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Modelling & Analysis of Hybrid Composite Joint

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Abstract: **Composite materials are widely used in the various Fields. Due to the high strength they are widely used in the low weight constructions and also used as a suitable alternative to metals. In various applications and also for joining various composite parts together, they are fastened together using adhesives or Mechanical fasteners. Modeling of 3-D Models of joints such as riveted and hybrid was completed in Proe 5.0 and ANSYS 14.0 considering macroscopic characteristics that is whole plate as single isotropic material and microscopic behavior that is considering different properties for fibres and matrix. The results were found in terms of vonmises stress, shear stress. ANSYSFEA tool has been used for stress distribution characteristics of various configurations of double riveted single lap joint with various joining methods namely riveted and hybrid the present study deals with the analysis of single lap joint subjected to the given tensile load and the stress distribution in the members under various design conditions are found.**

Keywords: **Composite, Materials, MRC, CMC, PMC, joints, Hybrid, plate**

1. INTRODUCTION

Combining two or more materials together to make a composite is more work than just using traditional monolithic metals such as steel and aluminum. Monolithic metals and their alloys cannot always meet the demands of today's advanced technologies. Only by combining several materials can one meet the performance requirements. For example trusses and benches used in satellite need to be dimensionally stable in space during temperature changes between -256^{0}F and 200^{0}F. Limitations on coefficient of thermal expansion thus are low and may be of the order of ±1 ×10 in./in./°F (±1.8 × 10–7 m/m/°C) Monolithic materials cannot meet these requirements; this leaves composites, such as graphite/epoxy, as the only materials to satisfy them.

In many cases, using composites is more efficient. For example, in the highly competitive airline market, one is continuously looking for ways to lower the overall mass of the aircraft without decreasing the stiffness and strength of its components. This is possible by replacing conventional metal alloys with composite materials. Even if the composite material costs may be higher, the reduction in the number of parts in an assembly and the savings in fuel costs make them more profitable. Reducing one kilogram of mass in a commercial aircraft can save up to 360 gal (1360 l) of fuel per year; fuel expenses are 25% of the total operating costs of a commercial airline. Composites offer several other advantages over conventional materials. These may include improved strength, stiffness, fatigue, impact resistance, thermal conductivity, corrosion resistance .etc.

High stiffness and strength can be attained for composite laminates. However, these characteristics are quite different from those of ordinary materials to which we often need to fasten composite laminates. Often, the full strength and stiffness characteristics of the laminate cannot be transferred through the joint without significant weight penalty due to stress concentration created by drilling a hole in the laminate. So study of joints plays crucial role in design of composite structures. Joint efficiency has been a major concern in using laminated composite materials. Relative inefficiency and low joint strength have limited widespread application of composites. The need for durable and strong composite joint is even urgent for primary structural members made of laminates. Because of the anisotropic and heterogeneous nature, the joint problem in composites is more difficult to analyze than the case with isotropic materials. Two major classes of laminate joints are bonded joints and bolted joints. These joints should receive special attention with a view to share in the total cost and, especially in aerospace application where safety is very important.

2. COMPOSITE MATERIALS

2.1. Introduction: A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite material or composite possesses superior properties .which are not obtainable with a single constituent material. So, in technical terms, we can define a composite as a multiphase material from a combination of materials, differing in composition or form, which remain bonded together, but retain their identities and properties, without going into any chemical reactions.The components do not dissolve or completely merge. They maintain an interface between each other and act in concert to provide improved, specific or synergistic characteristics not obtainable by any of the original components acting singly.

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2.2. Different types of composite materials: Classification based on types of composites

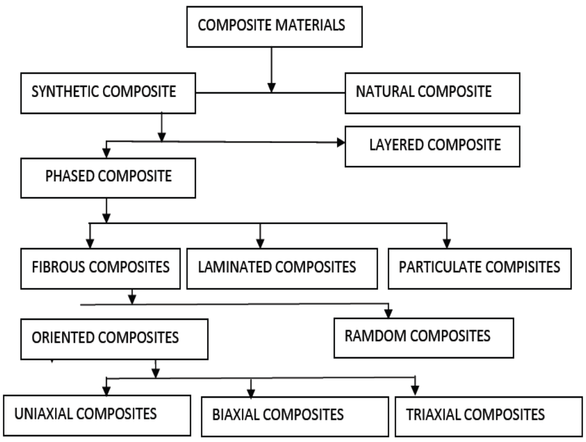

Fig.1.Classification based on types of composites

Classification of Composites: Based on reinforcement composite materials are classified as :-

1) Fibrous composite materials: Fiber composites consist of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are generally anisotropic and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum, and ceramics such as calcium–alumino silicate. Continuous fiber composites are emphasized in this book and are further discussed in this chapter by the types of matrices: polymer, metal, ceramic, and carbon. The fundamental units of continuous fiber matrix composite are unidirectional or woven fiber laminas. Laminas are stacked on top of each other at various angles to form a multidirectional laminate.

Fig.2. Continuous, chopped and woven fibrous composite materials

Continuous Fibers are long, straight and generally layed-up parallel to each other.

Chopped Fibers are short and generally randomly distributed (fiberglass).

Woven Fibers come in cloth form and provide multidirectional strength.

2). Flake composite materials: Flake composites consist of flat reinforcements of matrices. Typical flake materials are glass, mica, aluminum, and silver. Flake composites provide advantages such as high out-of-plane flexural modulus, higher strength, and low cost. However, flakes cannot be oriented easily and only a limited number of materials are available for use.

3). Particulate composite materials: Particulate composites consist of particles immersed in matrices such as alloys and ceramics. They are usually isotropic because the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. Typical examples include use of aluminium particles in rubber; silicon carbide particles in aluminium; and gravel, sand, and cement to make concrete.

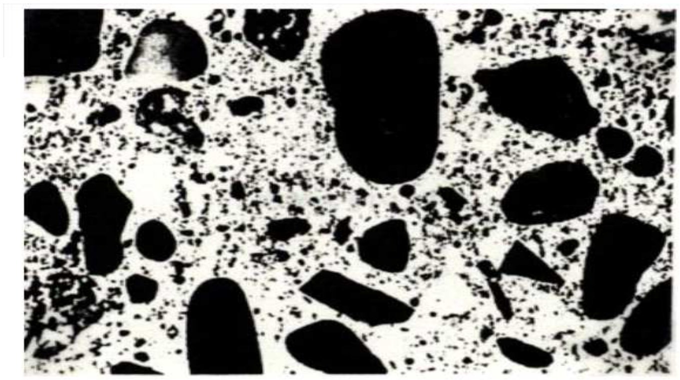

Fig. 3. Particulate composite material

Based on type of matrix composite materials are classified as

1)Metal matrix composites(MRC): These are characterized by metal matrix

Ex: Silicon carbide fibres aluminum matrix(Sic/Aluminum)

2)Ceramic matrix composites(CMC): Composed of ceramic matrix

Ex: silicon carbide fibres + Calcium alumino silicate matrix(Sic/ CAS)

3)Polymer matrix composites(PMC): It consists of polymer as matrix.

Ex: Graphite fibres+ epoxy matrix

4) Nano Composites: Nanocomposites consist of materials that are of the scale of nanometers (10^{-9} m). The accepted range to be classified as a nanocomposite is that one of the constituents is less than 100 nm. At this scale, the properties of materials are different from those of the bulk material. Generally, advanced composite materials have constituents on the microscale (10^{-6} m). By having materials at the nanometer scale, most of the properties of the resulting composite material are better than the ones at the micro scale. Not all properties of nanocomposites are better; in some cases, toughness and impact strength can decrease. Applications of nanocomposites include packaging applications for the military in which nanocomposite films show improvement in properties such as elastic modulus, and transmission rates for water vapor, heat distortion, and oxygen. Body side molding of the 2004 Chevrolet Impala is made of ole fin based nanocomposites. This reduced the weight of the molding by 7% and improved its surface quality. General Motor currently uses 540,000 lb of nanocomposite materials per year.

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2.3. Mechanical behavior of composite materials:

Micro Mechanical behaviour of composite materials: Study of composite material behaviour where interaction of the constituent material is examined in detail as part of the definition of the behaviour of heterogeneous composite materials. Strength and Stiffness are function of fiber volume fraction. As we know that composite material consists of fiber and matrix.

Void in composite material causes theoretical density of composite to be higher than the actual density. Void increases matrix property decrease. Increase in void decrease shear stiffness and compressive strength.

Fiber Volume faction $V_f = \frac{\upsilon_f}{\upsilon_c}$ $\quad$ $\upsilon_{c,f}$ =Volume of composite, fiber. $\quad$ $\rho_{c,f}$ = Density of composite, fiber.

Matrix Volume faction $V_m = \frac{\upsilon_m}{\upsilon_c}$ $\quad$ $\upsilon_{c,m}$ =Volume of composite, matrix $\quad$ $\rho_{c,m}$ =Density of composite, matrix.

Evaluation of the Four Elastic Moduli

There are four elastic moduli of a unidirectional lamina

- Longitudinal Young's modulus (E_1)
- Transverse Young's modulus (E_2)
- Major Poisson's ratio, (ν_{12})
- In-plane shear modulus,(G_{12})

Advantages of composite materials:

- Composites ratios of strength-to-weight and stiffness-to-weight are several times greater than steel or aluminum.
- Fatigue properties are generally better than conventional metals.
- Toughness is often greater too.
- Design costs -- lower for composites
- Composites offer excellent resistance to corrosion and fretting.
- Low thermal expansion coefficient.

Applications of composite materials:

- Widely used in Aircrafts ,Satellites and Aerodynamics.
- In space application graphite epoxy structures have coefficient of thermal expansion=0.
- In automotive high weight saving leads to fuel economy goals.
- Commercial applications such as fiber glass, fishing rods and artificial limb.

3. COMPOSITE JOINTS

3.1. Introduction to joints: The permanent assembly of individual manufactured components is an important aspect of fabrication and construction. There are many ways for accomplishing this including the use of fastenings such as bolts and rivets, the use of adhesives, and by soldering, brazing and welding. Joint design is dependent upon the nature of materials to be joined as well as the method of joining. The primary purpose of joints is structural, they may have other functions such as electrical or thermal conductor or insulator, sealant, or vibration damper. Typically, there are two basic joining methods mechanical and adhesive.

3.2 Mechanical Joining: The basic method of mechanical joining is done by drilling holes in the two materials to be joined (such as two composite laminates) and then placing a mechanical fastener through the holes and fixing the fastener in place. The types of fasteners usually dictate the fixing method. For instance: bolts are fixed with nuts, screws are fixed through the interaction of the threads and the materials to be bonded, rivets are fixed by heading the rivet itself, and pins are fixed by simple interference with the holes.

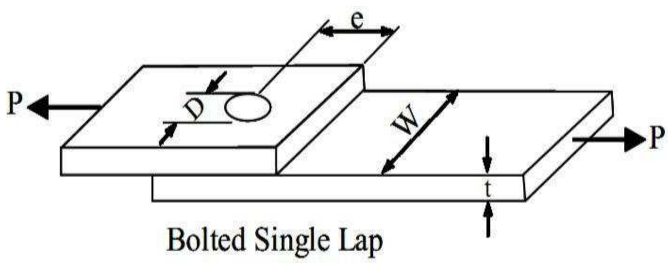

Fig.4.Mechanical lap joint

3.3 Adhesive Joining: A wide variety of materials is available when adhesives are used to bond materials together. The choice of which adhesive is best is usually depend by the type of composite to be bonded, the application of the bonded composite, the service environment, and cost. The general classes of adhesives are: structural, hot melt, pressure sensitive, water-based, and radiation cured.The most common polymers in the structural adhesives class are: epoxies, polyurethanes, acrylics, cyanoacrylates, anaerobics, silicones, and phenolics. Adhesively bonded composite joints have the following three basic failure modes:

➔ ***AdhesiveFailure:*** Failure of a bonded joint between the adhesive and the substrate Primarily due to a lack of chemical bondingbetween the adhesive and the bonding substrate It Can be indicative of poor surface preparation or contamination Or, incorrect adhesive selection for the substrate materials. Adhesive comes clean from one surface or both

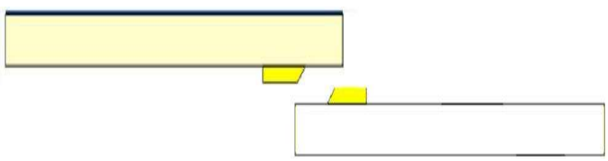

Fig.5. Adhesive failure

➔ ***Cohesive failure*:** Failure of an adhesive joint occurring primarily in the adhesive layer Optimum type of failure in an adhesive bonded joint when failure occurs at predicted loads Lower failure loads are indicative of poorly cured adhesive or m Lower failure loads are indicative of poorly cured adhesive or moisture or other contaminants present in the adhesive

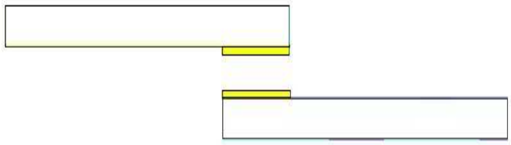

Fig.6. Cohesive failure

➔ ***Substrate failure***: Interlaminar fracture in composite structures, usually between the first and second plies adjacent to the bondline; can be common in composite laminates especially those with brittle epoxies.

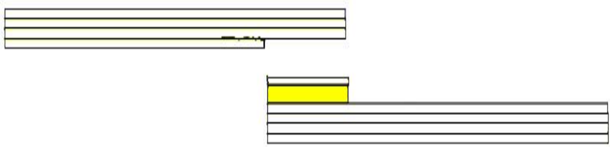

Fig.7. Substrate failure

4. MODELING

4.1 GEOMETRY

Geometry1: To analyze the behavior of riveted and hybrid composite joints considering macroscopic behavior that is assuming Glass fibre epoxy matrix material as single isotropic material i.e GFRP(Glass Fibre reinforced Plastic) models were created considering following dimensions.

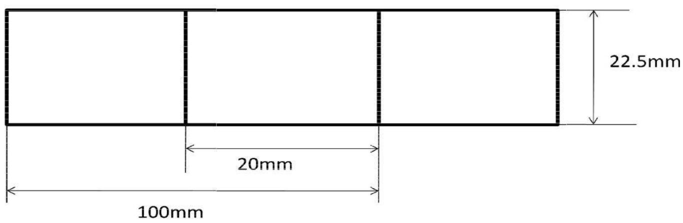

Fig.8. Geometry1

Table1: Geometry1 details

Width of the plate	22.5 mm
Length of the plate	100mm
Thickness of plates =	2.5 mm
Plate overlaps =	20 mm
Diameter of the holes in plates =	4mm
Diameter of the rivet head =	6mm
Total rivet height	13mm

Geometry 2:In real situation, assuming GFRP as isotropic material is not correct consideration as both glass fibres and epoxy matrix individually may be isentropic but as a composite they shows anisotropic behavior. So to analyze more realistic behavior of composite material microscopic behavior was c considered i.e Glass fibres in epoxy matrix were modeled. To model Glass fibres in epoxy matrix following dimensions were considered.

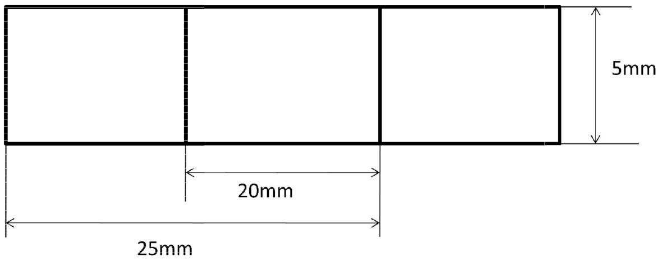

Fig.9. Geometry 2

Table2: Geometry 2 details

Width of t he plate	5mm
Length of the plate	25mm
Thickness of plates	2.5mm
Plate overlaps	20mm
Diameter o f the holes in plates	4mm
Diameter o f the rivet head	6mm
Total rivet height	13mm

4.2. Materials:

4.2.1. Glass fibers*:* Glass is the most common fiber used in polymer matrix composites. Its advantages include high strength and chemical resistance, and good insula ing properties.

Table 3: Glass fiber Properties

Property	**Units**	**Value**	
		S glass	**E glass**
Ultimate tensile strength	MPa	3447	4585
Young’s modulus	GPa	72.4	85

5. RESULTS

After solving the models with applied load of 5000N results found in terms of Vonmises stress and shear stress. Considering GFRP as isotropic material(6.1 and 6.2) following results were obtained.

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5.1. Riveted Join: The maximum value of vonmises stress for riveted joint is 435.98Mpa and the minimum value of stress is 0.5498Mpa. The rivet was meshed by using solid 45, an 8 node brick element. The composite laminates were designed and meshed using hexagonal element. The minimum value of shear stress in GFRP was found to be -44.68Mpa, it was located on the laminates. The maximum value of the shear stress in GFRP was found to be 64.5Mpa, it was located around the rivet head. The images of analysis result of vonmises stress, shear stress and normal stress of riveted joints are shown in the figure

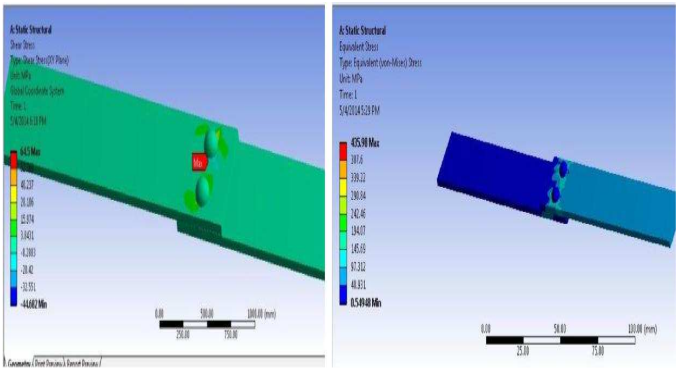

Figure.10. Vonmises, shear stresses in riveted joint

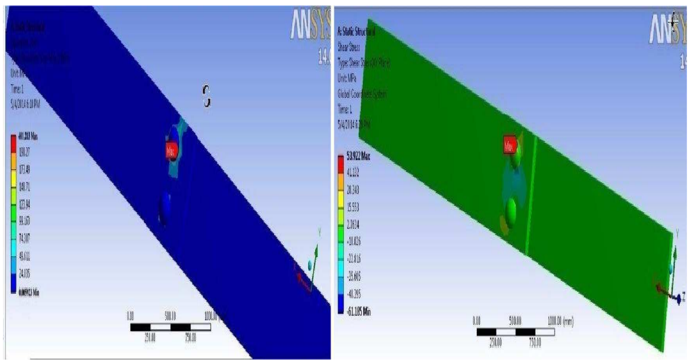

Figure.11. Vonmises, shear stresses in hybrid joint

5.2 Hybrid Joint : This model is similar to the riveted joint, excepts that it has a thin layer of adhesive between the laminates the minimum value of stress in GFRP was found to be - 6.385MPa and was located on the laminates. The maximum value of stress in GFRP was found to be 53.92MPa in the adhesive layer and rivet portion. The images of analysis result of vonmises , shear stress, normal stress of the hybrid joint are given in the Considering Glass fibres and epoxy as different isotropic materials with different properties , loading conditions applied and following results were obtained.

5.3 Riveted joint with fibres and matrix: The maximum value of vonmises stress for riveted joint is 284Mpa and the minimum value of stress is 0.542Mpa. The rivet was meshed by using 10 node solid 187 element. The minimum value of shear stress in GFRP was found to be -57.4Mpa, it was located on the laminates. The maximum value of the shear stress in GFRP was found to be 58.6Mpa, it was located around the rivet head. The images of analysis result of vonmises stress and shear stress of riveted joints are shown in the figure

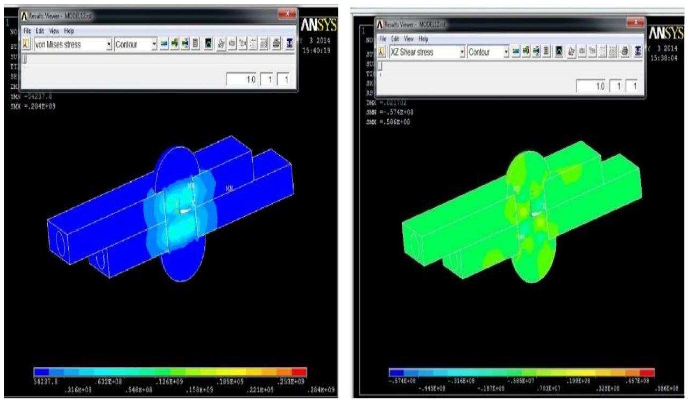

Figure.12. Vonmises, shear stresses in riveted joint (Microscopic Consideration)

5.4 Hybrid Joint for Glass/Epoxy:

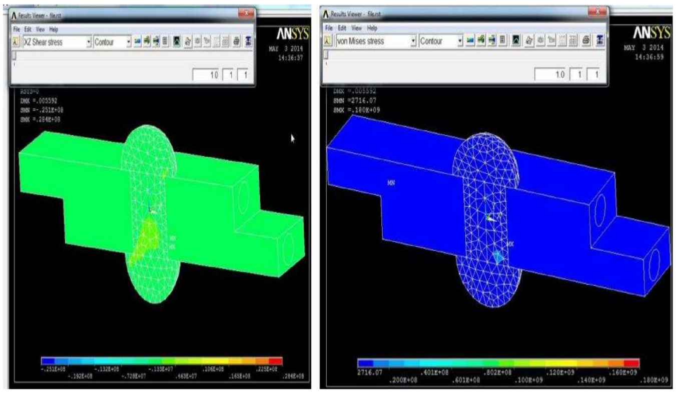

Figure.13. Vonmises, shear stresses in hybrid joint(Microscopic consideration)

This model is similar to the riveted joint, excepts that it has a thin layer of adhesive between the laminates the minimum value of stress in GFRP was found to be -6.385MPa and was located on the laminates. The maximum value of stress in GFRP was found to be 53.92MPa in the adhesive layer and rivet portion. The images of analysis result of vonmises , shear stress, normal stress of the hybrid joint are given in the Comparing results of joints, we found that the shear stress are induced in hybrid joint compared to less than the rivet joint.

- Maximum Shear stress in XZ plane induced in rivet joint is = 58.6MPa
- Maximum Shear stress in XZ plane induced in Hybrid joint is = 28.4MPa

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- Vonmises stress induced in rivet joint is = 284MPa
- Vonmises stress induced in hybrid joint is = 180MPa

6. CONCLUSION

In this thesis we have observed the macro mechanical behavior of composite materials. We modeled riveted, bonded and hybrid joint with specific geometry in ProE .Then imported into the ANSY Work Bench by considering isometric properties analyzed and results are obtained. We created the models of composite riveted and hybrid joints in ANSYS Mechanical APDL 14.0 considering microscopic behavior that is considering both glass fibres and matrix as different materials. Results shows that stresses induced in hybrid joint are comparatively less than that of riveted joints

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