EXPERIMENTAL ANALYSIS OF COMPOSITE LAMINATE ON DOUBLE LAP JOINTS WITH DIFFERENT ORIENTATION

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ABSTRACT

The composite structural members are highly used in the following applications such as aerospace, automobiles, robotic arms, architecture etc., has attracted extensive attention in the past decades. In such applications and also for joining various composite parts together, they are fastened together either using adhesives or mechanical fasteners. The purpose of the project is to investigate the mechanical strength of the double strap joints in the composite laminate. In this present work, GFRP composite Lap joints with different stacking sequences such as 0^o, angle ply [$+45^o/-45^o$], cross ply [$0^o/90^o$] are used to determine the mechanical strength and different failure mechanisms when subjected to tensile test. The load vs displacement values will be determined using Universal Testing Machine (UTM). The experimental results will be compared with them. From the experimental observation, maximum ultimate loads and maximum displacements are found for composite lap joints with zero degree orientation compared with [$0^o/90^o$] and [$45^o/45^o$] composite double strap joints. Based on the experimental results, Composite strap joints with zero degree orientation are suitable orientation for structural applications.

I.INTRODUCTION

ASTM D 5868 test method provides comparative apparent shear strength data for joints made from a number of FRP materials. The results from this standard test would assist in selection of adhesive type and FRP surface treatment by comparing the joints of various FRP adhesives. ASTM D 3528 and D 3165 provide the guideline for conducting the test for determining the tensile shear strength of adhesives used for double-strap and supported single-lap metal joints, respectively. ASTM D 3528 test provides guideline for determining the tensile shear strength of adhesives used for bonding metals, was adopted as a test specification in this study for fabricating FRP specimens that would be subjected to a pure tension.

1.1 Specimen details

The FRP plates were made of vinyl ester and glass fibers, and surface of the plates were sand-blasted before bonding with adhesives. The ratio of fibers embedded in the vinyl ester resin was 0°, 90°, 45°, -45 and with thicknesses h=3. Experimental details

1.2 Test setup

A universal testing machine with a load capacity of 150kN and a maximum crosshead speed of 500mm/min was used. The tests were conducted under the displacement control at a constant head-loading rate of 1.27mm/min up to failure.

1.3 Test plan

A systematic test plan was developed in this study to investigate the influence of design parameters on the load-displacement response, joint strength and failure modes of adhesively bonded lap joints. These parameters include adhesive type; adhesive layer thickness t and overlap length l.

The effect of the thickness is determined with use of adhesive layer on the joint strength, specimens with four different adhesive layer thickness t = 0.2, 0.5, 1.0, and 2.0mm the overlap length providing overlap lengths l=25, 50, and 100 mm were prepared.

1.4 Experimental investigations

- Effect of parameters on the load-displacement response and joint strength
- Effect of adhesive type

Failure behavior of tested specimens

Most specimens were fractured suddenly with a slight bursting sound, indicating a brittle, catastrophic failure. ASTM D 5573 classifies the failure modes into six categories. A majority of fractured specimens in these investigations were classified as the thin-layer cohesive (TLC) failure pattern or the light-fiber-tear (LFT) failure pattern.

II TYPICAL JOINT TYPES

The basic types of bonded joints are shown diagrammatically. In practical structures two or more basic types may be used in combination – and the relative dimensions of the joints may vary from those shown in the diagrams. In most cases the stress distribution throughout the joint can be improved by leaving intact the small amount of resin squeeze-out (fillet) and tapering the overlap to remove the sharp, right-angle ends

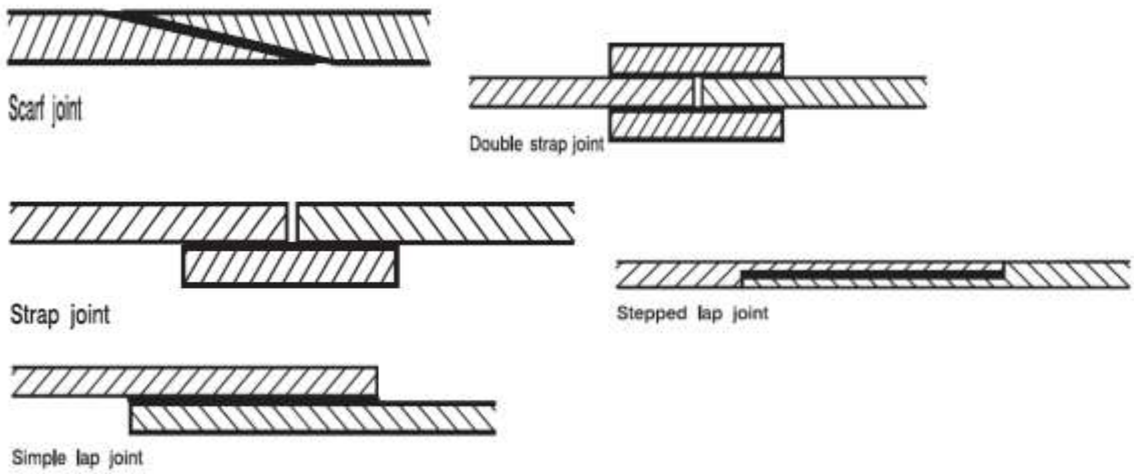


Fig 3: Types of joints.

2.1 Fabrication of composite plate

Fabrication of laminated composites includes selecting a material system or a group of material systems and determining the stacking sequence for the laminate based on applied loads and constraints on optimizing and constraining factors such as cost, weight as related to aerospace and availability. Based on all the factors, glass/epoxy laminated composite plates were fabricated.

2.2 Fabrication of Glass/Epoxy Laminates

Figure 4: Hand lay up process

The laminated composite plates were prepared by hand layup method. Hand layup refers to the manufacturing process for Fiber Reinforced Plastics (FRP) products in which an operator deposits the thermo set resins and reinforcements in or on a mould by hand or by using hand tools. It is a non-mechanized open mould manufacturing method and hence it is also not a capital intensive process. This method is also referred as contact moulding.

2.3 Advantage of Hand Lay Up Method

- No need of costly metal dies and other equipments.
- Plates of any dimensions can be prepared based on our necessity.
- No need of electricity.

2.4 Tools and Materials for Lay-Up

Glass fiber cloth, Epoxy Resin, Scissors, Weighing balance, Rollers, Releasing agent, Solvents.

2.5 Preparation of Glass/Epoxy Laminates

The preparation involves the gel preparation, weight calculation, rolling and curing processes. The following are the precautions which should be taken care while fabricating a composite laminate:

1. The fiber layer should be uniformly placed.
2. The fiber cloth should not be damaged.
3. The fiber – resin ratio should be properly maintained as per standards.
4. Rolling should be perfect so that there is no air bubble inside the laminas.
5. A proper weight should be mounted so that it cures under pressure.

The glass fiber cloth is taken and cut into specific dimensions and with proper orientation. The required number of layers for obtaining the total thickness can be determined by taking in to account the mat density and the carbon-to-resin ratio by weight.

The glass fibers are weighed and the resin is taken as 1:1 ratio by the weight of the fiber. Then hardener is added by 10% of the weight of the resin or fiber. The resin and hardener is completely mixed which forms the matrix.

2.6 Preparation of Gel Coat

Gel coat is a thin layer of resin about 0.5 mm thickness applied on the outside surface of the product, if the product requires a superior finish.

- The gel coat provides the colour, glossiness or texture to the products.
- The gel coat conceals the carbon fiber pattern from seeing on the surface.
- The gel coat also provides a resin rich protective layer that protects the carbon fiber getting in contact with water and chemicals.

If the gel coat is too thin, the fiber pattern will become visible. If the gel coat is too thick, crazing and star crack can appear on the gel coat. The gel coat resin is generally of the same grade as the lay-up resin.

If the surface is to be subsequently painted the gel coat will be of pure resin and not pigmented and it will be very thin. In all other cases, a specially prepared gel coat resin system will be used.

2.7 Lamination Preparation

- A layer of Resin is applied with a brush on the gel coat which has already gelled or cured.
- The cut glass fiber mat is placed over the resin.
- By a stippling action using Resin wetted Brush; the resin is squeezed to the top surface. Care should be taken to see that the required glass-to-resin ratio is uniformly obtained.
- Using metal roller the layer is consolidated and the air bubbles removed. It is important that all the air entrapped in the first layer is removed. Otherwise, the air entrapped between gel coat and first layer of mat will expand later causing blistering.
- Adjacent pieces of mats shall be properly overlapped.
- After the first layer is laid up, subsequent layers are laid up in a similar manner.
- The procedure has been repeated till the required thickness has been built Compression moulding.

2.8 Compression moulding

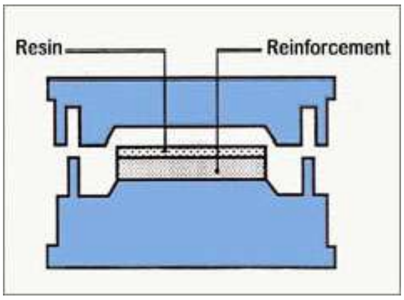


Figure 5: Compression Moulding Machine

GFRP laminates of size 300*300 mm are fabricated with three layers of uni-directional glass fibres with epoxy as the binding medium. The symmetry ply $[0^o/0^o]_3$ laminates were then cured by a compression moulding machine at 100kPa pressure and room temperature for 24 hours.

III.SPECIMEN PREPARATION

3.1 Cutting Specimens from the Laminate

Figure 6: Water jet cutting

- Specimens having dimensions 101.6x25.4x3mm, has to be cut from the laminate.
- For this process we used Water jet cutting machine, which uses abrasive sand mixed with water as the cutting tool.
- Specimens are cut from the each GFRP laminate.

3.2 Surface Preparation and Curing

Considering bonded joints the surface preparation takes an important role in perfect bonding, we used hand abrasion technique to introduce roughness in the surface. The entire mould with glass fabric lay-ups has been kept in 24 hours for curing. The curing has been done at a room temperature. If the specimen is not cured properly the strength of the bond drastically reduces. The major defects found in bonding of two materials are dis-bonding, porosity, voids is mostly due to improper curing. There is also a possibility of voids generation due to vaporizing of water molecule present in the adhesive. To prevent dislocation of specimen in bond region proper load should be applied.

Figure 7: ASTM Standard Double lap joint specimens for test

The GFRP panels made from the compressed molding process are to the sized to the required dimensions for the tests to be done. This is done by diamond cutting tool. The tests and their dimensional requirements are shown in the figure 7 and 8.

Tensile test on DOUBL STRAP JOINT specimen:

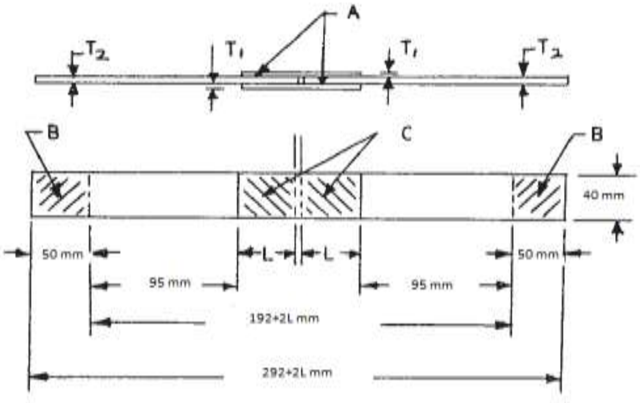


Fig 8: ASTM Standard Double lap joint specimens with dimensions

T1 = 1.6 mm

T2 = 3.2 mm

A = Test Glue lines

B = Area in Test Grips

C = Shear areas

IV ASTM D 5868 – 01 STANDARD TEST METHOD FOR LAP SHEAR ADHESION FOR FIBER REINFORCED PLASTIC (FRP)

4.1 Scope

This test method describes a lap shear test for use in measuring the bonding characteristics of adhesives for joining fiber reinforced plastics to themselves and to metals. The method is applicable to random and fiber oriented FRP.

This test method is intended to complement Test Method D 1002 and extend the application to single-lap shear adhesive joints of fiber-reinforced plastic (FRP) adherends. This test method is useful for generating comparative apparent shear strength data for joints made from a number of FRP materials, providing a means by which FRP surface treatments may be compared.

4.2 Summary of Test Method

This test method describes a procedure for the testing of lap shear bond strengths, using composite materials not recommended in Test Method D 3163 such as FRP.

4.3 Test Substrate

Substrates—Fiber reinforced plastic (FRP) as specified, with metal composition (heat treat, temper, and condition) and roughness as specified when bonding FRP to metal.

Dimensions—Cut fiber-reinforced plastic parts into flat coupons 1 by 4 in. (25.4 by 100 mm) at a nominal thickness of 0.1 in. (2.5 mm). metal with a nominal thickness of 0.06 in. (1.5 mm). It is recommended that a diamond tip water-cooled saw blade be used, or a cutting method capable of producing sharp cut edges.

4.4 Surface Preparations

Prepare the surface of the FRP in accordance with Practice D 2093, or as recommended by the adhesive manufacturer. Surface roughening, solvent cleaning, and surface primers are acceptable, provided they do not reduce the FRP bulk properties. Use surface preparation adaptable to actual production conditions.

Prepare the surfaces of metals to eliminate burrs or bevels. Clean and dry them or surface treat them prior to bonding by using procedures prescribed by the adhesive manufacturer.

4.5 Preparation of Test Joints

Applications of Adhesive—Apply the adhesive in accordance with the adhesive supplier's recommendations or as documented in the test report. In the case of two-part adhesives, mix in accordance with the supplier's suggested procedures. Adhesive Cure— Cure the adhesive at room temperature or elevated temperature using prescribed conditions determined by the adhesive supplier. Joint Geometry— Control joint geometry by appropriate fixturing, using glass beads or other suitable means to control a 0.03-in. (0.76-mm) adhesive bond line thickness. Use the minimum number of glass beads in the glue line needed to hold bond line thickness. Fixturing pressure is allowed. Lap shear overlap will be 1 by 1 in. (25.4 by 25.4 mm). Conditioning— Allow bonded parts to cool to room temperature for at least 1 h if elevated temperature cures are employed. If the adhesive is room temperature cured, allow full-cure time plus 10 % prior to testing.

4.6 Testing

Initial grip separation is 3 in. (75 mm) with 1 in. (25.4 mm) minimum of each sample end held in the test grips. The specimen loading rate is 0.5 in. (13 mm)/min. Note that a loading rate of 0.5 is an important difference compared to other ASTM standards.

Prepare a minimum of five lap shear samples in each case and test.

4.7 Report the following information

- Complete identification of the adhesive tested, including type and manufacturer's code number.
- Complete identification of the substrates used (including type of resin and fiber orientation) and method of surface preparation prior to bonding.
- Cure schedule time and temperature for bonding sample, as well as any other conditions, such as sample conditioning, environmental exposures, etc.
- Individual peak load values, psi (kPa) and averages by maximum and minimum values.
- Test temperature and conditions.
- Type of failure (such as fiber tear, cohesive, adhesive) should be reported, in accordance with Practice D 5573.

III.RESULTS AND DISCUSSION

3.1 Mechanical Characterization of Double Lap Joints

One of the main complications in the study of the mechanics of the composite material is the multiphase failure behavior. At the same time, it is difficult to characterize all the failure modes from a single oriented specimen. In order to avoid these complexities, specimens with different stacking sequences may be used for the characterization of failure modes in composite laminates. In this present work GFRP composites Lap joints with different stacking sequences such as 0^o, 90^o, angle ply [$+45^o/-45^o$], cross ply [$0^o/90^o$] are used to determine the mechanical strength and different failure mechanisms when subjected to tensile test .

3.2 Ultimate Loads For Different Orientation Composite Lap Joints

The maximum failure loads were predicted by using the load Vs Displacement curve shown in figure 10, 11 and 12. The ultimate failure load and elongation of the each specimen was tabulated as shown in the table 1, 2, and 3. This test is conducted to determine the tensile properties of the material particularly composites. ASTM (American standards for testing of Materials) ASTMD638-03.This specification gives the drawing of the specimen to be prepared for conducting the test with tolerances. The prepared tensile specimen were inspected after machining and loaded in the tensile testing machine or universal testing machine and the tensile force is given load Vs displacement curve is generated till the specimen is broken. After the tests were completed, the specimen displacements and the failure loads were recorded and the average values were determined and tabulated shown in the table 1, 2, and 3.

Figure 9 :Tensile testing machine

Table 1: Load Vs Displacement values for [$+45^o/-45^o$]

Ult./Break load (KN)			Displacement (mm)			Average Load (KN)	Average Displacement (mm)
Sp1	Sp2	Sp3	Sp1	Sp2	Sp3	3.5	1.52
3.2	3	4.5	1.25	1.6	1.7		

Table 2: Load Vs Displacement values for [0^o]

Ult./Break load (KN)			Displacement (mm)			Average Load (KN)	Average Displacement (mm)
Sp1	Sp2	Sp3	Sp1	Sp2	Sp3	6.5	1.21
6.9	6.8	6	1.22	1.22	1.19		

Figure 11: Load Vs Displacement curve for double Lap joints-[0^o]

Ult./Break load (KN)			Displacement (mm)			Average Load (KN)	Average Displacement (mm)
Sp1	Sp2	Sp3	Sp1	Sp2	Sp3	3.33	1.08
3.5	3.5	3	1.19	1.15	0.9		

Table 3: Load Vs Displacement values for [0°/90°]

Figure 14: Light Fiber Tear Failure observed in double lap joints

There are several factors that could contribute to the failure of two adhered surfaces. Sunlight and heat may weaken the adhesive. Solvents can deteriorate or dissolve adhesive. Physical stresses may also cause the separation of surfaces. When subjected to loading, deboning may occur at different locations in the adhesive joint. The major fracture types are the following:

3.3 Cohesive fracture

Cohesive fracture is obtained if a crack propagates in the bulk polymer which constitutes the adhesive. In this case the surfaces of both adherents after debonding will be covered by fractured adhesive. The crack may propagate in the centre of the layer or near an interface. For this last case, the cohesive fracture can be said to be "cohesive near the interface". Most quality control standards consider a good adhesive bond to be cohesive.

3.4 Interfacial fracture

The fracture is adhesive or interfacial when deboning occurs between the adhesive and the adherent. In most cases, the occurrence of interfacial fracture for a given adhesive goes along with smaller fracture toughness. The interfacial character of a fracture surface is usually to identify the precise location of the crack path in the interphase.

3.5 OTHER TYPES OF FRACTURE

The mixed type, which occurs if the crack propagates at some spots in a cohesive and in others in an interfacial manner. Mixed fracture surfaces can be characterised by a certain percentage of adhesive and cohesive areas.The alternating crack path type which occurs if the cracks jumps from one interface to the other. This type of fracture appears in the presence of tensile pre-stresses in the adhesive layer.

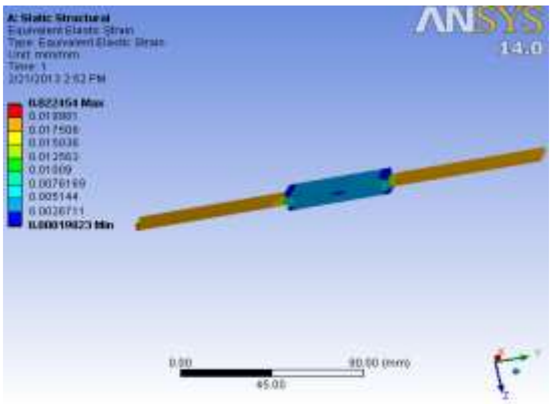
Fracture can also occur in the adherent if the adhesive is tougher than the adherent. In this case the adhesive remains intact and is still bonded to one substrate and remnants of the other. For example, when one removes a price label, adhesive usually remains on the label and the surface. This is cohesive failure.

Once the matrix gets failed, de-bonding failure occurred. De-bonding represents the separation of fiber and matrix. Even though matrix failed in the initial stage, the fibers would carry the load till the material completely gets failed (ultimate strength). From the Fig (10) maximum failure loads are determined by using the Load Vs Displacement curve. The ultimate failure load and elongation of the each specimen was tabulated as above Table 4. However, mechanical characterization of failure modes in double lap joints is a complex research subject, especially because damage phenomena are superposed during the mechanical loading of the laminate. In this work, the different failure mechanisms are identified using tensile test for double lap joints in composite laminate. For damage characterization, the ultimate loads are obtained during tensile test. After thorough investigation of tensile test data, it is found that three different failure mechanisms such as adhesive failure, light fiber tear failure and fiber tear failure shown in the figure 13 and 14. From the experimental observation, maximum ultimate loads and maximum displacements are given for composite lap joints with zero degree orientation compared with [0^o/90^o] and [45^o/45^o] composite double lap joints.

IV FINITE ELEMENT ANALYSIS OF SINGLE LAP JOINTS

The chosen finite element code has been the commercial package ANSYS due to its flexibility for handling information contained in files written in a more or less free format. In the static analysis the blade deflection and the von Misses stresses were analysed.

Failure load prediction is obtained using ANSYS FEA tool. The commercial FEA software ANSYS 10 has been used to analyze the models. The laminates (adherent) were made of Glass/epoxy composite with 00 degree orientation and the adhesive used was standard Epoxy based resin. The composite laminates of FEA model for bonded joints were developed by using Layered 46, a 3-D brick element. The adhesive layer was modeled using SOLID-45, an 8-node brick element. The adherent and adhesive were glued together using Boolean operation. Finer mesh was used in the design.



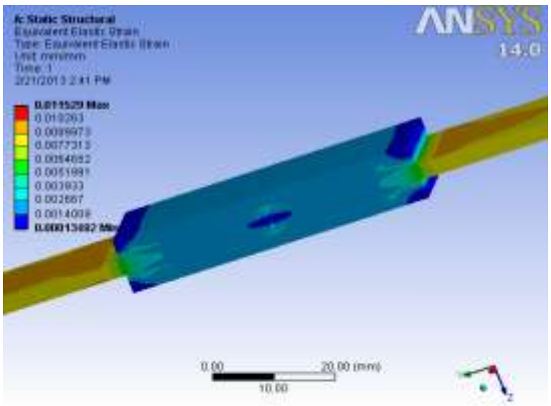


Figure 15 **Figure 16**

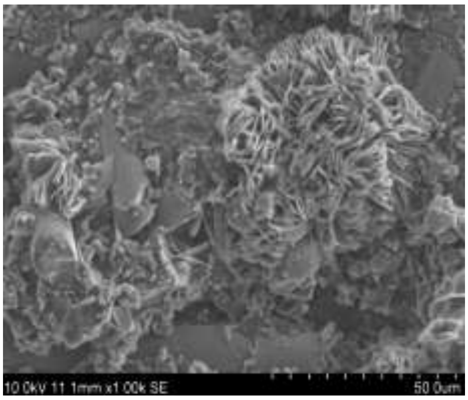
Figure 15: Stress distribution in double lap joints using ANSYS FEA

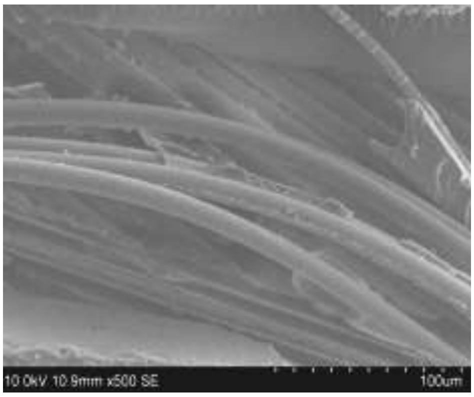
Figure 16: Strain distribution in double lap joints using ANSYS FEA

From the figure 15 and 16, the stresses was distributed throughout the structure and also maximum stress was located on the over lap region of the double strap joints. From FEA results, initial failure was occurred at the overlap edge of the joints.

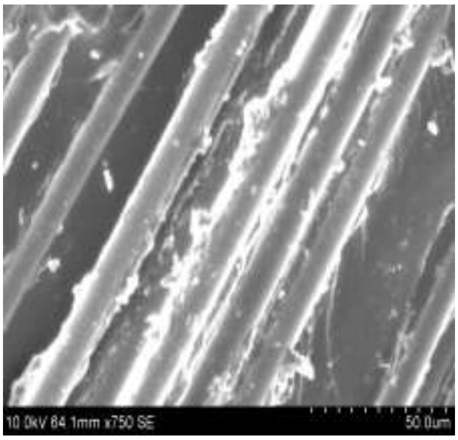
V SCANNING ELECTRON MICROSCOPE (SEM) TECHNIQUE

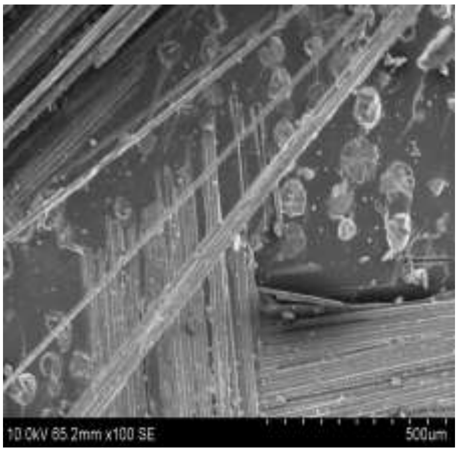
The studies of failure/fractured surfaces are done using Scanning electron microscope. Fig. 17 shows, the microstructure of the specimen which has been taken at two range of feed rate of 100 µm/min and 50 µm/min. The fractured surface of composite specimen was examined; then microstructure indicated that damage modes are observed in composite specimen. The corresponding images taken using SEM is shown in Fig. 17. Scanning electron microscope examinations of sample specimens subjected to fully reversed tension- compression test indicated that the failure mechanisms associated with fiber and fibre direction such as fiber tear failure, matrix failure, fiber bend and fiber failure failure as shown in Fig. 17 (a), (b),(c) and (d).





(a)Matrix failure (b) Fiber bend





(a)Fiber Tear Failure (b) Fiber Failure

Figure 17 : Failure mechanisms are observed using Scanning Electron Microscope

VI CONCLUSION

GFRP composites are being used in a large number of diverse applications ranging from aerospace to automotive equipment. The mechanical characterization of these materials is necessary to further enhance their application spectrum. The various proportions of glass fiber are mixed with epoxy resin and then prepare to double strap joint specimens.

6.1 The concludes was that

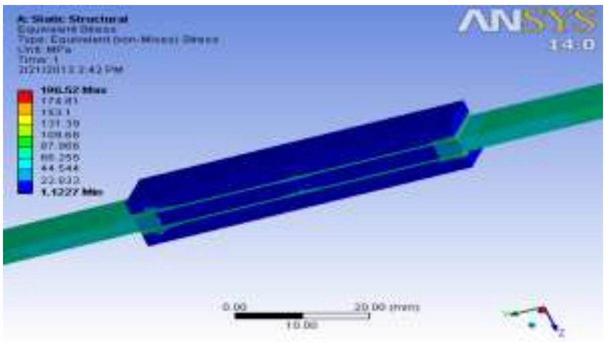
1) A tensile test studies shows that ultimate load and displacements was high in the case of double strap joints at 0^0 orientations compared to other orientations of strap joints.
2) However, mechanical characterization of failure modes in double lap joints is a complex research subject, especially because damage phenomena are superposed during the mechanical loading of the laminate.
3) In this work, the different failure mechanisms are identified using tensile test for double lap joints in composite laminate. For damage characterization, the ultimate loads are obtained during tensile test.
4) After thorough investigation of tensile test data, it is found that three different failure mechanisms such as adhesive failure, light fiber tear failure and fiber tear failure using SEM images.
5) FEA observations are in good agreement with experimental results and also initial failure occurred at the overlap edge of composite double strap joints.
6) Composite lap joints with zero degree orientation are suitable orientation for structural applications.

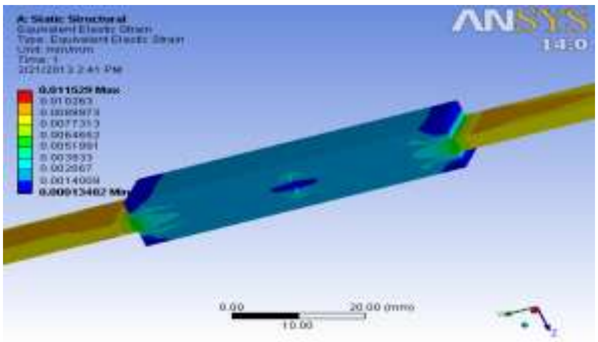
VII FUTURE ENCHANCEMENT

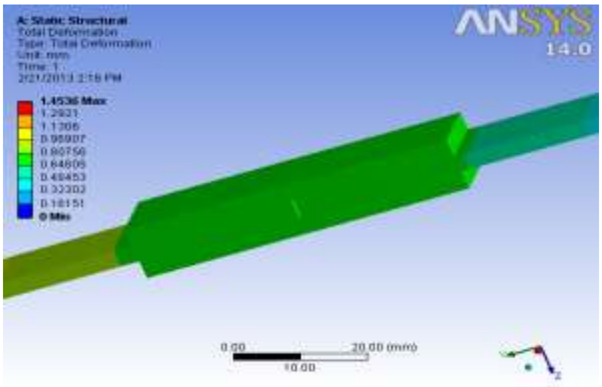
Aeronautic/aerospace applications, both military and commercial, are accounting for a large share of the growing composite market in value. Composite materials offer many superior properties that have enabled composites manufacturers to gain significant market share in a variety of industries. Increased usage of composites in military and space systems, as well as in commercial aircraft development, is expected to continue far into the foreseeable future.

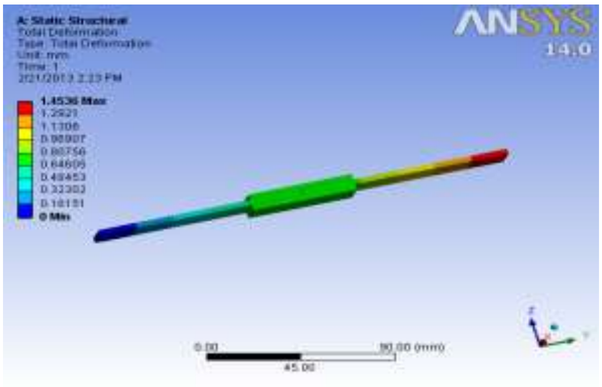
- Future composite structures: From metal Mimics to composite constructions.
- Opportunities for polymeric-based composite Applications: Enhanced Toughness Materials and Moulded Discontinuous short Fiber composite Technology for Transport Aircraft parts and component Application.
- composite materials for marine applications. key challenges for the future.
- multifunctional polymer-based structures for human tissues reconstruction
- Textile-reinforced and polymer-modified mortars (TRM) a new generation of composite materials for strengthing and seismic retrofitting of structures.
- Current and future application of polymer composites in the field of tribology
- Graphite Nanoplatelet composites and there applications.

VIII. OUTPUT SCREENSHOTS









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