrations can cause ply delamination since they will include through thickness tensile and shear stresses. Mechanical joints add weight to the structure from the added weight of the bolt or rivet.

They also pose a risk for corrosion since the laminate and fastener may comprise dissimilar materials and moisture can be trapped in the crevices inherent in such joints. However mechanical joints can be readily inspected before assembly and while in service. Examples of two typical bolted joints are the single lap joint and double strap joints as shown in Fig.2.1

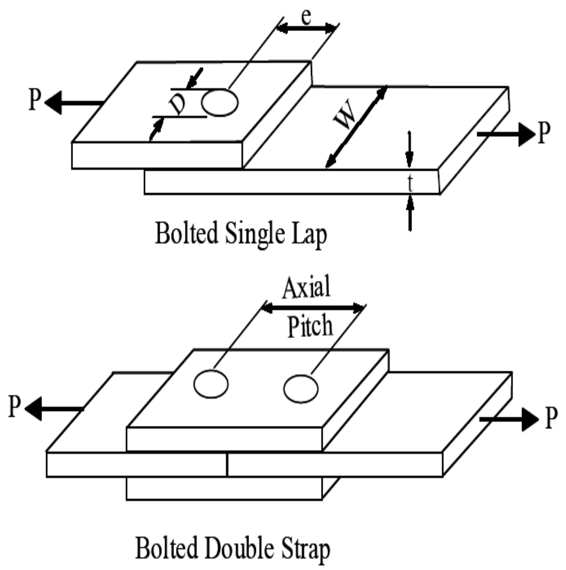


Figure 2-1. Basic types of mechanical joints.

The single lap joint is the simplest and most weight efficient but the load results in a moment due to off-set load. The double lap joint eliminate the moment but adds additional weight from the straps and additional bolt. A circular hole in tensioned FRP plates may be classified into three types as follows: (1) open-hole tension: the FRP plates were subjected to uniaxial tension with no constraint imposed on the hole, filled-hole tension: a bolt, φ = dB, was inserted inside the hole, φ = dH, with/without a clamp-up load. A washer, φ = dW, was inserted between a bolt head and tail and the FRP plate to distribute the clamp-up load, as shown in Fig.2.2. The FRP plates were subjected to uniaxial tension, and (3) bolted joint, bolt-loaded hole: double-lap bolted joints were subjected to a uniaxial load with/without clamp-up load.

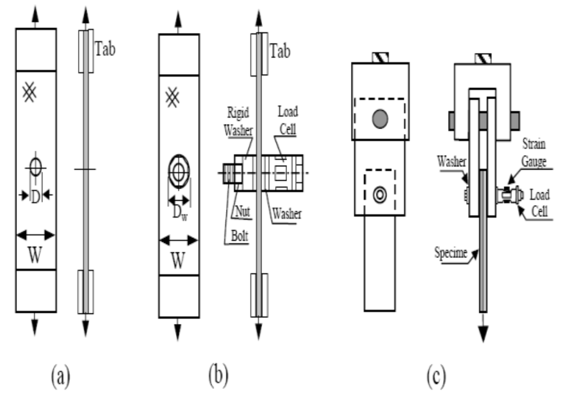


Figure 2-2. Geometries of the (a, b) specimens for open- and filled-hole tension tests, and (c) bolted joint test setup.

In the case of open-hole tension, the mode of failure mainly depends on the fiber/matrix interface. A weak interface results in longitudinal crack propagation along the interface, while a strong interface results in transverse crack propagation across fibers leading to premature composite failure. However, an interface of intermediate strength leads to optimum composite performance between these extreme conditions. Based on the specimen geometry and the interfacial strength of unidirectional FRP, the crack emanating from notches, such as circular holes, may grow parallel to the loading and fiber direction, i.e. notch insensitive. A schematic description of the damage pattern for a composite laminate is shown in Fig. 2.3

In the case of Fiber Breakage & Matrix Cracking mode of failure, damage is localized to the stress concentration areas before final failure. Edge Delamination mode of failure may occur in both open- and filled-hole specimens in an early loading stage. The edge delamination grew throughout the width of the open-hole specimens. In addition, a Fiber-Matrix Splitting mode occurred along the zero degree plies (in the direction of the applied load) emanating from the edge of the hole.

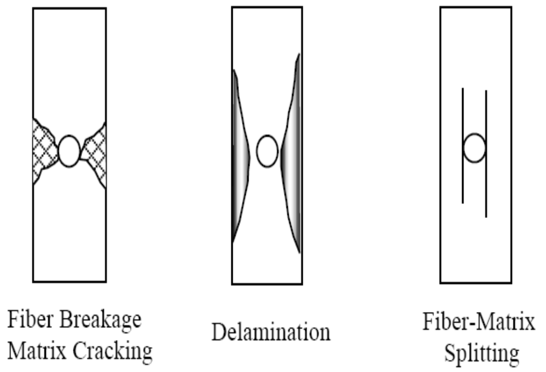


Figure 2-3. Typical tensile failure modes in composite laminates containing a circular hole.

IV. HYBRID JOINTS

In an attempt to improve the joint strength of composite materials, a hybrid of adhesive and bolted joints has also been explored [88], Fig. 5-1. Hybrid joints failed at a higher load than the bolted joints and with the proper clamping torque reached the same failure load as the adhesive joints. Furthermore, unlike the adhesive joints, hybrid joints failed in two steps, first by initiation of fiber tear (akin to delamination in laminated continuous fiber composites) at one of the lap ends and then by tensile failure across the bolt hole.

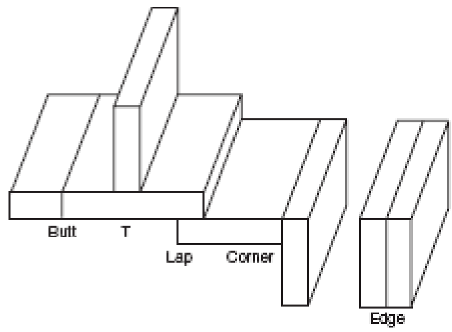
This led to a slightly higher overall elongation at failure for specimens with the hybrid joints. Failure in fatigue also started by fiber tear and when the fiber tear progressed to the bolted area, a combination of half-net-tension failure and splitting (cleavage failure) occurred. In both static as well fatigue, failure was initiated by fiber tear and the round washers with their edges located slightly away from the lap ends were not effective in preventing fiber tear.

Fu and Mallick found that, hybrid joints give better static as well as fatigue performance than adhesive joints in structural reaction injection molded composites when fiber tear, the primary failure mode in adhesive joints, is either prevented or delayed by the presence of clamping. Their finite element analyses proved that the presence of the lateral clamping pressure can significantly decrease the maximum peel stress at the interface, which helps in achieving improved joint performance.

Joint Types

The American Welding Society defines a joint as “the manner in which materials fit together.” As shown in Figure 6-1, there are five basic types of weld joints:

- Butt joint.
- T-joint.
- Lap joint.
- Corner joint.
- Edge joint.

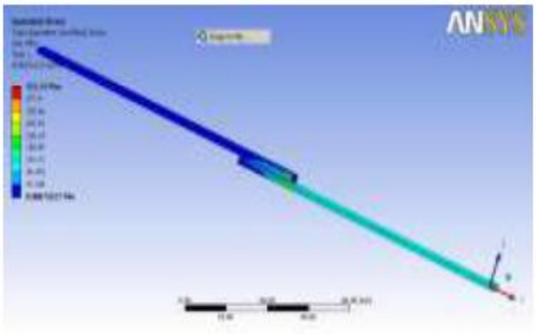


Weld Types

There are various types of welds that can be made in each of the basic joints. They include: **Butt joint,**.

- Square-groove butt weld.
- Bevel-groove butt weld.
- V-groove butt weld.
- J-groove butt weld.
- U-groove butt weld.
- Flare-V-groove butt weld.
- Flare-bevel-groove butt weld.

V. Bonded joints



5.1 Categories of plastic waste

Categorisation can help us understand plastic waste and identify sources. However, most classifications have a purpose and waste is often categorised with a specific goal in mind. For example, a waste classification designed to support a recycling programme would identify commonly recycled plastics (Barnes et al., 2009). Classification can also depend on policy, for example, Moore et al. (2011) conducted a study on plastic debris in two Californian rivers that categorised pieces as below (Fig.4.1)or above 4.5mm, because Californian law defines rubbish as being 5mm or greater.

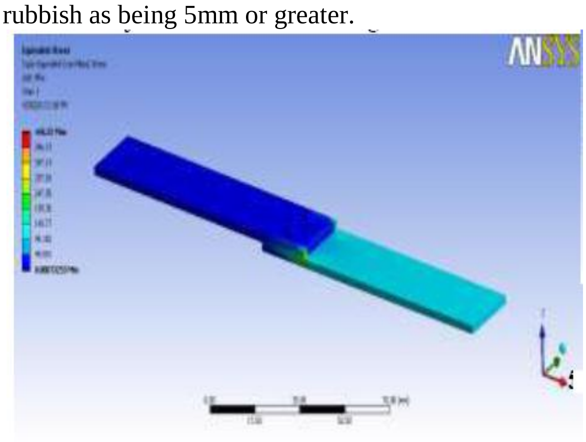
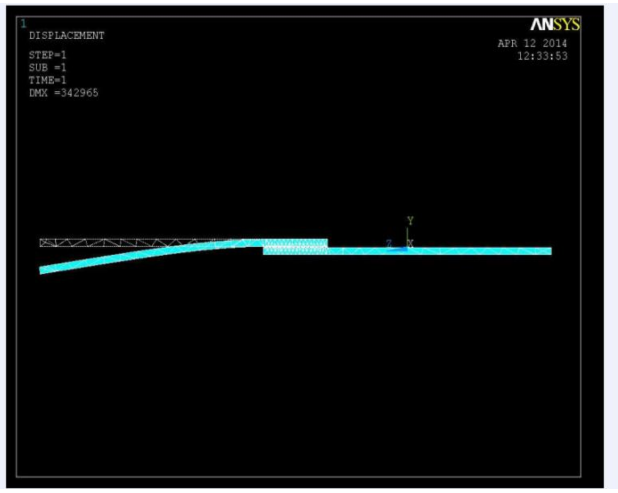


Fig 4.1.Vonmises stress of riveted joint

VI. ANSYS ANALYSIS RESULTS

BONDED JOINT



5.1 The marine surface - monitoring plastic waste floating at sea

Surveys at sea are more costly and challenging than beach surveys and can only assess standing (or floating) stocks rather than accumulation rates, because it is impossible to perform a complete clean-up. Amounts of floating debris can be estimated either by direct observation or by net trawls.

In general, net-based surveys tend to be less subjective. Most research has been done using Neuston or Manta trawl nets, which have a small mesh (usually 0.3mm, and small net opening and thus focus on microplastics). Manta trawls have been used to sample and characterise the large gyre systems in the oceans with elevated amounts of clustered marine litter (Pichel et al., 2007). One of the most well known research programmes that use this method is the Algalita Centre, which regularly monitors the North Pacific Subtropical Gyre (see Figure 7). In 1999, they reported just under 335,000 items of plastic per km2, weighing 5.1 kg per km2 (Moore et al., 2001).

VII. CONCLUSION

In this analysis, FEA for the prediction of stress distribute on in bonded, riveted and hybrid joints have been carried out 3D models were created by using PROE (creoparametric) and analyzed using ANSYS workbench FEA software .shear stress was used to compared the results with three joining methods .

The shear stress with hybrid joint has less value of stress and also the carbon fibre reinforced plastic is more strength than any other composite material. The stress induced by using ANSYS is less than the material ultimate stress and ultimate limit.

The total deformation for both the materials in hybrid joint is less. It was found that a well designed hybrid joint is very efficient when compared to bonded, riveted joints in case of repair situation in aircraft fuselage panels ,structures etc.

Increasing the efficiency of composite single-shear lap joints using bonded inserts. CFRP with aluminium alloy plates can be tested in experimental. CFRP with aluminium alloy plates can be tested in experimental and can find the strength and stress distribution with different composite materials. The joint design can be made and optimization of riveted joint can be performed. Stress and Failure Analysis Of Laminated Composite Pinned Joints can be performed.

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