The paper presents a study of the fatigue failure behavior of unidirectional angle ply composite laminate. Today a lot of research is directed to understand the fatigue failure behavior of laminated composites. These materials usage is increasing in all sorts of engineering applications due to high specific strength and stiffness, low weight and corrosion resistance. Fibre reinforced composite materials are selected for weight critical applications, due to good rating as per the fatigue failure is concerned and these materials are anisotropic in nature. The failure behavior made the study of these materials complicated. Present research work is aimed at designing a suitable test-rig which is capable of generating data related to dynamic failure behavior of laminated composite specimens. The valuable data generated from the test rig is logged and analyzed for, further investigation, to understand the failure behavior of laminated composites of glass polyester subjected to cyclic loading.

**Keywords:** FRP, Load cell, Eccentric mechanism, Flexural Fatigue, Stiffness degradation

**INTRODUCTION**

The standard fatigue testing equipments are very expensive. In this scenario the need for the indigenous test-rig fabrication arises. The authors of this paper are interested to analyze the fatigue failure behavior of composite laminates, for this flexural fatigue test rig is designed and fabricated.

Design of wind turbine blades, aeroplane wings, boat hulls, must consider to prediction of stiffness, static strength under overload conditions, dynamic response and fatigue lifetime under the anticipated loading spectrum. The turbine blade design is based on a material database combined with appropriate structural and structural dynamic analysis and lifetime prediction methodology.

In NASA contractor’s report, James H Williams, flexural fatigue experimentation on graphite epoxy laminates is reported (NREL/SR-500-24379). This report discusses the effect of
manufacturing, processes, parameters, on stiffness reduction profiles, the specifications of the test coupons to be subjected flexural fatigue analysis and discusses the Mechanical characterizations of flexural fatigue.

Mahmood et al. (2006) is reported, that the accumulated fatigue damage model was presented and applied based on CLT. That employs stiffness degradation as a single measure of damage estimation. Several checks were carried out on the model in order to assure proper simulation of the damage progress. All load cases are identified, calculated and evaluated and negligible cases are ignored. The fatigue damage progress in a wind turbine composite blade. Considering the conservative nature of the employed technique, the investigated blade will have 18.66 years in the worse situation and 24 years in the best situation.

James H Williams et al. (1982) is reported that the study was conducted in a pendulum type repeated impact apparatus especially designed and fabricated for determining single and repeated impact strengths. A well-defined impact fatigue (S–N) behavior, having a progressive endurance below the threshold single cycle impact fracture stress with decreasing applied stress has been reported. Fractographic analysis revealed fracture by primary debonding having fibre breakage and pullout at the tensile zone, but a shear fracture of fiber bundles at the compressive zone of the specimen is reported by the fatigue process of mechanical components under service loading is stochastic in nature. The prediction of time-dependent fatigue reliability is critical for the design and maintenance planning of many structural components. Despite extensive progress made in the past decades, life prediction and reliability evaluation is still a challenging problem reported by Sankaran Mahadevan and Rita Roy et al. (2001) reported that the vast majority of fatigue loading experiments are constant amplitude tests, although this type of fatigue loading is hardly present in real in-service fatigue loading conditions. The present experimental work is focusing on flexural fatigue analysis of 73 volume fraction glass fiber loaded test coupons, as this grade of fiber loading is generally achieved in filament wound products. The following sections briefly discusses about the design of the test rig and also discusses the method of data processing and interpreting the data by presenting the data in the form of stiffness degradation curves are reported by Mr. W Van Paepegem, J Degrieck (2001); Philip D Clausenb, 2005.

**DESIGN OF EXPERIMENTAL SET-UP**

The present work is aimed at establishing a standard test procedure for analyzing and understanding the flexural fatigue failure behavior of composite laminates. Composite materials’ failure behavior is very complex from the conventional isotropic materials due to the influence of matrix interfacial relations and the polymer matrix fracture behavior. Considering the above mentioned factors, the test-rig is designed, and continuously monitor the health of the laminate throughout the test. The capability of the test-rig critically depends on the dynamic load sensing transducer and data logging system. This work provides an approach to the design and fabrication methodology of dynamic load transducer and the data logging system development.

This explicit paper publishes the details of design and calibration process of load transducer and software interfacing aspects of the test rig.
with the computer. The data generated from the test rig’s data logger could be analyzed to predict fatigue life characteristics of composite laminates. These are the following Figures 1 and 2 furnished below represents the proposed model, the schematic representation of the test rig and real-time test rig.

**Eccentric Mechanism**

The eccentric mechanism is a system mounted on the circular disc to convert the rotary motion into translator motion. This enables the specimen to receive evenly distributed compressive and tensile loads. One end cover holding the load cell is fixed to the eccentric mechanism.

**Dynamic Load Sensor Design and Fabrication**

The selection of the correct load transducer is followed by the following steps:

1. Material selection.
2. Proposing geometric models of high sensitive and medium sensitive.

**Material Selection for the Load Cell Body Fabrication**

The material selection is based on the elastic property that is young’s modulus. This should be capable of providing sufficient elastic strain for a given load application range. As per the present load application range of 0-1000 N the material selected for this application is an aluminum alloy of Young’s modulus 70 GPA. The S-N curves of the aluminum alloy were considered during the design of the load cell body. The load cell body is
manufactured to meet the functional requirement of the experimental work.

**Signal Conditioning System**

Signal conditioning system is a simple amplification circuitry where a signal in mV coming from the load cell is amplified to a ratio of 1:100 and displayed on the digital output provided on the system panel. The circuit is so arranged that the signal from the load cell in mille volts is amplified in to volts.

**Data Logger**

Dynamic load sensing is a mechanism, which senses the fluctuating loads with respect to time. A Load cell (Strain gauge type) is a transducer, which senses the varying loads and changes its dimensions proportional to stress. The Strain gauge is incorporated in the bridge circuit and change in its resistance due to strain will unbalance the bridge. This unbalance voltage is amplified by instrumentation amplifier.

A Real time application of dynamic load sensing which convert the analog voltage from Instrumentation amplifier to data acquisition system (i.e., 6009 NI). This digital signal is fed to computer USB.

**EXPERIMENTATION**

The present work is aimed at establishing a standard test procedure for analyzing and understanding the flexural fatigue failure behaviour of composite laminates. Composite materials' failure behaviour is very complex when compared to the conventional isotropic materials due to the influence of matrix-reinforcement interfacial relations and the polymer matrix fracture behavior. Considering the above mentioned factors, the test-rig is designed to continuously monitor the health of the laminate throughout the test. The capability of the test-rig critically depends on the dynamic load sensing transducer and data logging system. This work provides an approach to the design and fabrication methodology of dynamic load transducer and the data logging system development.
This explicit paper publishes the details of design and calibration process of load transducer and software development for the interfacing aspects of the test rig with the computer. The data generated from the test rig’s data logger could be analyzed to predict fatigue life characteristics of composite laminates.

The sensing element which is an Electrical type Load cell senses the strain. The Strain gauge is glued to the Load cell. The Resistance of the strain gauge is 350 ohms under unstrained conditions. This strain gauge is incorporated in the Bridge circuit, whose other three arms are standard 350 ohms resistors. This Bridge is excited by 10 V DC supply. Under no load condition, i.e., when strain gauge is not strained the bridge is under balanced condition. When load is applied on the load cell, the dimensions of strain gauge gets changed thereby its resistance is varied. The amount of strain applied on the load cell proportionally changes the resistance of the strain gauge. This change in resistance causes the bridge to unbalance. This unbalanced voltage is proportional to the load applied on the specimen.

The unbalanced voltage from bridge is of low magnitude which is very hard to sense is fed to Instrumentation amplifier. The advantage of Instrumentation amplifier over a general amplifier is that they eliminate offset voltages from the signal voltage. A general Instrumental amplifier amplifies both signal and offset voltages whereas Instrumentation amplifier nullifies the offset and amplifies the signal alone. The amplified signal will be corrupted by the power line pickups (i.e., 50 Hz) and other electromagnetic interferences. These noise is filtered by a low pass filter whose higher cutoff frequency less than 50 Hz. The filtered signal is an analog signal and it is to be converted.

Preparation of Composite Laminate by Compression Moulding Technique
Glass fiber material consisting of extremely thin fibers about 0.005-0.010 mm in diameter. The Unidirectional fibers are available in the standard form of 600 GSM. Unidirectional fibers are cut to the required size and shape and these are stacked layer by layer of about 4 layers to attain the thickness of 5 mm as per the ASTM D 3039 Standard Specimen. Bonding agent (Polyester) is applied to create bonding between 4 layers of sheet. Polyester is a copolymer; and, it is formed from two different chemicals. These are referred to as the “resin” and the hardener”. The resin consists of monomers or short chain polymers. The process of polymerization is called “curing”, and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours. In this work the composite laminate is prepared using compression moulding technique. Here four plies of E-glass fiber are taken in a symmetric manner i.e. (+90°, -90°, -90°, + 90°) one over the other and Polyester resin is used as an adhesive. The size of the mould taken is 30 × 30 cm.

1. Type of resin : Polyester
2. No of plies : 4
3. Type of Fiber : E-Glass Unidirectional (UD) Fiber
4. Hardener : MEKP (Methyl Ethyl Ketone Peroxide)
5. Nature of Laminate : Symmetric
6. Method of preparation: Compression mould Technique Initially the glass fiber is to be cut in required shape of the size 30 × 30 cm of required orientation. Two plies of positive orientation (anti-
clockwise) and other two in negative orientation (clockwise) are to be prepared. A thin plastic sheet is used at the top and bottom of the mould in order to get good surface finish for the laminate. The mould has to be cleaned well after that Poly Vinyl Acetate (PVA) is applied in order to avoid sticking of the laminate to the mould after curing of the laminate.

Then a ply of positive orientation is taken and placed over the sheet. Sufficient amount of resin which is prepared before (hardener of quantity 10% of the resin is to be mixed with the resin and get stirred well) poured over the ply. The resin poured in to the mould uniformly and it is rolled in order to get the required bonding using a rolling device. Enough care should be taken to avoid the air bubbles formed during rolling. Then on this ply, other ply of negative orientation (clock wise) is placed, after this, other two plies are placed and rolling is done. After the rolling of all plies, the covering sheet (plastic sheet) is placed and the mould is closed with the upper plate. The compression is applied on the fiber-resin mixture by tightening the two mould plates uniformly. Enough care should be taken to provide uniform pressure on the laminate while fixing plates. After enough curing time (4-5 h) the laminate is removed from the mould plates carefully.
Preparation of Specimen for the Tensile Test

After preparing the laminate, in order to find the ultimate tensile strength of the composite laminate conduct the tensile test with UTM, and the specimen is prepared using ASTM standards D3039. The specimen is prepared in dog-bone shape which has a gauge length of 150 mm. The specimens prepared are now tested on the UTM machine and the ultimate tensile strength of the each specimen is determined. As there is a difference in their orientation, each specimen exhibits a definite behaviour during failure.

Flexural Fatigue Analysis

The specimen is fixed vertically to a rigid platform as shown in Figure 8. The dynamic load sensor is fixed to the specimen through a hinge as represented in the schematic diagram as shown in Figure 1. The real time assembly is furnished in the Figure 2. The dynamic load sensor’s other end is assembled to the eccentric mechanism pivot. The eccentricity is provided based on the deflection load calculations made from the experimental results; on rotating the eccentric mechanism a complete symmetrical reversible bending about the neutral axis of the laminate is induced. The deflection force is measured from the signal conditioning system digital display. The induced load is estimated in view of providing bending stress on the laminate, the stresses were kept 50% below the yield strength of the individual laminates. The bending loads are estimated from the tensile test results of the respective laminates [±0°], [±20°], [±30°], [±40°], [±45°], [±55°], [±65°], [±75°] and [±90°], the frequency of cyclic loading is of 1.93 Hz. As the eccentric mechanism is rotating the bending load is measured in the indirect from of voltage generated from the dynamic load sensor. The NI6009 data lager with 8 channel analog and digital signal receiving capability has been used to log the data generated from the load sensor the voltage generated from the load sensor is conditioned by a signal condition system and then the analog output from the signal condition systems is fed through the date logger to PC. The LABVIEW software provided by National Instruments’ is used to log the data in the form of time versus voltage. As the cyclic loading is applied on specimen is converted in the form of a perfect sinusoidal voltage wave form is stored in the PC in the LABVIEW file format. As the test
is continuously performed on the specimen the continuous data points of voltage and time are stored in the PC.

The LABVIEW software has the provision of collection of snapshot for a period of 3.33 s. And then there is a provision of exporting the data into EXCEL format in the form of time versus voltage data points. Number of such snap shots in regular intervals of one snap shot for 5 min are taken and exported to EXCEL file format, from the beginning of the test to end of the test.

The test is stopped when the residual stiffness of the laminates is almost constant after number of cycles of fatigue loading. It has been observed from the test that the stiffness of the test coupon is continuously degrading due to the failure of the top and bottom layers because of cyclic loading. Once the top and bottom layers of laminate are damaged, the continuous redistribution of stresses lead to the prevention of further damage due to pivoting effect occurrence in the laminate. Once this state is reached further reduction in stiffens observed is almost zero.

Data Processing
To understand the flexural fatigue failure behavior of the laminate, the data collected in the EXCEL format (files) are further processed to understand the flexural fatigue failure phenomena of the laminate. As there are so many constraints in the electronic equipment functional behavior such as “creeping “ of strain gauge resister’s resistance and overheating of the signal condition system’s electronic circuits, over a period of time lead to a faulty data generation. In view of filtering this faulty data a dynamic calibration technique has been followed during processing the data that is the default offset voltage generated by the signal conditioning system has been subtracted from each snapshot data to arrive at realistic response from the test specimen. The peak of the sinusoidal wave form has been considered and the voltage generated is proportional to the deflection load falling on the specimen, then from each snapshot one data point is collected from the beginning of sinusoidal wave form from each snap shot data, then from all these points voltage versus time curve is obtained by plotting all these data points. As the voltage is proportional to the load falling on the specimen, the voltage has been converted into load in Newton’s and plotted in the form of load verses time which is representing the residuals stiffness of the laminate instantaneously corresponding to the time, then this curve once again converted onto load versus number of cycles by converting time into number of cycles by multiplying with this frequency of cyclic load application.

Specifications of the Flexural Fatigue Specimen
Flexural fatigue specimens are made with specifications mentioned in Van Paepegem and J Degrieck (2001). Flexural fatigue specimens are moulded in compression. With reference to the NASA report the thickness of the specimen is 2.5 mm and 35 mm width, the effective length is 50 mm. In the present experimental work in view of accommodating the specimen with the custom-built flexural fatigue test rig., the effective length is increased to 100 mm, in the same proportion the thickness and width was considered to 5 mm and 30 mm, respectively.

Estimation of Bending Load to be Simulated for Conducting Flexural Fatigue Analysis
The basic definition of high cyclic fatigue, the stresses induced cyclic loading should be well
below the 50% of the ultimate tensile stresses (strength) of the specimen subjected to fatigue loading. The present work is focusing on flexural fatigue analysis of glass polyester balanced symmetric laminates. In view of simulating such stresses the following calculations provides the estimation of bending loads to be simulated on specimens.

Let $M = \text{Bending Moment} = W \cdot L$ (Where $W$ is the bending load and $L$ is the effective length of the specimen) $f_b = \text{Bending Stresses}$

And $I = \text{Moment of Inertia of the specimen} = \frac{b \cdot t^3}{12}$, where $b$ is the width of the specimen and $t$ is the thickness of the specimen.

The load to be simulated is estimated from classical bending beam equation, i.e., $M/I = f_b/Y$, Where $f$ is the bending stresses to be simulated as per the definitions of high cyclic fatigue loading. And $'Y'$ is the half the thickness of the specimen.

The bending load could be estimated by the following formula, $W = \frac{f_b}{I/Y}$.

**Criterion for Conducting Flexural Fatigue Test**

The specimen of 100 mm long 30 mm width and 5 mm thick is subjected to flexural fatigue test. The flexing load is to be applied on the specimen is considered from the tensile test results conducted on the specimens prepared from the same laminate used for the fatigue test. The maximum tensile strength is the basis for the bending load to be applied on the specimen and it is arrived from the calculations based on bending equation such that the stresses due to bending are equivalent to 50% of the stresses of maximum tensile strength of the material.

**Numerical Modeling of Stiffness Degradation Curve**

As the flexural fatigue failure behavior of laminates exhibiting stiffness decay with respect to number of cycles of load application. In the present work making use of Origin Lab software, curve fitting tool room, exponential decay, first order curves were fitted to the experimental data in order to understand the failure behaviour by numerically modeling them.

The curves from Figure 11, 13, 15, 17, 19, 21, 23, 25 and 27 exhibit the stiffness degradation behaviour of $[\pm0^\circ]$, $[\pm10^\circ]$, $[\pm20^\circ]$, $[\pm30^\circ]$, $[\pm40^\circ]$, $[\pm45^\circ]$, $[\pm55^\circ]$, $[\pm65^\circ]$, $[\pm75^\circ]$, $[\pm90^\circ]$ of angle ply laminates made of glass-polyester.

**Flexural Fatigue Failure Behavior of Glass Polyester Composite Laminate**

a) at $0^\circ$ Orientations

![Figure 10: $0^\circ$ Orientation Specimen After Flexural Fatigue Test](image)

![Figure 11: Stiffness Degradation Behaviour of $[\pm0^\circ]$ Orientation of Angle Ply Composite Laminate](image)
b) at 10° Orientations

Figure 12: 10° Orientation Specimen After Flexural Fatigue Test

Figure 13: Stiffness Degradation Behavior of [±10]° Orientation of Angle Ply Composite Laminate

Equation\(\; y = A_1 \exp(-x/t_1) + y_0 \)

\begin{align*}
\text{Bending Load in N} & \\
\text{No. of cycles (sec)} & \\
\text{R}^2 & = 0.96485 \\
\text{Value Standard Error} & \\
\text{Bending Load} & \\
\text{y0} & = 4.72857 \pm 0.72472 \\
\text{A1} & = 61.15746 \pm 1.68565 \\
t_1 & = 6142.4187 \pm 363.31904 \\
\end{align*}

d) at 30° Orientations

Figure 16: 30° Orientation Specimen After Flexural Fatigue Test

Figure 17: Stiffness Degradation Behavior of [±30]° Orientation of Angle Ply Composite Laminate

Equation\(\; y = A_1 \exp(-x/t_1) + y_0 \)

\begin{align*}
\text{Bending Load in N} & \\
\text{No. of cycles (sec)} & \\
\text{R}^2 & = 0.82197 \\
\text{Value Standard Error} & \\
\text{Bending Load} & \\
\text{y0} & = 19.297 \pm 0.31159 \\
\text{A1} & = 38.166 \pm 2.38045 \\
t_1 & = 700.72 \pm 90.33109 \\
\end{align*}

c) at 20° Orientations

Figure 14: 20° Orientation Specimen After Flexural Fatigue Test

Figure 15: Stiffness Degradation Behavior of [±20]° Orientation of Angle Ply Composite Laminate

Equation\(\; y = A_1 \exp(-x/t_1) + y_0 \)

\begin{align*}
\text{Bending Load in N} & \\
\text{No. of cycles (sec)} & \\
\text{R}^2 & = 0.73698 \\
\text{Value Standard Error} & \\
\text{Bending Load} & \\
\text{y0} & = 22.41181 \pm 0.6052 \\
\text{A1} & = 15.25566 \pm 1.02931 \\
t_1 & = 11520.74 \pm 409192.1921.9365 \\
\end{align*}

e) at 40° Orientations

Figure 18: 40° Orientation Specimen After Flexural Fatigue Test

Figure 19: Stiffness Degradation Behavior of [±40]° Orientation of Angle Ply Composite Laminate

Equation\(\; y = A_1 \exp(-x/t_1) + y_0 \)

\begin{align*}
\text{Bending Load in N} & \\
\text{No. of cycles (sec)} & \\
\text{R}^2 & = 0.63759 \\
\text{Value Standard Error} & \\
\text{Bending Load} & \\
\text{y0} & = 38.166 \pm 2.38045 \\
\text{A1} & = 700.72 \pm 90.33109 \\
t_1 & = 11520.74 \pm 409192.1921.9365 \\
\end{align*}
f) at 45° Orientations

Figure 20: 45° Orientation Specimen After Flexural Fatigue Test

Figure 21: Stiffness Degradation Behavior of [±45]° Orientation of Angle Ply Composite Laminate

\[ y = A_1 \cdot \exp\left(-\frac{x}{t_1}\right) + y_0 \]

Adj. R-Square = 0.88821

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
<th>Standard Error</th>
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</thead>
<tbody>
<tr>
<td>(y_0)</td>
<td>27.81912</td>
<td>0.23899</td>
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<td>(A_1)</td>
<td>21.2616</td>
<td>1.20285</td>
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<td>(t_1)</td>
<td>2266.320</td>
<td>223.83705</td>
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g) at 50° Orientations

Figure 22: 50° Orientation Specimen After Flexural Fatigue Test

Figure 23: Stiffness Degradation Behavior of [±50]° Orientation of Angle Ply Composite Laminate

\[ y = A_1 \cdot \exp\left(-\frac{x}{t_1}\right) + y_0 \]

Adj. R-Square = 0.89521

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<th>Parameter</th>
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<tr>
<td>(y_0)</td>
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<td>(A_1)</td>
<td>15.7853</td>
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<td>(t_1)</td>
<td>3310.9153</td>
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h) at 55° Orientations

Figure 24: 55° Orientation Specimen After Flexural Fatigue Test

Figure 25: Stiffness Degradation Behavior of [±90]° Orientation of Angle Ply Composite Laminate

\[ y = A_1 \cdot \exp\left(-\frac{x}{t_1}\right) + y_0 \]

Adj. R-Square = 0.81104

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<tr>
<td>(y_0)</td>
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<td>(A_1)</td>
<td>35.4869</td>
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<td>(t_1)</td>
<td>991.152</td>
<td>60.61375</td>
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i) at 65° Orientations

Figure 26: 65° Orientation Specimen After Flexural Fatigue Test

Figure 27: Stiffness Degradation Behavior of [±65]° Orientation of Angle Ply Composite Laminate

\[ y = A_1 \cdot \exp\left(-\frac{x}{t_1}\right) + y_0 \]

Adj. R-Square = 0.88902

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<td>(y_0)</td>
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<td>(A_1)</td>
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<td>(t_1)</td>
<td>2810.152</td>
<td>223.83705</td>
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RESULTS AND DISCUSSION

In the author’s point of view flexural fatigue occurrence is very common in most of the fibre reinforced components like leaf spring, wind turbine blades, aeroplane wings, boat hulls, and even most of the automotive components. Hence, this aspect has been considered as a critical property to be investigated. In the literature the information regarding flexural fatigue aspects of laminated composites is very limited and there is no standardized testing procedure available, very few researchers like Van Paepegem published few papers on flexural fatigue aspects of laminated composites made of glass epoxy. He carried out experiments on cross ply laminates and published result regarding the flexural fatigue failure behavior. In the present work the custom built flexural fatigue test rig is designed and fabricated to perform flexural fatigue experiments on laminates of $[\pm 10^0]$, $[\pm 10^0]$, $[\pm 20^0]$ $[\pm 30^0]$ $[\pm 40^0]$ $[\pm 45^0]$ $[\pm 55^0]$ $[\pm 65^0]$ $[\pm 75^0]$ and $[\pm 90^0]$ angle ply balanced symmetric laminates made of glass polyester at constant amplitude at a frequency of 1.93 RPS at 50% stress ratio, in view of choosing best orientation sequence for critical applications.

CONCLUSION

The stiffness degradation curves established from the data generated by the test rig clearly exhibits that the stiffness reduction rate is very high during first few fatigue cycles. Then the specimen attains pivoting state where in the top and bottom layers of the specimen were damaged and then due to continuous redistribution of bending stresses further damage to the laminate in the subsequent layers is prevented. The curves fitted to the experimental data are having the exponential decay nature. The test result yielded for $\pm 45^0$ is

\[ y = A1 \times \exp(-x/t1) + y0 \]

Adj. R-Squared: 0.98063

<table>
<thead>
<tr>
<th>Bending Load in N</th>
<th>Value</th>
<th>Standard Error</th>
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</thead>
<tbody>
<tr>
<td>$y0$</td>
<td>11.2915</td>
<td>0.12996</td>
</tr>
<tr>
<td>$A1$</td>
<td>39.9980</td>
<td>0.85218</td>
</tr>
<tr>
<td>$t1$</td>
<td>1089.48</td>
<td>23.35981</td>
</tr>
</tbody>
</table>

Equation

\[ y = A1 \times \exp(-x/t1) + y0 \]
best orientation of tacking for flexural fatigue for critical applications. Since the data is plotted between bending load in Newton versus number of fatigue cycles in the constant amplitude flexural fatigue test, the curve can also be treated as stiffness versus number of cycles.

REFERENCES


