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FATIGUE LIFE ESTIMATION OF DEGRADED E-GLASS FRP TEST SPECIMEN USING SIMULATION & EXPERIMENTAL VALIDATION

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Abstract—Increased popularity in the structural, automotive, aero and wind turbine sectors damaged and eventual failure during operation.Fatigue time-consuming and costly work are the results of life testing. The objective is to predict progressive fatigue damage and lifetime of the composite laminate, based on the fatigue characteristic of the E glass fibre, longitudinal, transverse and flat shear.Various types of fibre-orientation sheets made from composite materials were produced.This paper focuses on fiber orientation effect on the strength of fatigue of [±45 °] and [0/90 °] and Unidirectional enhanced composites (GFRP). The composite is manufactured using a layout method from E-glass fiber and epoxy resin and hardener. Such application are often exposed to fatigue loads, and therefore, In order to achieve a proper design, the fatigue behavior of the composites must be studied.This is achieved through an experimental characterization in which many specimens are tested for various parameters (i.e., fiber/matrix ratio, fiber orientation, staking sequence, etc.).The test setup is designed to be validated and reasonably functional. S-N-curves showed the results that unidirectional orientation has a greater fatigue depending on the fiber orientation. The results have shown that the GFRP fibre orientation significantly affected the mechanical characteristics and the fatigue behaviour.

Keywords— Fibreglass reinforced composite, Fatigue testing machine, fibre orientation, fatigue life, degradation life

I. INTRODUCTION

In recent year, uses of composite materials are widely applicable for manufacturing and engineering field like aerospace, automotive industries and medical field. Mixture of two or more materials is made of composite materials and alloys are made of two or more materials, but alloy changes its properties differ, but composite changes are not. Due to these advantages, composites are stronger, low cost and lightweight material for any application.In the automobile and aerospace sectors in particular, their use has been increasing. It is well known that the main advantages of these materials are generally their high weight stiffness and strength ratios, which can be customized to measure the mechanical properties of laminated FRP composites by controlling its volume fraction as well as its ply thickness by fibers.For the same reason, in only one direction (the direction of the fibers) unidirctional composites have predominant mechanical properties. In the absence of accurate forecast methods, it would be extremely difficult and costly if composite structures used FRP composites were optimised. Mainly because of the many parameters to be addressed for performance management.

A blend of different material types like refinement, resin, filling and so on, varying in shape or working on a large scale. They do not solidify or merge, although they work well. The device can normally be identified and show an interface between the two. In a comparison between composite and conventional materials, composites are better properties like (metals, ceramics, or polymers). Usually artificial, materials, which constitute a three-dimensional combination of two or more chemical materials and a separate interface among the components, produced for the purpose of providing the property that no single component can performed. Composites are a mixture of two materials where one material is in use in the type of fibers, sheets or particles and one material, called the reinforcing phase, is fixed in the other materials known as the matrix phase. The material matrix is like ceramic, metal and polymer and reinforcing materials are.

GFRP materials are defining two categories, low cost, premium special, low cost are general used of fibers, and premium are costly but more preferable90% glass fibers are used for general purposes among the industry. Fiber glass is generally called E-Glass fiber glass and is designed according to the ASTM Standard. The fibers left behind are premium fiberglass with a special purpose. E-glass fibers possess numerous mechanical properties and other benefits.

The S-N curve still appears to be the most popular way to distinguish between fatigue behaviour. For the description of S-N curves, there are several empirical questions. Mostly based on a classic power law which gives a direct line to the fatigue information log but certain posse refinements to take into account the average stress or the maximum-minimum stress ratio.Other theories have been formulated for characterizing the composite materials ' fatigue behaviour. There are essentially three types: theories based on residual strength degradation, theories based on module changes, and theories based on the actual mechanism of damage. Most life-prediction methods currently favoring polymer composite materials are based on degradation of residual strength.

II. REVIEW OF LITERATURE FOR ANALYTICAL AND EXPERIMENTAL WORK

Using the **Hashin initiation criteria** [35], For a laminate with cyclic loading less than its maximum static strength, the properties of the laminate are deteriorated as the number of cycles goes by, the following four modes of damage starting tension, fiber compression, matrix tension and matrix compression.Failure criteria and material degradation rule are shown [15]. **Tsai-Hill, Tsai-Wu criterion, and Hashin** failure criterion have proposed that Static failure criterion for composite laminated failure have planned to model composite laminated failure. The static strength and fatigue strength in static failure criterion it can be obtain fatigue failure criterion and Figure [1] shows the experiment data with strength and different stress ratio. **Wei Lian, Yao, Weixing [13]** is to Simulate the evolution of fatigue damage to composites and predict the laminate's fatigue life by the Finite Element Analysis (FEA) method based on fatigue features in longitudinal, transverse, and in-plan shear directions.Damage evolution law indicated how the material can be degraded **Ever J. Barberoa, Mehdi Shahbazi**[34].ANSYS has two evolution types: the instantaneous reduction of rigidity and the mechanical continuum. Since instant stiffness reduction, which is suddenly applied when the criterion is met, does not provide any information about the evolution of damage, this study uses the PDA method for the evolution of damage.

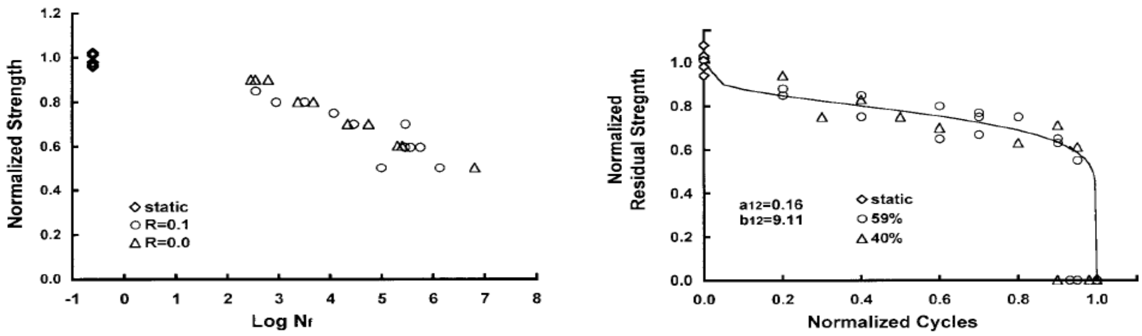


Figure 1Experimental data of static strength and fatigue life of lamina under in-plane shear loading with deferent stress ratios[12,14]

M. Naderi, A.R. Maligno[15] Includes two types of (1) Sudden degradation in general, (2) gradual degradation of the material characteristics degradation rule. If the part fails and its property soon diminishes to transport a load and breaks it is called sudden degradation. If the part failures are due to failure criteria. This deteriotion is called progressive degradation when the component is carried with cyclic load and reaches a level when the component can not sustain the load and final breakage occurs. The component can be degraded on each cycle with the increase in cycle number. The unidirectional residual strength and stiffness are less than the random stress ratio equations to achieve life of fatigue[15].

E. Pach I. Korin, and J.P. Ipin[22] developed experiment a machine to perform fatigue tests of composite materials under constant amplitude load cycles and a wide-ranging of load ratios is presented in those work. Due to high cost of testing component they produce fatigue machine for composite materials of low cost and easy to manufacture was built. Its major features are low cost, simplicity, reliability, and small size.**R.J.Huston**[8] For testing residual strength and residual rigidity model, results obtained from repeat fatigue tests for unidirectional carbon fibre reinforced epoxy were used. During spectral loading, fatigue testing was carried out in order to correlate the results with residual strength predicted cumulative damage. **Mehdi Nikforooz , JohnMontesanob[21]** Fatigue tests have been performed both at room temperature on unidirectional and cross-ply specimens. Furthermore, the degradation of stiffness for laminates was investigated and compared with glass / epoxy with the same lamination. Composites of glass and polyamide have a decreased rigidity than glass and epoxy.**M. Abo-Elkhier Hamada, AA El-Deen [1]** Experimental analyzes were performed with specimens for which the modal parameters (natural frequency, damping ratio and modal shape) were previously subjected to fatigue loadings. Glass Fiber Reinforced Polyester (GFRP) is the compositional material for experiments. The results demonstrated that changes in modal parameters provide an appropriate way to predict composite structures ' fatigue behavior.

M.A. Badie, E. Mahdi, A.M.S. Hamou[33] The future results of the experiment are designed to unreasonably investigate the composite drive shaft's torsional rigidity. The composite tube behaviorshould be examined under different sequences of stacking and fiber orientation. This section presented both the analysis of finite elements and the experimental results.The example of the design is used to validate the results of finite-element analysis used to study the mechanical performance of the composite drive shaft. These experiments only examined torsional rigidity and its relation to the material type, the angle of orientation and the stacking sequence of the fibres.

III. TYPES OF FIBER GLASSES:-

- A-glass – A stands for alkali glass and it made with soda lime silicate. This glass fibers are used where E- Glass fiber are not used. A-glass is the prevail glass used for containers and windowpanes.
- AR-glass – AR stands for Alkali Resistant glass and it made with zirconium silicates. It is used in Portland cement substrates.
- C-glass – C stands for Corrosive resistant glass and it made with calcium borosilicate. It is used in acid corrosive environments.
- D-glass – D stands for low dielectric constant glass and it made with borosilicate. It is used in electrical applications.
- E-glass – E-Glass fiberis made with alumina-calcium borosilicate and it is alkali free. It is electrical resistivity glass. For a general purpose and strength upon electrical it’s preferable for industry. It is the most normally used fiber in the FRP composite industry.
- ECR-glass – An Electrical glass fiber with higher acid corrosion resistance and it made with aluminium in silicates. Applicable where strength, electrical conductivity and acid corrosion resistance is required.
- R-glass – R stand for reinforcement glass made with calcium alum in silicates and it is used where higher strength and acid deterioration resistance is required.
- S-glass – S stand for high strength glass made with magnesium alum in silicates. Applicable where high strength, high stiffness, intense temperature resistance, and acidic confrontation is required.
- S-2 glass – Glass parallel to S glass, but with to some extent enhanced properties with, S-glass.

Above all glass fiber are use for the many usable application. Composite materials will in future be produced using an incorporated design process which leads to beneficial parameters in the design, such as mass, form, rigidity, strength, durability etc. Recent industrial design tools have to show customers that they can manipulate each of those parameters by manipulating design changes immediately.

The fiber enhanced plastic (FRP) is a polymer fibres, or is also referred to as fiber enhanced plastic or polymer. Usually, the fibers are glass, carbon, aramid and basalt. Other fibers like paper, wood or asbestos have hardly ever been utilized. The various polymers are typically an epoxy, vinyl ester or polyester plastic, although FRP materials are commonly or are still applied in the aerospace, car, marina, and manufacturing industries with phenol formaldehyde resin. "Reinforced fiberglass plastics" or FRP is using glass fibers of textile grade. These textile fibres are different from other forms of glass fibres used to intentionally catch air, for insulate application. Fibre fabrics are web-form material that has both deformed and wet directions. There are different types of fiber arrangement like mat web form or woven or non-woven. Generally, mats are manufactured in cut dimension and using chopped fibers, and it also in continues mat using continuous fibers. The length of the chopped glass fiber is 3 to 26 mm; threads are then used in plastics most commonly deliberate for moulding processes.

IV. METHODS AND MATERIALS

Fibreglass reinforced composite is the material under investigation, and the specimen is prepared and produced in the workshop. During the infusion process, several steps are taken. The processes can be divided into several fragments, namely process materials, the infusion process supply and the completion process. E glass fiber (woven), epoxy, and corresponding hardener are the basic materials used in this work.

Figure 2. E-Glass fiber[±45°],[0/90°] and Unidirectional

The fabrication of the composites is carried out through the hand lay-up technique. Fibres of [±45°],[0/90°] and Unidirectional measuring 60 cm x 60 cm, with four pieces for each orientation, were prepared as shown in Fig 2.

Figure 3. Epoxy resin and hardener

The "Mold release" is used to polish a cleaned glass surface six times to facilitate the disassembly process at the end of the process. On the mirror surface are placed glass fibers which have been cut. A glue is sprayed on each layer of fiberglass in order to attach each layer. This step continues to the fourth layer. Next, after setting the fourth layer, peel ply layer was applied.

Hands lay-up method is generally used for E-glass fiber and other material. The procedure is that firstly, measure the fiber, resin and hardener weight fraction, take a polyester paper, and apply grease on a paper, after that put a fibreglass sheet and apply the mixtures of resin and hardener and it shown in fig. 3.

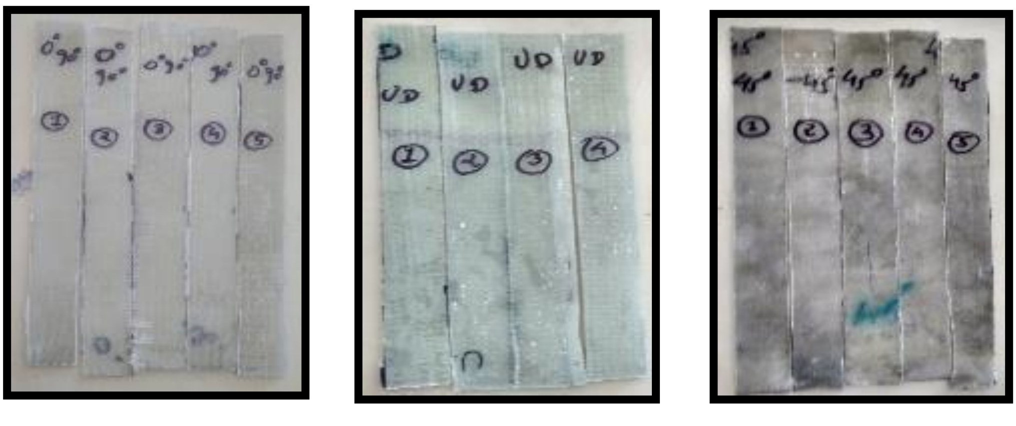


Figure 4. Test sample of different orientation

Above fig. 4 illustrated that the specimens are cut to the each of the sheet according to the ASTM standards and accepted for the fatigue test. Following fiber volume fraction and weight fraction formula are derive below section.

A. FiberVolume And Weight Fraction Of Composite Materials:

MoldSize: = Length × Width × Thickness

Density of Epoxy: =1.5 g/cc × 0.94 g/ml

= 1.41 g/cc

F.V.F Fiber Volume Fraction= $\frac{volume\ of\ fiber}{volume\ of\ composite}$

Volume Of The Resin:= volume of composite – volume of fiber

Density Of Resin:= 1.41 g/cc

$= \frac{m}{v} = \boldsymbol{\rho}$

m = $\boldsymbol{\rho} \times \boldsymbol{v}$

where **m** is the mass of resin;

where$\boldsymbol{v}$ is the total volume of the epoxy resin;

and $\boldsymbol{\rho}$ is the density of the resin.

V. Machine description

In accordance with the ASTM D 3479 / 3479 M standard and an database developed by Sandia7 with more than 2500 7-fatigue tests of FRP composite materials, the maximum machine load values, frequency ranges and load ratios have been adopted.

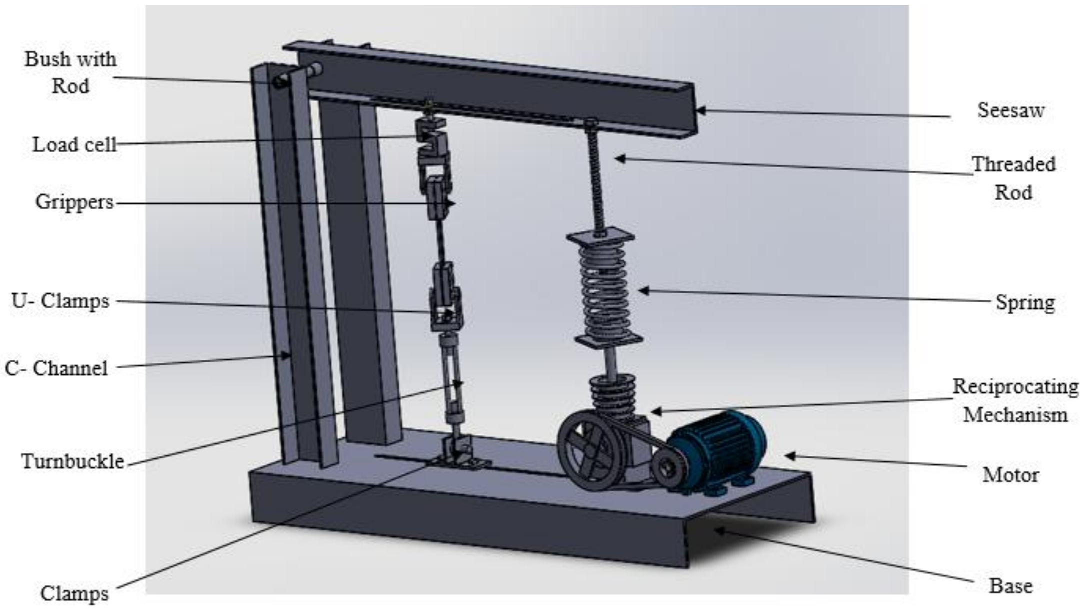


Figure 5. Solid model of fatigue test machine

This machine is the first prototype in fig. 5 in order to achieve the necessary power and dimensions, the maximum load was limited to 10kN, however, this capability enables the test conditions in many ways, even more so if we consider that the sample width can be varied. For specimens consisting of only one-way, fibrous laminae and fibers parallel to the test axis, the standards ASTM D3479/D 3479 M recommend 15 mm in width and the remaining 25 mm. The machine can measure up to 100 mm in length with the recommended thickness ranges between 1 and 2,5 mm. The fig. 6 showing the actual experiment test setup. The mechanism used in the machine to generate the load cycles consist of a set of helical springs that are compressed (or expanded) by means of reciprocating mechanism driven by an electrical motor. The deformation of these springs generate a force applied on the see saw of the machine, which can pivot on a pair of bushes placed at one extreme and in this way the load to the grips is transmitted.

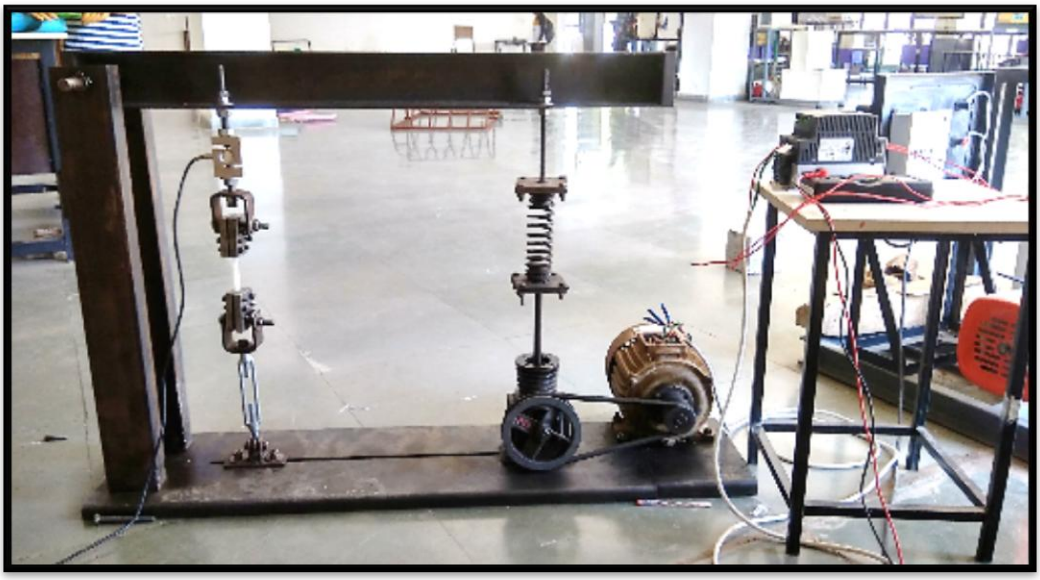


Figure 6. Experimental fatigue test machine

The seesaw and the machine frame are fastened by guides, enabling the horizontal distance to change to the point where the seesaw is swiveling. This is inversely proportional to the abovementioned distance and the force of the specimen (attached to the grips) is therefore used to determine the charge magnitude before testing begins.

The springs were compressed or expanded with two threaded rods and a nut with right-hand and left-handed thread, when the specimen was placed at least the load in the cycle was generated. This system has been located up and down the springs. For the $0 < R < 1$ (tension-tension cycle), the threaded piece was turned in the direction in which the threaded rods move away and therefore they compress the springs.

Two locking nuts blocked the threaded component once the preloaded value was adjusted. Each piece has levers to prevent additional use. In order to corroborate their strength under fatigue charge, all critical components of the machine were analyzed. A load cell on the load line (up to grip) had been placed. It amplifies its signal and transfers it into a digital multimeter, allowing loads to be seen in real time and the information to be recorded in a lifetime.

VI. ANALYTICAL APPROACHES FOR FATIGUE LIFE AND PROGRESSIVE DAMAGE

E-Glass FRP material for the fatigue and progressive damage analysis and experimental process, it have some standard method like ASTM D 3479/D 3479M standards. The E-Glass fiber is more popular and inexpensive. The designation "E" means electrical implies that is an electrical insulator.

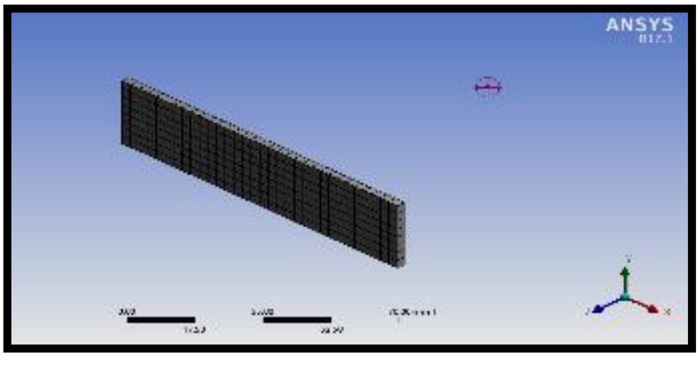


Figure 7. Specimen meshing model

The number of higher cycle 10^5 to 10^6 for fatigue analysis up to 50 MPa. The dimension of the FRP sheet as per ASTM D 3479/D 3479M Standard we are taken as 150mm x 25mm is shown in fig.7.

The prediction of fatigue life is illustrated in fig. 9 and work is continueon the basis of their fatigue analysis. The magnitude of the fatigue life test is 3000 N, 10^5 to 10^6 cycles and the maximum stress is 50 MPa. The limiting condition of the module is that one end is attached to zero and the other end is loaded to 3000N.Through the Fatigue failure equation, we can solve the fatigue analysis. For the defining fatigue analysis, first step on ANSYS workbench to go static structural and go with engineering data. Then apply boundary conditions and further analytical procedures to find solutions after this import model. Choose the fatigue module tool and follow its next step to achieve a fatigue result to address the fatigue analysis problem. Fatigue tool contains many solutions such as fatigue, damage, stress, hypertension charts, sensitivity, etc. The S-N curve diagram was obtained and applied to the analysis shown in Fig. 8 from the experimental data for UD specimen.

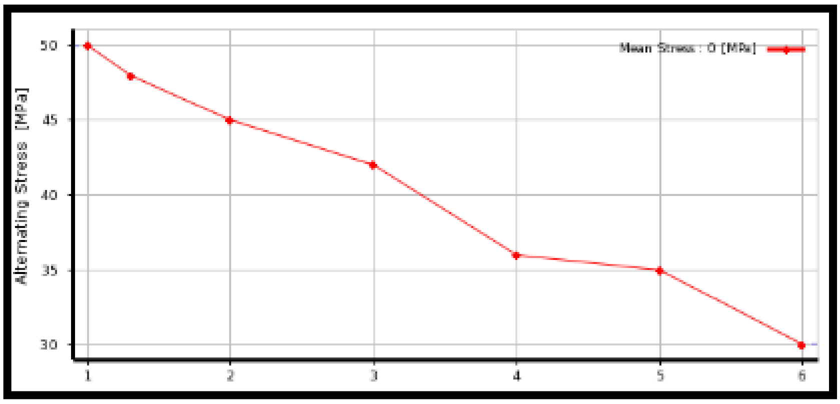


Figure 8. Predicted S-N curve

The fatigue life of UD is compare with analysis and do progressive damage analysis for the initial damage status & shear damage of UD plies. For a fatigue life of UD plies, fiber orientation of E-Glass fiberis shownfig. 9same as different fiber orientation like 0˚+ 90˚, ±45˚ for PDA analysis.

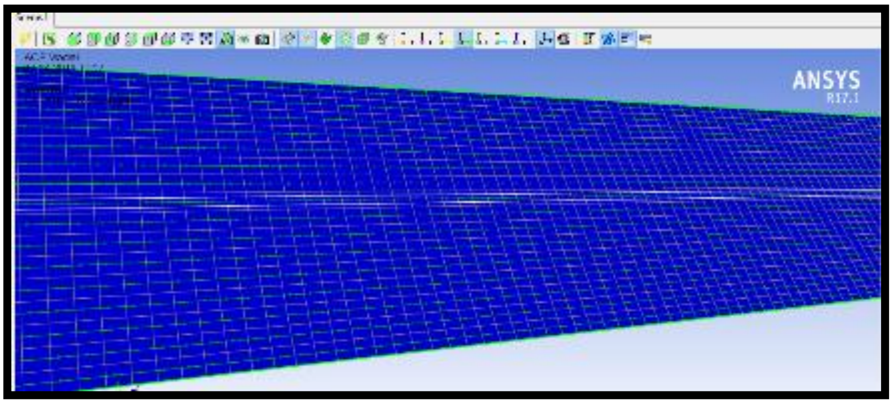


Figure 9. Fiber orientation

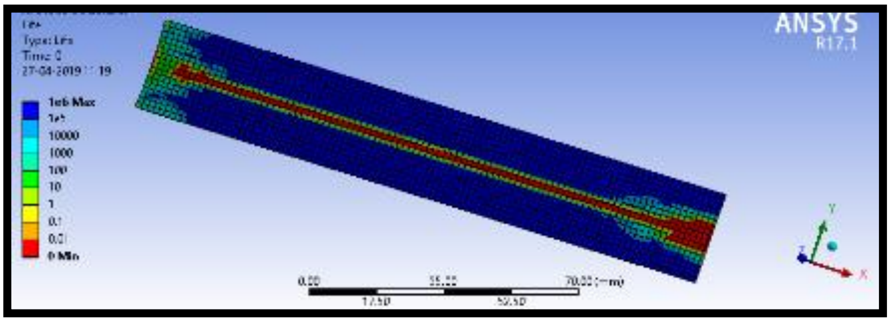


Figure 10. Fatigue life

The fatigue life result is shown in fig. 10that when we applied 3000N load and stress ratio is maximum at 0 to 10 no. of cycle then module have crack or any other activities due to fatigue. Andaslo when run a cycle at 10^5 to 10^6 and stress is minimum up to 10 MPa then modules have work on infinity no. of cycle.

The damages fig. 11occur during cyclic loading to know how much damage occur on 3000 N and how damage will reduce for the further experiment it shown in figure. The damage is occure at minimum 1000 no. of cycle and maximum at1e^{32}. The progressive and localized structural damage occurs when a material is subjected to cyclic loading. Round holes and smooth transitions or fillets will increase the fatigue strength of the structure.

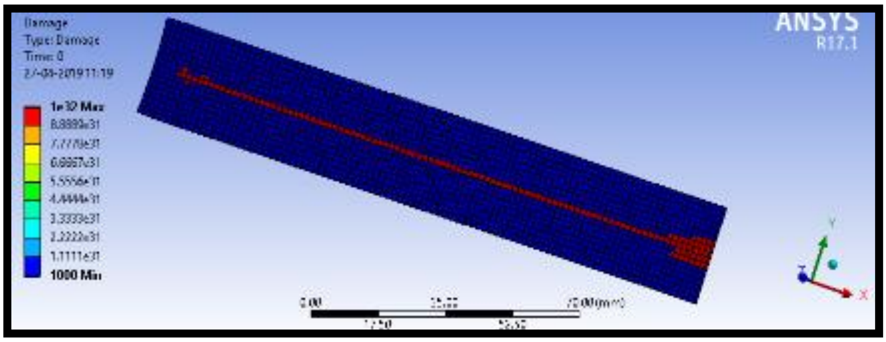


Figure 11. Fatigue Damage

Equivalent stress (also called von Mises stress) is often used for design, because it can be represented as a single positive stress value by arbitrary three-dimensional stress. The equivalent stress foresees the yield in ductile is a part of the theory of maximum equivalent stress failure. The equivalent stress is generated on UD plies is minimum at 8.712 and maximum is 100.18 max. which is shown in fig. 12

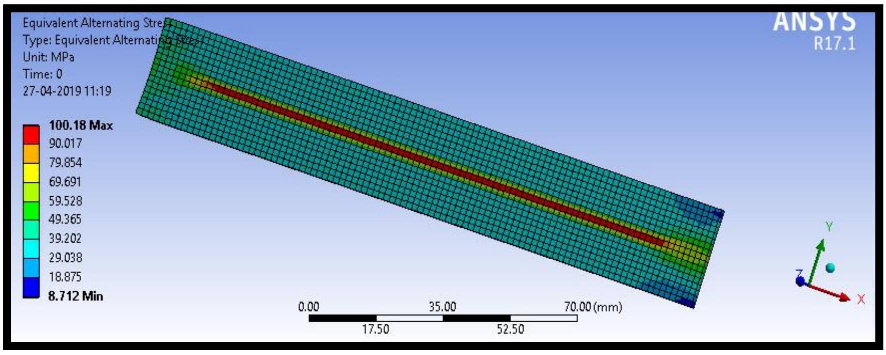
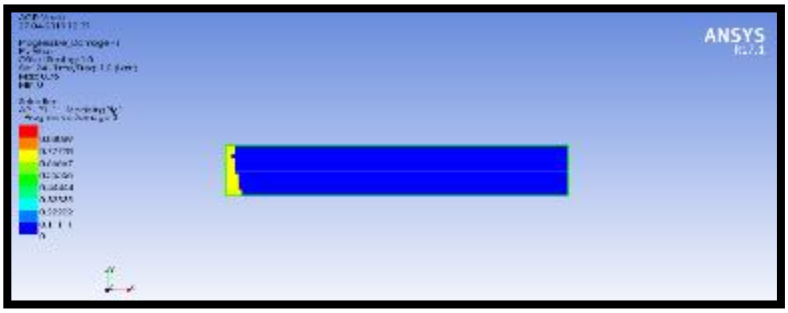
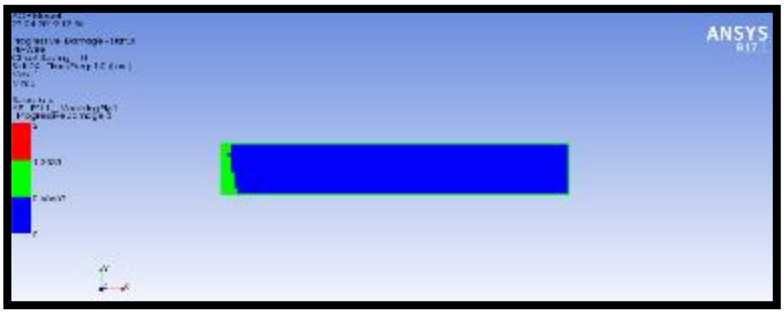


Figure 12. Von-misses stress

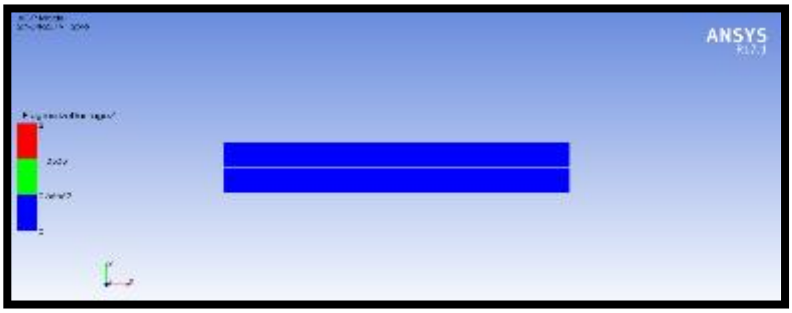
The PDA is a wide-ranging label used to predict damage initiation and development for various modelling approaches. For structural analysis, progressive methods for the modelling of failure are presented, including failure initiation and degradation of the material. These gradual failure formulations may be used with a non-linear tool for the analysis of final elements on a user-defined material model.Progressive damage analysis result of damage variable, tensile damage and matrix failure damage variable for different types of cross ply for E-Glass fiber are show in fig. 13



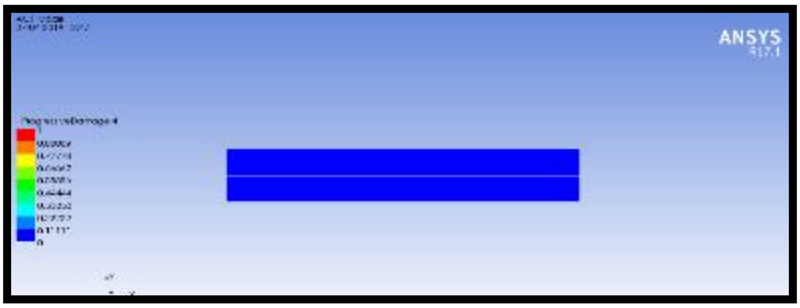
(A)



(B)



(C)



(D)

Figure 13. (A, B, C, D) are the progressive damage of the ply

Above all figure are express 0˚+ 90˚, ±45˚ progressive damage has been occur during loading condition and repeatedly applied stress on it, damage will occur localized or progressive. The initial point of the loading faces have stress applied and damage will occurs from that point, these analysis can be done through ANSYS 17.1 workbench with the help of ANSYS composite pre/static structural/post.

During ACPre material properties, model and setup all the properties have been done and then its setup transfer with shell element to the static structural model and then applied all the boundary condition and solve the result. After that ACPost is link the ACPre then update the result and obtain the progressive damage on selection of ply, which we can choose from result section.

VII. RESULT AND DISCUSSION

In this chapter, an analysis of the various data obtained and measured during and after the experiments is presented. Four different process outputs were measured as a part of this dissertation work. Therefore, these chapter included fatigue analysis of maximum strength of Unidirectional plies life and also validate with the experiment data for the degradation life of the specimen. As mentioned in the previous chapter, Formation of FRP specimen and machine parts, the experiment was conducted and experiment data should be observe in table 1.

The above table illustrate the experiment data, which perform for three FRP Specimen. No. of reading are measured for the each specimen and calculate the average of that measurement S-N curve are generated from the Experiment average data and is shown in fig. 14S-N curve are describes, From the experimental data the, generated S-N curve on the X-axis No. of cycles and Y-Axis Stress, which are measure during working. The gradual decreasing

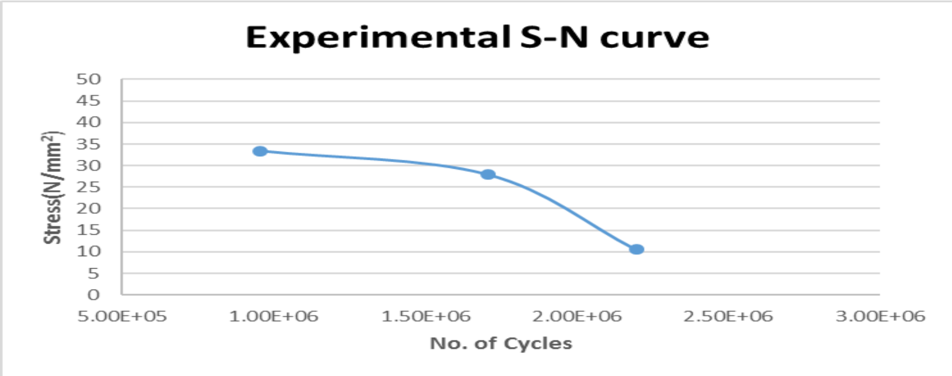


Figure 14. S-N curve of different cross ply data

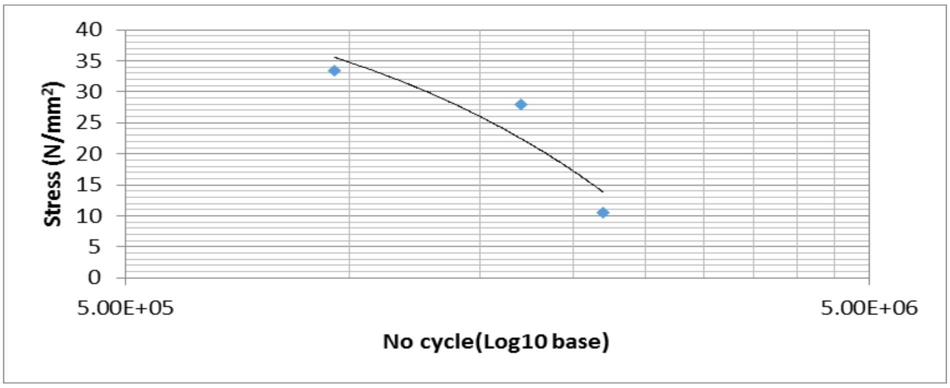


Figure 15. Trend line graph

Experimental data or any other condition, output or process or a general tendency of data points to move in certain direction over time are represented on this fig. 15trend graph.

A. TESTING SPECIMEN RESULT

the section fig. 16, it introduce the specimen's testing result and how much time specimen are sustain load and measure the degradation time.

Figure 16. ±45° fatigue test

The fig. 16 This shows that the samples are fiber oriented to ±45 ° and the stress generated is 11 Mpa on average for the determination of the fatigue strength of the applied cyclic load (max= 75), thus, the S-N curve defines a break at 10^4 or 10^5 cycles.

In addition, for this specimen the average load can be measured at 200 kN and the average stress is 28 Mpa, with a fibre of 0 ° 90 ° orientation at the test specimen. It can break with 10^4 or 10^5 cycles, the strength of this fatigue specimen. The first and second test specimens are the same, but this test specimen has more time to take a break than other the test specimen.

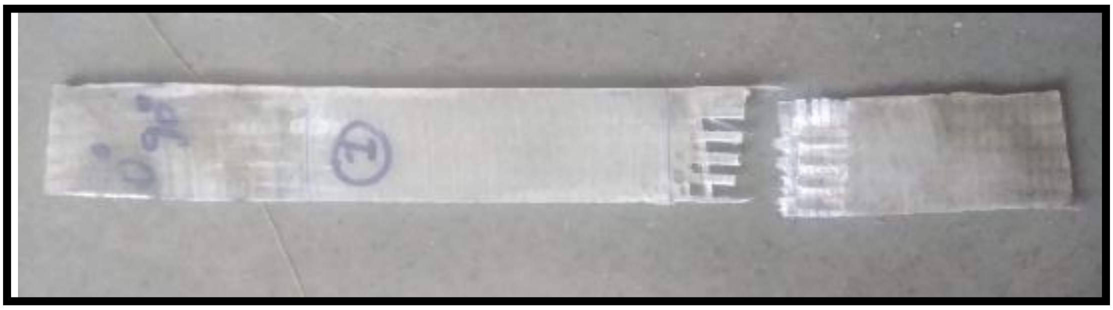


Figure 17. 0°90° fatigue test

The fig. 17 is showing the breakage at the end of the specimen. The fiber orientation is 0°90°, Therefore the initial crack and should be on 0°90° angle. Furthermore, it can be concluded that 0°90° have more fiber strength rather than ±45°.Other test specimen is tested and its fiber orientation angle is unidirectional fig.18Generally, Fiberglass have

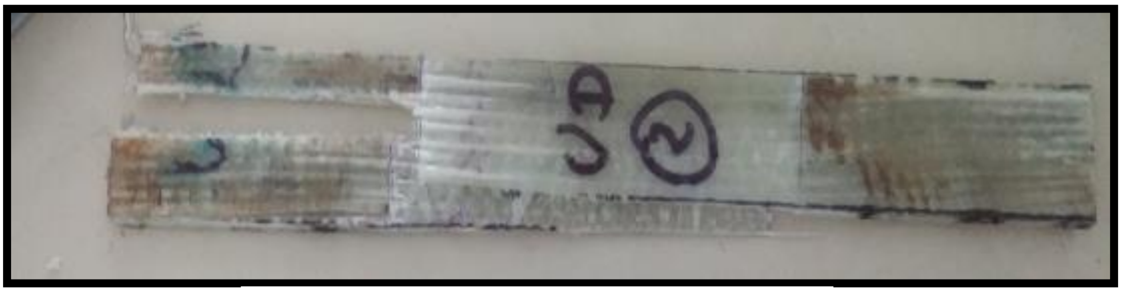


Figure 18. UDfatigue test

strength that is more tensile rather than shear strength. The unidirectional fiber strength are more efficient than other so it will take a more time to break the specimen and measure the fatigue life, for this test specimen 294 kN load and stress is 34 MPa were apply. The result indicate that the UD specimen have more strength and life rather than other orientation fiber sheets.

B. DEGRADATION LIFE

Degradation can be measured when the original crack develops from a cyclic load to a crack or degradation point that measures how long this initial crack and crack growth is able to survive. The initial crack growth time to a final rupture of the specimen may be measured-45 ° 45 °, 0 ° 90 ° and Unidirectional & all time measured for the initial crack growth shows in fig. 19. There are three specimen types tested in the present work and measure the degradation of the composite GFRP board and the measuring time shown in Table 1.

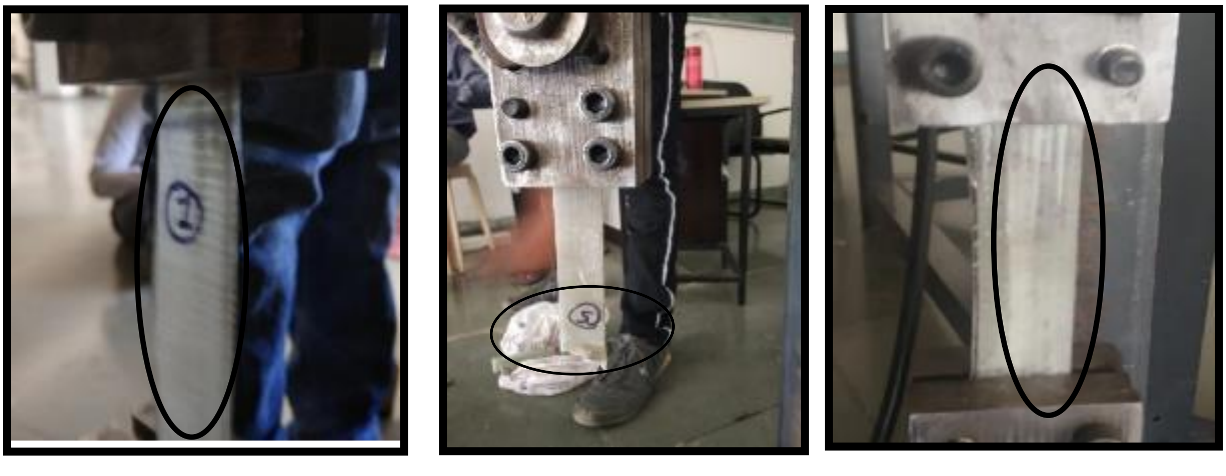


Figure 19. Degraded test specimen

Table 1. Fatigue degraded test data

Sr. No.	Material	Initial crack growth time	Final break time
1	±45°	08:20	09:45
2	0°90°	01:27	04:05
3	UD	12:40	03:30

UD plies may be estimated to have more sustainable energy than other orientation based on measurement of the degraded time and different types of boundary conditions. The UD plies have more than 127 minutes of degradation from experimental performance. From the results of the ANSYS & Experiment, Table 2 shows that the unidirectional sample is fatigue failure before 10^6 cycles, and if it is run after 10^6, it is called a cycle number that is infinite.

Table 2. Validation of Analytical and experimental

Sr. no	Numerical	Experimental	% of Errors
Total deformation (d)	0.50124	0.55785	10.14%
Life (time)	$2.0E+^{06}$	2.20E+6	8.97%
Damage (time)	1000.55	1168.5	14.37%

C. FOLLOWING LIST INDICATE THE PROBABLE SOURCES OF ERROR DURING EXPERIMENTAL MEASUREMENT

1) Lack of accuracy in development of experimental setup.
2) Instrumental errors.
3) Due to vibration generated during operating condition.
4) Due to friction of belt and pulley contact.
5) Due to fluctuation speed during operation.
6) Due to variation in test specimen thickness because of manual preparation.

VIII. CONCLUSION

- The GFRP sheet has been developed successfully by combining different materials and hand-laying methods.
- For making GFRP, specimen different types of techniques are use and different weight fraction and fiber fraction measure.
- Manual techniques for the production of GFRP specimen with appropriate dimensions are better suited among a variety of processes.
- Three types of oriented fibers with a difference in weight and fibre fraction are presently developed in this work, which is ±45 °, 0 °, 90 °and Unidirectional.
- The mechanical characterisation of GFRP increases the amount of reinforcement and increases the hardness and tensile strength.
- It can also be concluded from this work that Unidirectional has greater strength than other -±45 °, 0 ° 90 ° and that degraded crack growth in the unidirectional plating is more likely to sustain the crack before the whole specimen is fractured.
- It can also be concluded from this work that Unidirectional has greater strength than other -±45 °, 0 ° 90 ° and that degraded crack growth in the unidirectional plating is more likely to sustain the crack before the whole specimen is fractured.
- The experimental setup is easier for the experimental measurement of fatigue, and then another type of testing machine can be easily carried out and transferred.

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