RESEARCH ARTICLE OPEN ACCESS

Design Analysis and Experimental Evaluation of Composite Laminate Joints used in Aircraft

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ABSTRACT
This project work deals with study of various joints such as Bonded, Riveted & Hybrid used in aircraft body, made up of composite materials like Carbon fiber reinforcement polymer (CFRP), Glass fiber reinforcement polymer (GFRP), Sisal fiber and the combination of above three. Based on the outcome of the Stress, Strain and Deformation analysis using ANSYS 16.0 the opt composite material is to be selected for further study. Then a sample composite laminate is to be manufactured according to the ASTM standards. In addition, mechanical properties are to be analyzed for confirm whether it is matching with the design requirements. The objective of this project was to study the joints used in aircraft structure by introducing a natural fiber called Sisal. From the analysis and experimental study, the best suitable composite material for the aircraft structure is recommended as the combination of Glass fiber, Carbon fiber and Sisal.
Keywords – Bonded joint, Carbon fiber, Deformation rate, Epoxy resin, Glass fiber, Hybrid joint, Mechanical properties, Riveted joint, Sisal fiber, Strain, Stress

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Date of Submission: 03-03-2020 Date Of Acceptance: 22-03-2020

I. INTRODUCTION

The designing of the aircraft has to meet specific requirements which influence the complexity of its structure like Strength, Elasticity, corrosion resistance etc. Composite parts used in aircraft structure are joined together, either using adhesives or mechanical fasteners. The limitations of existing composites used in the field of aircraft like environmental degradation, moisture absorption and expensive nature leads to the development of a new composite material using natural fiber called Sisal. This improves the ability to absorb sound and noises and leads to increase the cabin comfort of the aircraft. The new composite can overcome the limitations of Glass fiber and Carbon fiber composites leads to improve the efficiency and performance of the aircraft by reducing the overall weight of the aircraft structure without affecting its strength. The joining of composite materials is a complex matter. Drilling holes in composite material weakens the strength of the joint and lead to delimitation. The additional usage of mechanical fasteners will increase the weight of structure. This is partially why bonding of composite materials has become very popular. Bonded joints offer higher static and fatigue strength as well as higher strength to mass ratios than other joining methods. But the bonded joint has certain limitations like its non-suitability at high temperature and it is not applicable for joining thicker sections. To enhance the performance of bonded joint for aeronautical certification purposes, research on the combination of bonded joints and rivets, called hybrid joints, which has major interest. Nowadays, the role of hybrid joint has been more important since it is a combination of both mechanical fastener and adhesive bond.

1.1 Problem Statement

Generally, the composite parts used in aircraft structure are joined together, either using adhesives or mechanical fasteners (bonded, riveted and hybrid). Mainly riveted joints are used in aircraft body instead of welded joint due to poor tolerant of aluminium materials towards heat. To reduce the overall weight of the aircraft's advanced composite materials like CFRP and GFRP are using today which are joint together using aluminium rivets. But carbon fibers can cause corrosion when CFRP parts are attached to aluminium. and CFRP cause environmental degradation after 10 years and glass fibers needs to be re-gel coated about every five years. These Carbon fibers and Glass fibers are expensive nature. To overcome the limitation of above composites it should be mixed with another suitable natural composite which can overcome the above demerit without affecting its strength.

1.2 Benefit of the work to the Society

The main advantage of using Natural fibers are its insulation towards the sound and its recyclable property. Since Sisal fibers are anti-static and it does not attract dust particles, moisture or water easily. The usage of natural fibers helps to achieve the sound insulation property which leads to improve the cabin comfort of the aircraft structure. By implementing natural fibers with CFRP and GFRP composites we obtained an improved mechanical property to the new combination. Which leads to improve the efficiency and performance of the aircraft by reducing the overall weight of the aircraft structure without affecting its strength.

1.3 Project Methodology

Design the composite plate that consist of materials like GFRP, CFRP and Sisal fiber induvial and combined. Then structural modeling is completed with the help of SOLIDWORKS software, each joint (Bonded, Riveted, Hybrid) modeled separately and assembled it. This assembly is then converted to IGS file. Finite element modeling is completed using the IGS file as geometry, the element type used for meshing is 2D shell elements with QUAD4 element topology. Static analysis will be carried out using ANSYS software. With the ANSYS identify the Stress, Strain and Deformation at each combination of material to identify the best materials for aircraft wing. Then the above combination of material is fabricated for identifying the Tensile strength, Impact strength, Bending strength, Hardness and Thermal conductivity of the composite material.

II. LITERATURE REVIEW

Raja et.al [1] explores the utilization of glass fiber with epoxy resins for testing different joints Stress, strain and deformation result were obtained. They conclude that the Epoxy resin helps to reduce the stress developed in various joints if it either contact with fiber or metal. **Durairaj et.al 2016** [2] discussed about the mechanical properties of glass fiber reinforced with polyester resin composite and carbon fiber reinforced with polyester resin composite. He prepared composites in the proportion of GF 10%, GF 15%, and GF 20% for Glass fiber reinforcement with polyester resin and CF5% and CF10% for carbon fiber reinforcement with polyester resin to from composites. Finally, it shows that the mechanical properties for GF15%, GF20% and CF10% gives higher values when compared to CF5% and GF10%. **Chowdhary et.al** [3] utilize carbon fiber for fabrication and testing of riveted and hybrid joint. They analyzed the static strength and fatigue resistance of purely riveted joint and purely hybrid joint. Found that Hybrid joint offers more strength and stiffness. **Rana et.al** [4] treated the natural fiber polymer composite with the glass fiber. i.e., sisal and glass fiber are reinforced into the epoxy matrix. Here two fixed layer of glass fiber with different weight percentage of sisal fiber (0%, 2%, 4%, and 6%) is reinforced with epoxy matrix composite. Mechanical properties are obtained. flexural strength is increase and tensile strength is decrease. The Impact strength increase in regular trend**. Ahire** [5] developed the model of (bonded, riveted, hybrid joint) and conducted the static analysis of 3D models using FEA software. Then tensile test is carried out to identify their load bearing capacity. He concludes that hybrid joints provide better strength. these joints are more reliable than the riveted and bonded joints. His future scope was to increase the thickness of adhesive layer in case of Hybrid joint for better performance and efficiency

III. MATERIAL AND METHOD

3.1 Carbon Fiber Reinforced Polymer

Carbon fiber reinforced polymer is a composite material consist of carbon fiber as its reinforcement phase, which provides the strength and stiffness and polymer resin in its matrix phase which bind the reinforcements together. It is extremely strong, Light in weight and Durable. CFRP has Good vibration damping and toughness properties. The carbon fiber consists of High dimensional stability due to its strong reinforcement phase. It also offers fatigue resistance. Figure 1 represents the Carbon fiber in chopped format.

Figure 1: Carbon fiber in chopped format

3.2 Glass Fiber Reinforced Polymer

Glass fiber reinforced polymer is a composite material consist of glass fiber as its reinforcement phase which provides strength and stiffness and thermosetting resins in its matrix phase which bind the reinforcement together. The glass fiber is available in chopped and mat condition. Glass fiber is a strong and lightweight material having many applications. But it is not as strong as carbon fiber. Glass fiber are cheaper than carbon fiber and It is less brittle in nature. GFRP are commonly used in the aerospace, automotive, marine, and construction industries. Figure 2 represents the Glass in mat format.

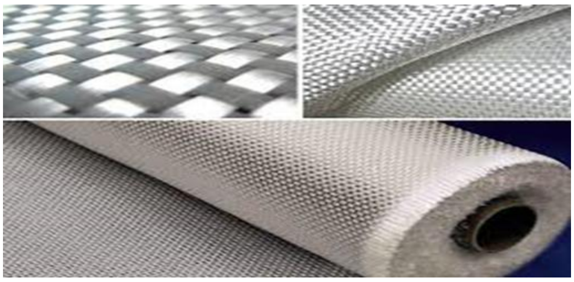

Figure 2: Glass fiber in mat format

3.3 Sisal Fiber

Sisal is a natural fiber obtained from the outer leaf skin of the sisal plant by removing the inner pulp from the leaf. One of the main advantages of Sisal fiber are its anti-static property and it does not attract dust particles and does not absorb moisture or water easily. These fibers having ability to absorb sound and impact. To attain fire resistance property, it should be treated with natural borax. Since sisal fibers are obtained from the nature it is recyclable and also it offers minimal wear and tear. Figure 3 indicates the Sisal fiber in chopped condition to develop the new composite.

Figure 3: Sisal fiber in chopped format

3.4 Resin

Araldite LY556 is a commonly used epoxy resin during the fabrication of composite materials. It is suitable for high performance composite FRP applications like Filament Winding, Pultrusion, Pressure Molding etc. LY556 has Good fiber impregnation properties, excellent mechanical, dynamic and thermal properties.

3.5 Hardener

Aradur HY 951 is a commonly used hardener for the encapsulation or coating of low voltage and electronic components. It has good mechanical strength, good resistance to atmospheric and chemical degradation and excellent electrical properties. HY 951 is a low viscosity hardener capable for curing at room temperature.

3.6 Adhesive

Araldite is a standard epoxy adhesive used in Bonded joint. These adhesive sets by the interaction of a resin with a hardener. One of the main advantages of this adhesive is that it can apply at room temperature. Even though warming will reduce the curing time and improve the strength of the bond. Araldite is available in many different types of packs, the most common containing two different tubes, one each for the resin and the hardener. Araldite joints are suitable for water proof, heat proof, stress proof applications. Araldite are resistant to most chemicals. It is Non-corrosive and non-toxic in nature. Mainly suitable for metals, ceramic, asbestos, glass, wood, leather rubber etc.

3.7 Bonded Joint

When two plates are joined together using an adhesive is called bonded joint. Bonded joint having ability to withstand required stresses. But it is not suitable at high temperature environmental conditions. Figure 4 represents the single lap joint.

Figure 4: Bonded joint with two plates

3.8 Riveted Joint

When two plates are joined together by rivets is called riveted joint. The riveted joint is mainly used for joining light metals. Rivets joint is permanent fastener to join the plates at very easily. The rivet material must be tough and ductile. They are usually made of steel, brass, aluminum or copper. Figure 5 represents the formation of a single lap riveted joint.

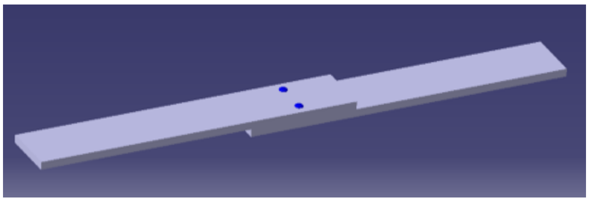

Figure 5: Single riveted lap joint

3.9 Hybrid Joint

Hybrid joint is the combination of both bonded joint and riveted joint. Nowadays, the role of hybrid joint has been more important because it is a combination of both mechanical fastener and adhesive bond. A hybrid joint can be used for joining thicker sections as well as in high temperature applications. Figure 6 represents the hybrid joint in a single lap riveted joint.

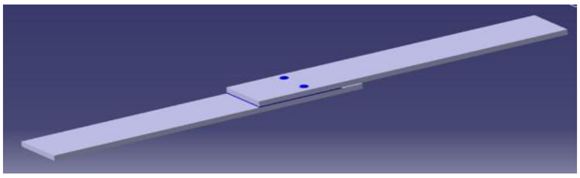

Figure 6: Single riveted hybrid joint

3.10 Tensile Test

Tensile test is the most commonly mechanical testing method to identify the tensile strength of the materials. During a tensile test the specimen is fixed on the tensile testing machine by which one end of the specimen is placed on a fixed side of the machine and the other end is placed on the movable side. The main concept behind the tensile test is that it applies a pulling force to a material and measures the specimen's response to the stress.

3.11 Bending Test

Bending testing is also known as flexure testing or transverse beam testing. It is used to measures the behavior of materials subjected to simple beam loading. Bending test is generally performed on relatively flexible materials such as polymers, wood, and composites.

3.12 Impact Test

Impact test is used to identify the ability of a material to withstand under impact load. This test is mainly used by the engineers to predict the behavior of material under actual conditions. During this test many materials fail suddenly under impact, at flaws, cracks, or notches. The most common type of impact tests uses a swinging pendulum to strike a notched bar of specimen to compute the energy required to fracture the bar.

3.13 Thermal Conductivity Test

Thermal conductivity test is used to identify the ability of a material to transmit heat. Thermal conductivity cab be simply measured in terms of watts per square metre of surface area for a temperature gradient of 1 K per unit thickness of 1 m. It is not always constant.

3.14 Hardness Test

Hardness test is used to identify the hardness of a material. It is a characteristic of a material, not a fundamental physical property. Durometer is a device used for measuring the hardness of a material, typically of polymers, elastomers, composites and rubbers. Increasing the value on the scale indicate a greater resistance to indentation and thus harder materials. Lower numbers indicate less resistance and softer material.

IV. RESULT AND DISCUSSION

4.1 Hybrid joint

4.1.1 Cfrp Composite Laminate

In case of Hybrid joint on Carbon fiber reinforced polymer material there is a maximum stress of 27.004 Mpa. Figure 7 represents the stress obtained in hybrid joint on CFRP material

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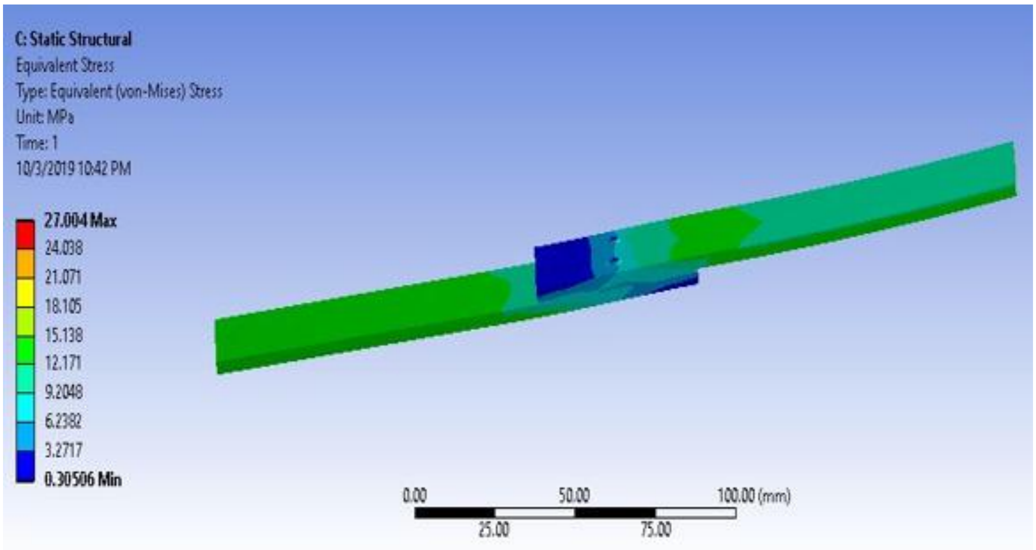

Figure 7: Stress obtained in Hybrid joint on CFRP

In case of Hybrid joint on Carbon fiber reinforced polymer material there is a maximum strain of 0.001009 mm/mm. Figure 8 represents the strain obtained in hybrid joint on CFRP material.

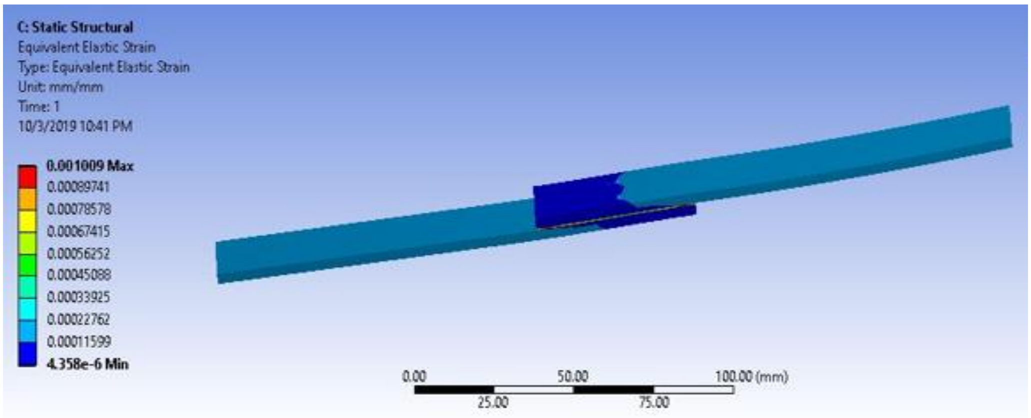

Figure 8: Strain obtained in Hybrid joint on CFRP

In case of Hybrid joint on Carbon fiber reinforced polymer material there is a maximum deformation of 0.31098 mm. Figure 9 represents the total deformation obtained in hybrid joint on CFRP material.

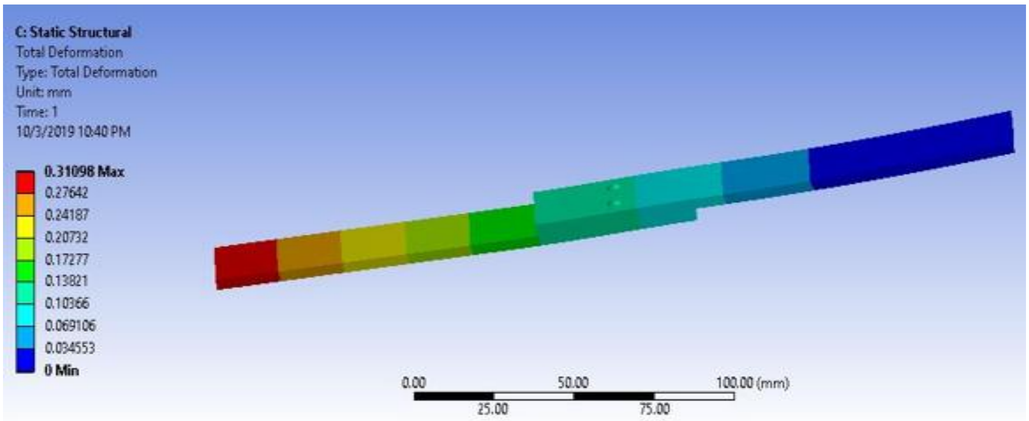

Figure 9: Total deformation obtained in Hybrid joint on CFRP

4.1.2 Gfrp Composite Laminate

In case of Hybrid joint on Glass fiber reinforced polymer material there is a maximum stress of 25.162 Mpa. Figure 10 represents the stress obtained in hybrid joint on GFRP material.

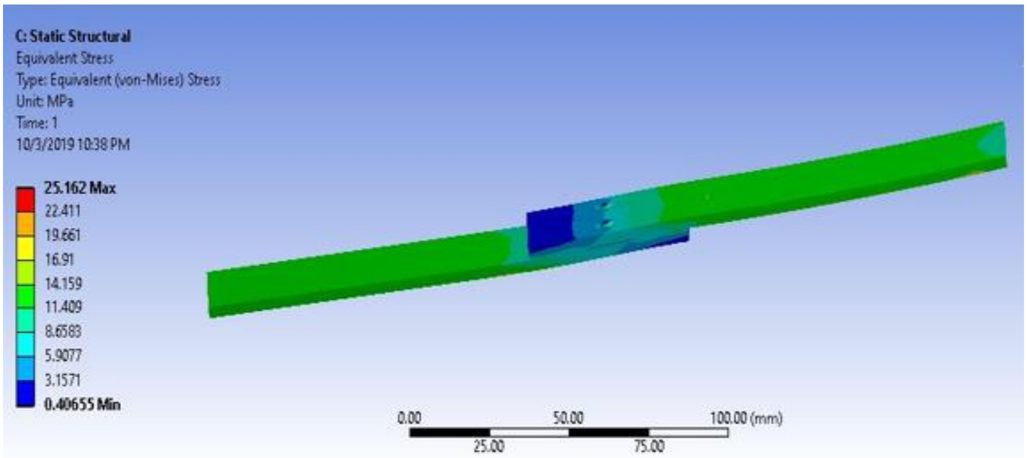

Figure 10: Stress obtained in Hybrid joint on GFRP

In case of Hybrid joint on Glass fiber reinforced polymer material there is a maximum strain of 0.0014525 mm/mm. Figure 11 represents the strain obtained in hybrid joint on GFRP material.

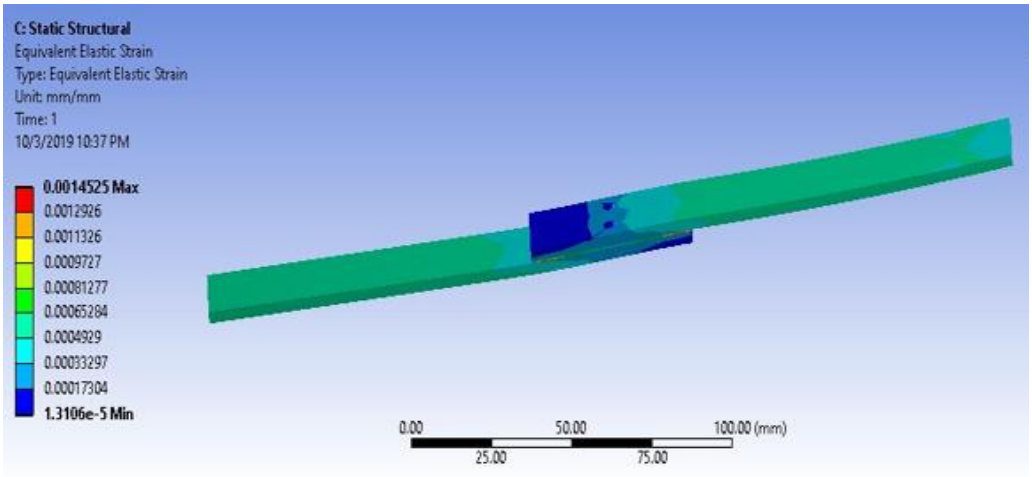

Figure 11: Strain obtained in Hybrid joint on GFRP

In case of Hybrid joint on Glass fiber reinforced polymer material there is a maximum deformation of 0.47213 mm. Figure 12 represents the total deformation obtained in hybrid joint on GFRP material.

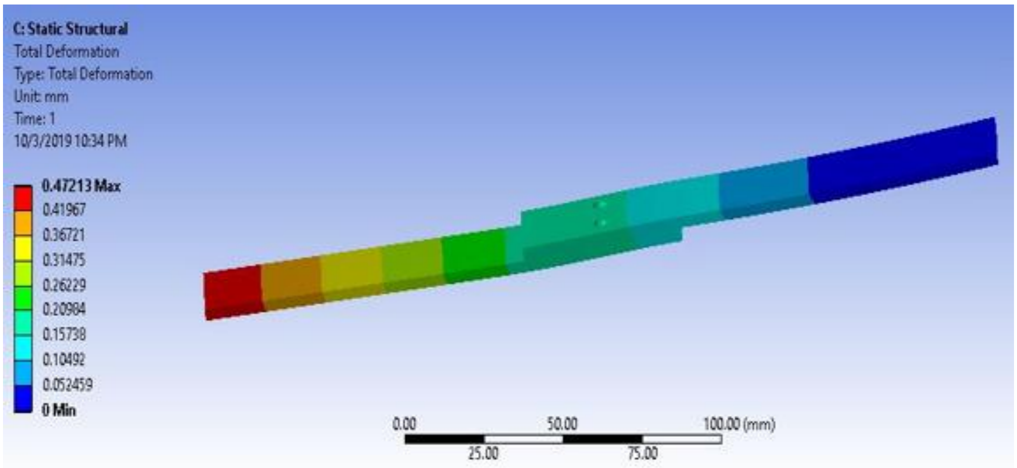

Figure 12: Total deformation obtained in Hybrid joint on GFRP

4.1.3 Cfrp + Sisal Composite Laminate

In case of Hybrid joint on CFRP+SISAL material there is a maximum stress of 23.437 Mpa. Figure 13 represents the stress obtained in hybrid joint on CFRP+SISAL material.

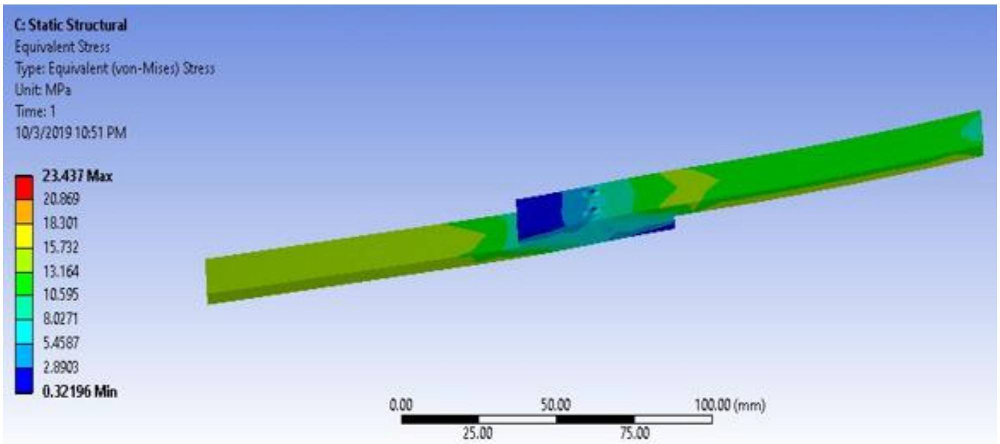

Figure 13: Stress obtained in Hybrid joint on CFRP+SISAL

In case of Hybrid joint on CFRP+SISAL material there is a maximum strain of 0.001202 mm/mm. Figure 14 represents the strain obtained in hybrid joint on CFRP+SISAL material.

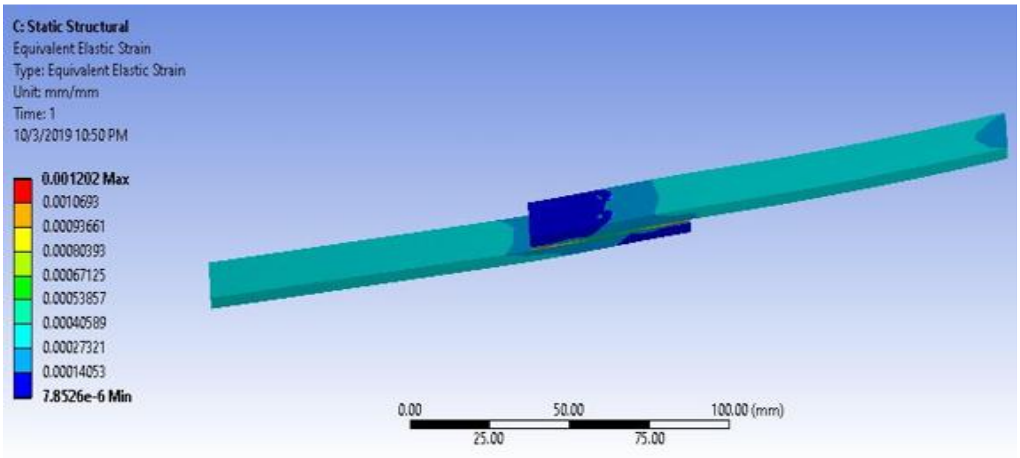

Figure 14: Strain obtained in Hybrid joint on CFRP+SISAL

In case of Hybrid joint on Cfrp+Sisal material there is a maximum deformation of 0.3784 mm. Figure 15 represents the total deformation obtained in hybrid joint on CFRP+SISAL material.

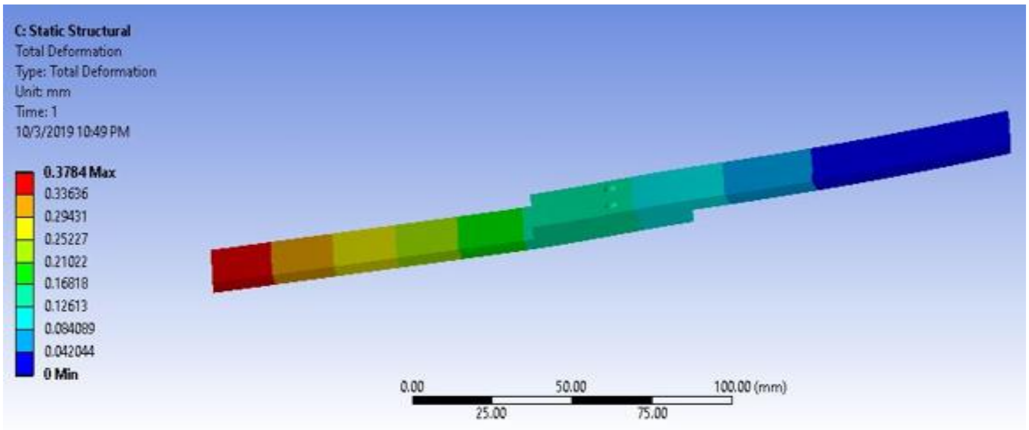

Figure 15: Total deformation obtained in Hybrid joint on CFRP+SISAL

4.1.4 Gfrp + Sisal Composite Laminate

In case of Hybrid joint on GFRP + SISAL material there is a maximum stress of 28.449 Mpa. Figure 16 represents the stress obtained in hybrid joint on GFRP + SISAL material.

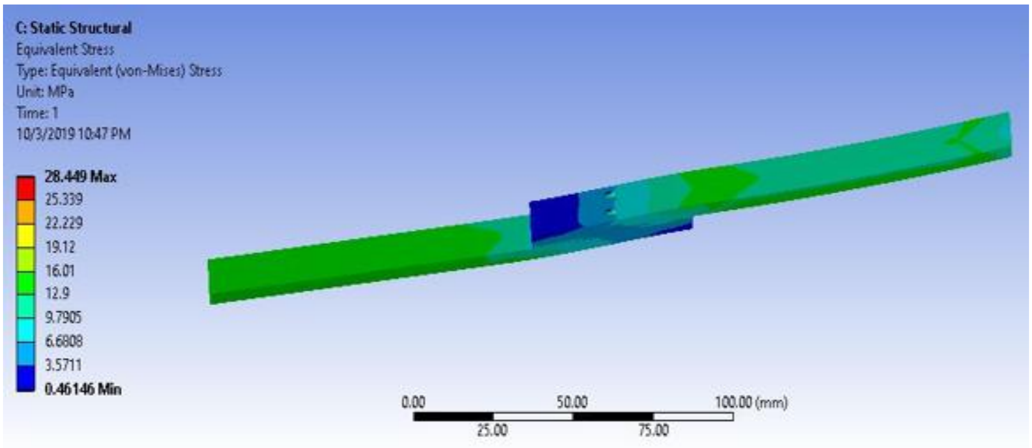

Figure 16: Stress obtained in Hybrid joint on GFRP + SISAL

In case of Hybrid joint on GFRP + SISAL material there is a maximum strain of 0.0016294 mm/mm. Figure 17 represents the strain obtained in hybrid joint on GFRP + SISAL material.

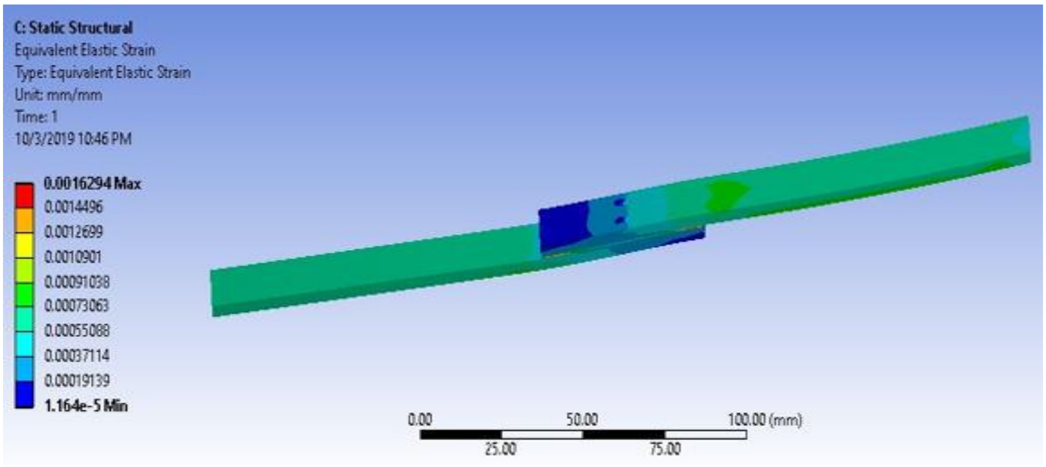

Figure 17: Strain obtained in Hybrid joint ON GFRP + SISAL

In case of Hybrid joint on Gfrp + Sisal material there is a maximum deformation of 0.5555 mm. Figure 18 represents the total deformation obtained in hybrid joint on GFRP + SISAL material.

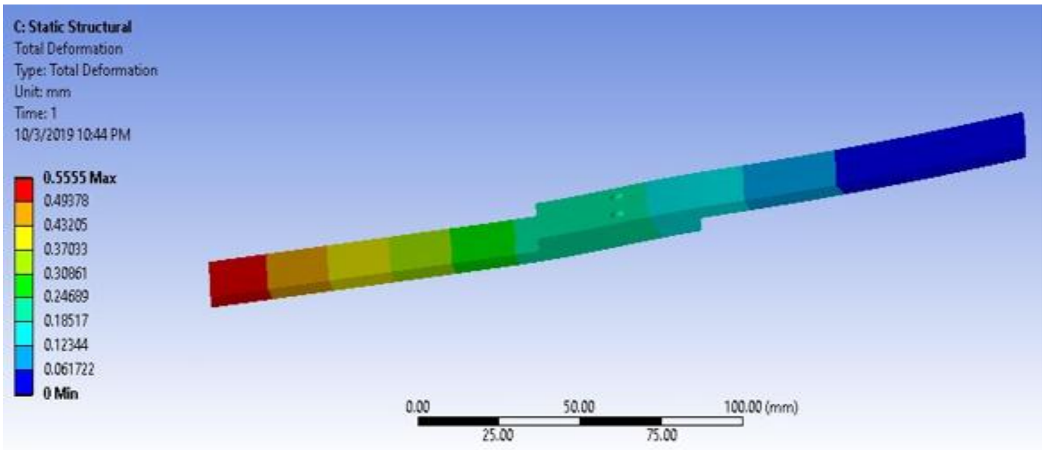

Figure 18: Total deformation obtained in Hybrid joint on GFRP + SISAL

4.1.5 Gfrp + Cfrp + Sisal Composite Laminate

In case of Hybrid joint on GFRP + CFRP + SISAL material there is a maximum stress of 24.297 Mpa. Figure 19 represents the stress obtained in hybrid joint on GFRP + CFRP + SISAL material.

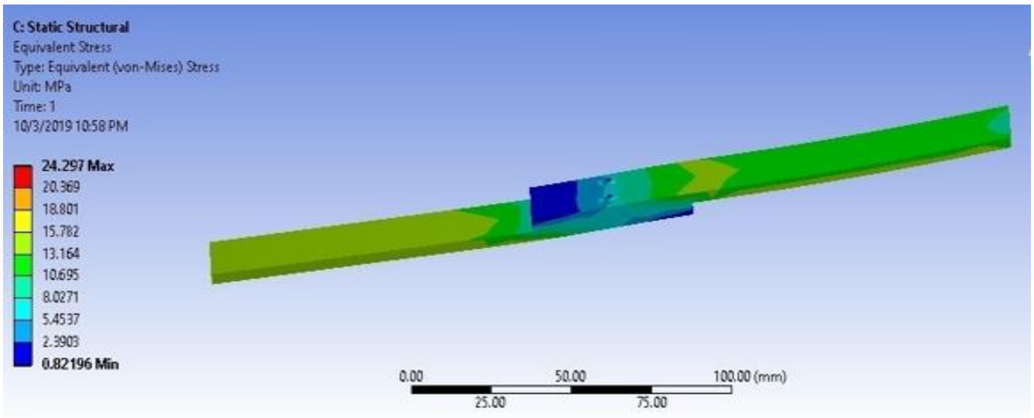

Figure 19: Stress obtained in Hybrid joint on GFRP + CFRP + SISAL

In case of Hybrid joint on GFRP + CFRP + SISAL material there is a maximum strain of 0.001322 mm/mm. Figure 20 represents the strain obtained in hybrid joint on GFRP + CFRP + SISAL material.

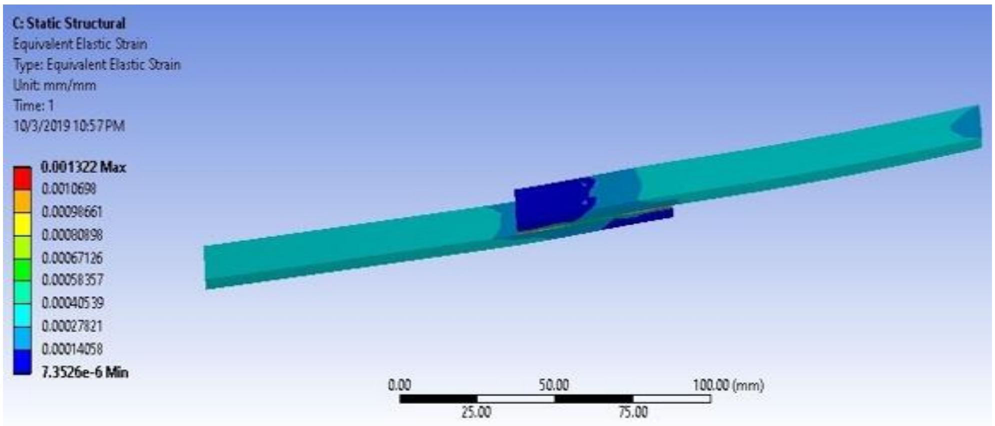

Figure 20: Strain obtained in Hybrid joint on GFRP + CFRP + SISAL

In case of Hybrid joint on GFRP + CFRP + SISAL material there is a maximum deformation of 0.4284 mm. Figure 21 represents the total deformation obtained in hybrid joint on GFRP + CFRP + SISAL material.

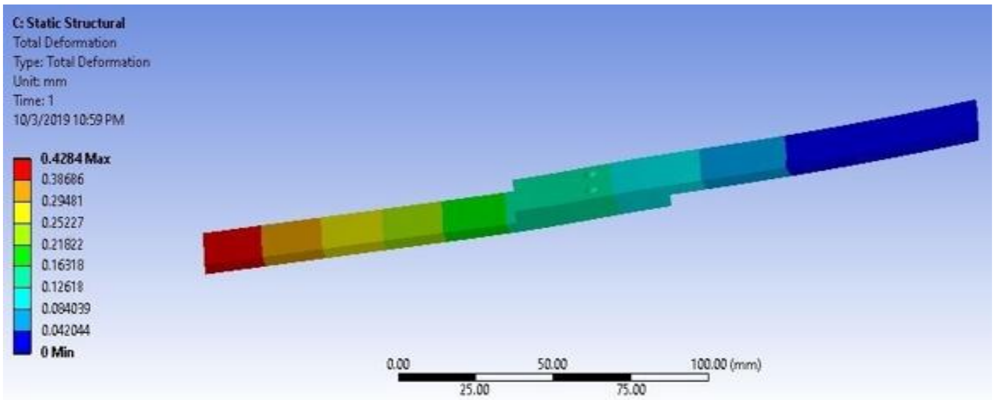

Figure 21: Total deformation obtained in Hybrid joint on GFRP + CFRP + SISAL

Table 1 represents the stress, strain and deformation in different combinations of materials with hybrid joint.

Table 1: Comparison table on Hybrid joint

Materials	Stress (Mpa)	Strain (mm)	Deformation (mm/mm)
GFRP	25.162	0.0014525	0.47213
GFRP+SISAL	28.449	0.0016294	0.5555
CFRP	27.004	0.001009	0.31098
CFRP+SISAL	23.437	0.001202	0.3784
GFRP+CFRP+SISAL	24.297	0.001322	0.4284

4.1.6 Comparison Graph of Stress on Hybrid Joint

Figure 22 represents the maximum stress in GFRP + SISAL and minimum stress in CFRP + SISAL. Higher stress means vibration and noise is high. So low stress is preferred. But we recommended the combination of GFRP + CFRP + SISAL is preferable while considering its raw material costs.

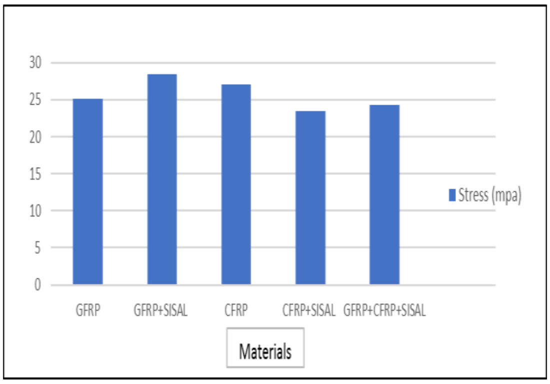

Figure 22: Comparison of stress on hybrid joint

4.1.7 Comparison graph of Strain on Hybrid Joint

Figure 23 represents the maximum strain in GFRP + SISAL and minimum strain in CFRP itself. Higher strain means higher ductility and lower tensile strength.

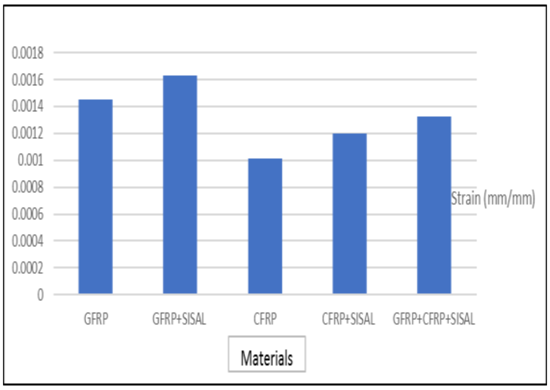

Figure 23: Comparison of strain on hybrid joint

4.1.8 Comparison of Deformation on Hybrid Joint

Figure 24 represents the maximum deformation in GFRP + SISAL and minimum deformation in CFRP itself. i.e., CFRP has less stiffness and GFRP+SISAL has more stiffness value. But we preferred the combination of GFRP+CFRP+SISAL due to its advantages.

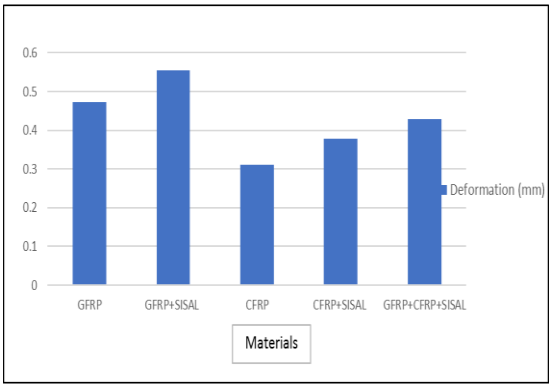

Figure 24: Comparison of deformation on hybrid joint

4.2 Riveted Joint

Table 2 represents the stress, strain and deformation in different combinations of materials with riveted joint.

Table 2: Comparison table on Riveted joint

Materials	Stress (Mpa)	Strain (mm)	Deformation (mm/mm)
GFRP	133.37	0.00196	1.6427
GFRP+SISAL	147.98	0.00217	2.0691
CFRP	85.189	0.00125	0.75816
CFRP+SISAL	110.64	0.001624	1.1346
GFRP+CFRP+SISAL	122.64	0.001744	1.3846

4.2.1 Comparison of Stress on Riveted Joint

Figure 25 represents the maximum stress in GFRP+SISAL and minimum stress in CFRP itself. Higher stress means vibration and noise is high. So low stress is preferred. We can see that while adding sisal fiber stress is increasing because sisal is a natural fiber which offers lower strength value than synthetic fiber. So, we recommended the combination of GFRP+CFRP+SISAL is preferable while considering its raw material costs.

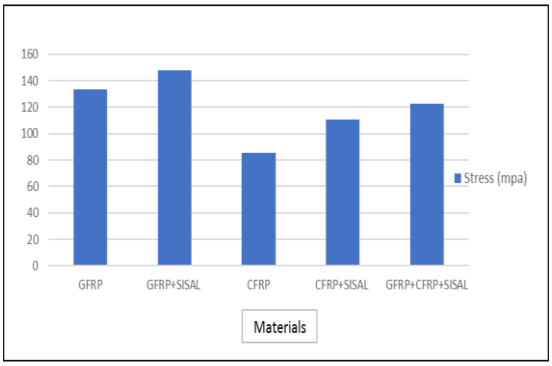

Figure 25: Comparison of stress on Riveted joint

4.2.2 Comparison of Strain on Riveted Joint

Figure 26 represents the maximum strain in GFRP+SISAL and minimum strain in CFRP itself. Higher strain means higher ductility and lower tensile strength.

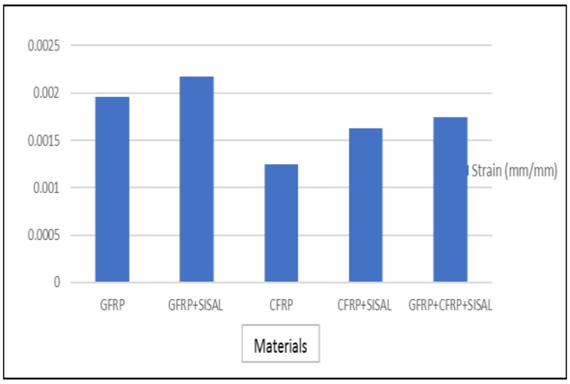

Figure 26: Comparison of strain on Riveted joint

4.2.3 Comparison of Deformation on Riveted Joint

Figure 27 represents the maximum deformation in GFRP+SISAL and minimum deformation in CFRP itself. i.e., CFRP has less stiffness and GFRP+SISAL has more stiffness value. But we preferred the combination of GFRP+CFRP+SISAL due to its advantages.

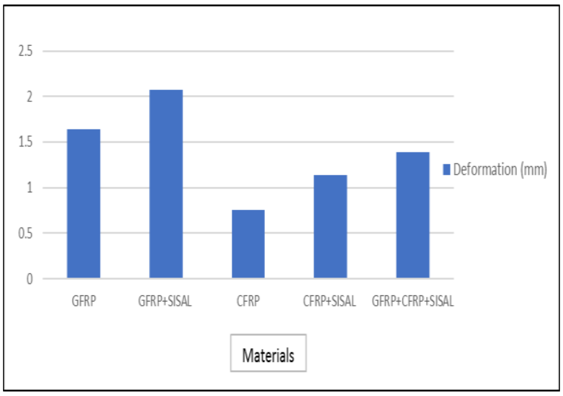

Figure 27: Comparison of deformation on Riveted joint

4.3 Bonded Joint

Table 3 represents the stress, strain and deformation in different combinations of materials with bonded joint.

Table 3: Comparison table on Bonded joint

Materials	Stress (Mpa)	Strain (mm)	Deformation (mm/mm)
GFRP	16.193	0.0015673	0.41862
GFRP+SISAL	17.546	0.0017546	0.48574
CFRP	15.968	0.0011103	0.2998
CFRP+SISAL	16.516	0.0012879	0.34713
GFRP+CFRP+SISAL	16.316	0.0014279	0.38213

4.3.1 Comparison of Stress on Bonded joint

Figure 28 represents the maximum stress in GFRP+SISAL and minimum stress in CFRP itself. Higher stress means vibration and noise is high. So low stress is preferred. If the material made with bonded joint with epoxy resin stress will reduced than riveted joint. hence material get more strength on bonded joint. But we recommended the combination of GFRP+CFRP+SISAL is preferable while considering its raw material costs.

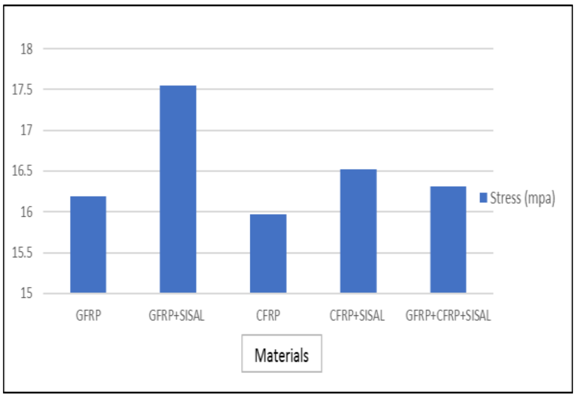

Figure 28: Comparison of stress on bonded joint

4.3.2 Comparison of Strain on Bonded joint

Figure 29 represents maximum strain in GFRP+SISAL and minimum strain in CFRP itself. Higher strain means higher ductility and lower tensile strength.

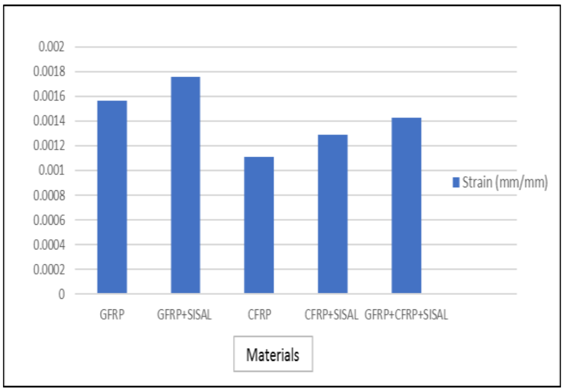

Figure 29: Comparison of Strain on Bonded joint

4.3.3 Comparison of deformation on bonded joint

Figure 30 represents the maximum deformation occur in GFRP+SISAL and minimum deformation in CFRP itself. i.e., CFRP has less stiffness and GFRP+SISAL has more stiffness value. But we preferred the combination of GFRP+CFRP+SISAL due to its advantages.

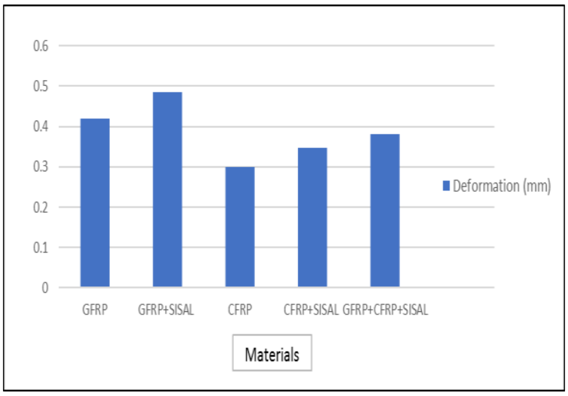

Figure 30: Comparison of deformation on bonded joint

4.4 Tensile test on Gfrp+Cfrp+Sisal Laminate

A universal testing machine (UTM) is used here to test the tensile strength. Figure 31 represents the dimensions of the specimen for tension test. Figure 32 represents a single riveted lap joint specimen fabricated with the combination of CFRP, GFRP and SISAL for tension test with 2 rivets according to D 3039 ASTM standard. Figure 33 represents the specimen after tension test. Here we can see that due to tensile load the specimen is split in to two pieces by breaking the rivet.

Tensile strength = 6.81 Mpa

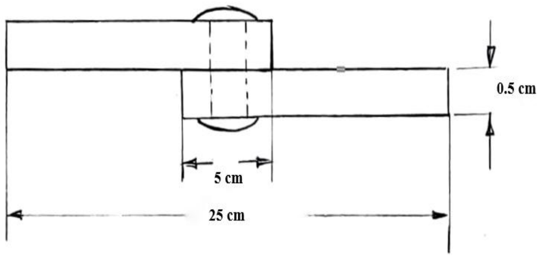

Figure 31: Schematic diagram of Tension test specimen

Figure 32: Specimen for Tensile test

Figure 33: Specimen after tensile test

4.5 Bending test on Gfrp+Cfrp+Sisal Laminate

A universal testing machine (UTM) is used here to test the bending strength. Figure 34 represents a single riveted lap joint specimen with 2 rivets according to D 3039 ASTM standard. Figure 35 represents the specimen after bending test. Here we can see that specimen fail due to bending load at the center of the specimen which cause breaking of the specimen.

Bending load = 0.69 KN

Figure 34: Test specimen for Bending Test

Figure 35: Specimen after bending test

4.6 Impact test on Gfrp+Cfrp+Sisal Laminate

Impact strength testing was performed by Charpy impact tester. Figure 36 represents the dimensions of the specimen for impact test. Figure 37 represents the lap joint with one rivet specimen according to ASTM D-5371 standard. Figure 38 represents the specimen after impact test.

Impact load = 108.5 J

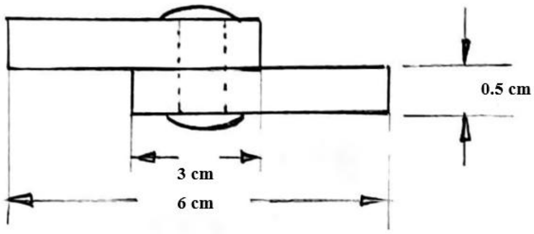

Figure 36: Schematic diagram of Impact test specimen

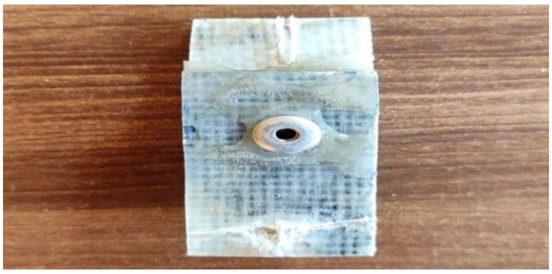

Figure 37: Test specimen for Impact Test

Figure 38: Specimen after Impact test

4.7 Thermal Conductivity test on Gfrp+Cfrp+Sisal Laminate

Measure the thermal conductivity of the sample fabricated according to ASTM D 785 standard using forced convection method with pin fin apparatus. Figure 39 represents the rectangular shaped specimen fabricated with the combination of CFRP, GFRP and SISAL for Thermal conductivity test.

Specimen Dimension: 100mmX25mmX5mm
Testing temperature: 100-degree Celsius
Thermal conductivity = 3.568W/m^{2}K

Figure 39: Test specimen for Thermal conductivity test

4.8 Hardness test on Gfrp+Cfrp+Sisal Laminate

Measure the hardness of the sample fabricated according to ASTM D 785 standard using shore durometer. Figure 40 represents the square shaped specimen fabricated for hardness test.

Specimen Dimension: 60mmX60mmX5mm
Shore hardness = 59 D

Figure 40: Test specimen for Hardness test

V. CONCLUSION

This study concludes the effect of various joints used in aircraft body made up of composite materials like Carbon fiber reinforcement polymer, Glass fiber reinforcement polymer, Sisal fiber and the combination of above three. To attain high static and fatigue strength hybrid joint can be used. From the above 3 cases it is concluded that hybrid joint with the combination of Glass fiber, Carbon fiber and Sisal fiber is more suitable for aircraft structure. These new composites can overcome the limitations of existing composites used in aircraft industry like moisture absorption, environmental degradation etc. The test result shows that the Stress in Hybrid joint is found minimum in the combination of CFRP and SISAL. Since the overall material cost is lower for the combination of CFRP, GFRP and SISAL with negligible variation in mechanical properties this combination is selected for further study. Strain result in Hybrid joint shows that minimum strain is found CFRP itself. Higher strain gives higher ductility and lower tensile strength. Deformation results in Hybrid joint shows a minimum deformation rate in CFRP since carbon fiber is stronger than other materials. While considering the overall cost of CFRP and its limitations although the combination of CFRP+GFRP+SISAL is recommended for aircraft structure.

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Akhilraj P "Design Analysis and Experimental Evaluation of Composite Laminate Joints used in Aircraft" *International Journal of Engineering Research and Applications (IJERA*), vol.10 (03), 2020, pp 01-14.