TuijinJishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No.4 (2023)

Enhancing GFRP Laminate Strength with MWCNT Modification: Fatigue Behavior Analysis with SEM outcomes

[1]Sai Prasanna Kumar J.V., [2]Boopathy G, S.Suthagar[3], N. Ramanan[4], Jegadeeswaran N[5]

[1,2,3]Department of Aeronautical Engineering, Vel Tech Rangarajan Dr. Sagunthala R & D Institute of Science and Technology, Chennai.

[4]Assistant Professor, Department of Mechanical Engineering, Sri Jayaram Institute of Engineering and Technology Chennai,

[5]School of Mechanical Engineering, REVA University, Bangalore, India

Abstract

Thermoset resins are widely recognized for their inherent brittleness. To mitigate this issue, certain filler materials are commonly employed to enhance their strength. In this study, we sought to disperse multiwalled carbon nanotubes with a purity of 99.99% into thermoset resin and evaluate the fatigue life of the resulting samples under tension-tension mode at varying stress levels. All samples were manufactured using both modified and unmodified thermoset resin, reinforced with 250 GSM of stitched woven rovings fabric, and machined as a cross ply with 7 layers. To determine whether the samples met reliability criteria, a two-parameter Weibull distribution was employed to model the life data. Starting from the null hypothesis, the suitability of the distribution for the fatigue data was validated using the Kolmogorov-Smirnov goodness-of-fit test. The analysis revealed that the fitted distribution fell within an acceptable range, and the hypothesis was accepted with a significance level of 0.05%. Furthermore, a comparison between the unmodified and modified samples, considering various percentages of nanotube distribution, demonstrated that the slope parameter for both types of samples remained within an acceptable range. Consequently, the reliability of the samples was ensured, with the distribution meeting the 0.05% significance level. All specimens were subjected to fatigue testing using a 100 kN fatigue-rated universal testing machine at an ambient condition and a frequency of 3 Hz.

Keywords:*Fatigue life, Multi walled carbon nanotubes, Weibull distribution, slope parameter, goodness-of-fit test.*

Introduction

Composite materials are replacing the traditional materials in almost in all industries. But their heterogeneous nature adversely influences mechanical properties, that too under dynamic conditions, and its reliability must be assessed when the composite components are used in sensitive areas. The reliability of a system can be estimated from failure data using both parametric and non-parametric methods. The later method is used to obtain rough estimates of the reliability characteristics, but the results cannot be estimated. Generally, in the former method, it is desirable to fit the life data to any statisticaldistribution and this will lead to better understanding of the failure mechanism and the results of this model can be extrapolated for its entire life span.

A statistical study was conducted to analyze the scattering of fatigue life data at two different temperatures. The study employed both log normal and Weibull distribution to investigate the impact of two different stress levels.[1] A bi-modal Weibull distribution was applied to design a pressure vessel, with burst strength serving as the design parameter.[2]The fatigue properties of natural fiber in pure tension were examined and compared to woven fiber components.[3] It was discovered that fiber content, interphase properties, and fiber architecture significantly influenced the fatigue properties. The bending fatigue behavior of unidirectional glass fiber hybrid composites was investigated, utilizing a two-parameter Weibull distribution function to study scatter and construct reliability graphs.[4] The acoustic emission parameters of Steel with SAE 1045 were related to the Weibull distribution function under fatigue load.[5] The bending fatigue of Krouse-type nuclear materials was explored, with the study utilizing Minitab to estimate the Weibull parameters for the fatigue life data.[6-8]

Study focused on the tensile strength of tri-component elastic-conductive composite yarn. The researchers investigated the influence of extension rate and gauge length on the tensile strength. They used a modified two-parameter Weibull distribution to model the strength variation and determine Weibull parameters suitable for industrial applications. [9-10] Research implemented the Weibull distribution to determine the probability parameter for laminated cementitious composites. The Weibull distribution proved to be effective in capturing the strength characteristics of the composites.[11] A theoretical model was developed to predict the fatigue limit of unidirectional fiber composites under cyclic loads. The model's predictions exhibited good agreement with data available in the literature, validating its accuracy in estimating fatigue limits.[12] investigation focused on the effect of immersing short fiber polyester composites in seawater for various durations, followed by subjecting them to bending fatigue. The findings revealed that immersion in seawater had an adverse effect on the fatigue life of the composites.[13] The Weibull distribution was employed to predict parameters for fiber-reinforced building materials. The Weibull distribution was found to be a useful tool for predicting the characteristics of these materials.[14]The Weibull distribution was utilized to describe the fatigue life of jute fiber-reinforced polyester composites. The study demonstrated a highly significant statistical correlation between the Weibull parameters and the fatigue life of the composites.[15]

In view of the fore going discussion, a general-purpose thermoset resin was reinforced with 250GSM unidirectional mat was cast into a cross ply laminate having seven layers. The ensuing fatigue failure data in tension- tension mode, was used to construct S-N curves and fit a Weibull distribution to the failure data, thus unknown parameters were estimated. Further the brittle resin was modified with multiwalled carbon nano tubes in various percent and their effects on the Weibull parameters were studied. A validation of the Weibulldistribution was carried out with K-S goodness fit.

2. Theoretical Background

The Weibull distribution is one of the most commonly used distribution in reliability engineering due to its versatility in modelling a variety of failure data. A two-parameterprobability density function of the Weibull distribution is given by

$$f(x)=\frac{\beta}{\alpha}\frac{x}{\alpha}^{\beta-1}\,e^{\frac{-x\beta}{\alpha}} \qquad (1)$$

In this present work α is the scale parameter and β is the shape parameter while x is the variable denoting the number of cycles to failure of the Weibull distribution. Integrating the probability density function to obtain the probability of failure

$$P_f = 1- e\frac{-x\beta}{\alpha} \qquad (2)$$

The reliability of the function can be thought as the designated survivor over a specific time period, and the probability of survival is given by

$$P_s = e\frac{-x\beta}{\alpha}(3)$$

Taking the logarithm on both sidesto obtain the scale parameter and shape parameter α and β respectively.

$$Ln(Ln(\frac{1}{1-Pf})) = \beta\ ln(x)- \beta Ln(\alpha) \quad (4)$$

One can observe that eq 4 has a linear relationship between both the terms of the equation. The slope of the line fit between the quantities will yield the shape and scale parameters. The survival of the sample over each cycle of failure at a given stress level is given by

P_s= 1- ($\frac{i-0.3}{n+0.4}$) (5)

In which n is the number of samples and i is the order of the failure data. There are several methods to estimate the shape and scale parameters of which the simplest is the least squares method, maximum likelihood method and the method of matching moments. Weibull paper wasdeveloped basing the relationship given equation 4. In this current work all three methods are used to obtain the parameter from the failure data.

2.1. Least squares method

From the equation 4, takes the form of a straight line

Y= a + bX (6)

While the two constants a and b can be obtained as

b =N $\frac{\sum_{i=1}^{N} Xi\, Yi - \sum_{i=1}^{N} Xi \sum_{i=1}^{N} Yi}{N \sum_{i=1}^{N} X^2 - (\sum_{i=1}^{N} x)^2}$ (7)

and a = $\bar{y}$ - b$\bar{x}$ (8)

where

$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} Yi$ and $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} Xi$

The variable yi = ln (ln ($\frac{1}{1-MR}$) and median ranks are used to evaluate this variable.

x_i = ln x_i and $x_i$is the i^{th} time to failure

From the analysis it can be observed that the shape parameter is given by

b=β (9)

and α = $e^{\frac{-\alpha}{\beta}}$(10)

Further to determine whether the Weibull probability density function represents the data acceptably well and when the parameters are determined with least squares method it is desirable to establish a goodness of fit by studying the relative value of the correlation coefficient.

2.2 Maximum Likelihood Method

Again, starting from equation 4 and assuming that if the failure is terminated after N units and at r^{th} failure and

$x_1 \leq x_2 \leq x_3 \leq \ldots\ldots \leq x_{rj}$(11)

Then the likelihood function can be written as

L(β, α) = f (x_1, x_2, ……x_r)

= $\frac{N!}{(N-r)!}$ ($\prod_{i=1}^{r} f(xi)$[1-F (x_r)]$^{N-r}$(12)

L(β, α) = $\frac{N!}{(N-r)!}\frac{\beta^r}{\alpha^r}$ [$\prod_{i=1}^{r} x_i^{\beta-1}$] exp [-$\frac{1}{\alpha\beta}$ ($\sum_{i=1}^{r} x_i^{\beta}$ +(N-r)x_r^{β})] (13)

Taking natural logarithm on both sided and partially differentiating with respect to α and β will yield two simultaneous equations and solving those two equations will yield the solutions for α and β.

$\frac{\partial Ln\, L}{\partial \alpha}$ = - $\frac{r\beta}{\alpha}$ + $\frac{\beta}{\alpha^{\beta+1}}$ [$\sum_{i=1}^{r} x_r^{\beta}$ + (N-r) x_r^{β}] = 0 (14)

$\frac{\partial Ln\, L}{\partial \beta}$ = $\frac{r}{\beta}$-r Ln α + $\sum_{i=1}^{r} Lnx_i$(15)

The maximum likelihood estimators (MLE) for β and α for the failure data is the solution to equations 14 and 15. Newton Raphson method or any other numerical method may be employed to determine these parameters.

2.3 Method of Matching Moments

Here the sample moments and the population moments are equated which will yield as many simultaneous equations as there are un parameters to be estimated. Solving the equations simultaneously will yield the sought parameters.

For the Weibull probability density function the mean and the variance can be written as

$$\bar{x} = \alpha\, \Gamma\left(\frac{1}{\beta} + 1\right) \quad (16)$$

$$\sigma_x^2 = \alpha^2 \left[\Gamma\left(\frac{2}{\beta} + 1\right) - \Gamma^2\left(\frac{1}{\beta} + 1\right) \right. \quad (17)$$

Using raw data $\bar{x}$ and σ_x may be calculated further matching the moments will yield

$$\hat{\bar{x}} = \alpha\, \Gamma\left(\frac{1}{\beta} + 1\right) \quad (18)$$

$$\widehat{\sigma_x^2} = \alpha^2 \left[\Gamma\left(\frac{2}{\beta} + 1\right) - \Gamma^2\left(\frac{1}{\beta} + 1\right) \right. \quad (19)$$

The above two equations may be solved to yield the Weibull parameters.

2.4**. Kolomogrov-Smirov Goodness Fit**

In analytical estimation there is a need to test and find whether a given set of data fits the distribution or not. For such tests two hypothesis need, be considered:

1. Data fits well in a specified distribution
2. Data does not fit well in the distribution.

The test procedure involves in computing a statistic based on sample data, followed by comparing it with the critical value. The hypothesis is accepted if the statistic is less than the critical value, or else the hypothesis is rejected. The significance level is the probability of erroneously rejecting the null hypothesis in favour of alternate hypothesis. There are many methods of carrying out the goodness fit. Chi-square goodness fit is a general-purpose test method, it can be administered to both discrete and continuous distributions. A very large sample size is required to obtain correct results. Another test for the continuous distributions is the Kolmogorov-Smirnov or simply K-S test. This method is valid with known parameters and fit can be observed as the maximum difference between expected cumulative distribution at time of failure and that of the cumulative distribution at the time of failure.

$$D_i = |(Q_E(T_i) - Q_o(T_i))| \quad (20)$$

Where $Q_E(T_i) = i/N$,

$$Q(T_i) = 1 - e\wedge\left(-(Ti/\eta)^{\beta}\right) \quad (21)$$

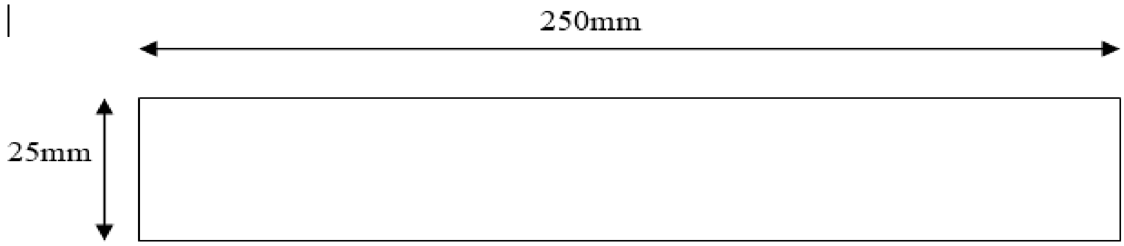
T_i is the variable in terms of the failure data and β, η are the scale and location parameters respectively. The hypothesis is considered accepted if the $D_{cr} > D_i$ at the required significance level. In this present work the K-S test is administered to thetest data and thus the distribution is validated.

3. Sample preparation and Testing

The objective of this present work was to determine the Weibull parameters for glass fiber reinforced polymer under fatigue loading. All raw materials were procured from M/S GO-GREEN COMPOSITES, Avadi, Chennai. A unidirectional glass fiber mat having 250 GSM and the standard general purpose epoxy resin: namely LY566 - Bi8sphneol A and HY951 hardener from Araldite was from M/S Huntsman Chennai, used for this study. ASTM D 3039 standards were used to machine the samples by casting a laminate using hand lay-up technique. Similar method was adopted in casting a laminate after strengthening the polymer resin with multiwalled carbon nano tubes (MWCNT), having 99.99 % purity and was used as received without any further requirement for refinement.

Initially to a known weight of the resin nano tubes were added at 1 and 3 percent by weight. Polymer resin was heatedup to 80 degrees to facilitate the easy dispersion of the multiwalled carbon nano tubes. Both the resin and the nano tubes were sonicated in Sonicator bath which had facility to impart temperature to the polymer rein. The nano composite laminate was cast using a suitable mould with application of poly viny alcohol as the release agents, and this release agents will facilitate the demoulding process. Again, the laminate was machined according to ASTM standards for the tensile test specimen namely D3039. All the samples had the dimensions as: 250 mm x 25mm x 8 mm. End tabs were not attached to the test specimens, but the samples were knurled on the either side to prevent the sipping of specimen at grips, knurling was done for 75 mm length, leaving a gauge length of 100 mm, Figureure 1. The laminate had cross ply conFigureuration with seven layers.The ultimate tensile strength of the samples was determined from 100 kN UTM under ambient conditions: at room temperature and atmospheric pressure, humidity.

Figure. 1 Schematic of the cross-ply cast using ASTM D 3039.



The ultimate stresses of the GFRP were found to be 500 MPa, 650MPa and 700 MPa for the unmodified, GFRP with 1% MWCNT and 3 % MWCNT modification respectively. Two stress levels were chosen as 50 and 70 percent of the ultimate tensile stress for each case. While the normalized stress was varied from 0.6 to 0.85 at each stress levels.

Fatigue testing was carried out for all the samples at constant amplitude of 3 Hz and at R=0.1. Loads were applied on the sample via load actuators as percent on the ultimate tensile stress. All the samples were tested till failure. These fatigue tests were carried out on servo hydraulic Instron at TWI systems Oragadam, Chennai, Figureure2.

Figure. 2. Fatigue rated UTM used for testing the samples at TWI, Chennai

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4. Results and Discussion

The SN curve was generated from the raw dataobtained from testing of the samples. The was applied through the actuators and at constant amplitude. About eighteen samples were tested for each stress levels. All the samples were tested up to failure. The raw data was fit to a distribution using least squares regression method. Further the modified samples were also tested in the similar way and the SN curves were also generated. The repetitive stresses created the damage imitation, expansion and final failure. The failure pattern is similar in the modified samples also. The modified samples paved way for the increase in the fatigue strength. At each stress level three samples were tested and no two samples gave same failure data. Perhaps the reason could be attributed to the fact that these polymer composites are heterogenous in nature and some inherent defects.

The S-N curves are plotted using the power law for various stress levels for a particular ultimate tensile stress. Figureure 2 was plotted for the un modified sample. The maximum and minimum load were calculated using R= 0.1at stress levels ranging from 0.85, 0.8, 0,75, 0. 65, and 0.6 at 3 Hz as the frequency. While the SN curves for the modified samples are shown in Figureures 3,4 & 5 for 0.5 %, 1% and 3 % of MWCNT dispersion to polymer resin. The failure data is presented in the table 1at different stress levels .

Table 1. Number of cycles to failure at different stress levels

Normalized Stress	σ_{UTS} **Unmodified- 500 MPa**		σ_{UTS} **GFRP + 1% MWCNT-600 MPa**		σ_{UTS} **GFRP + 3% MWCNT-700 MPa**	
	σ = 250 MPa	**σ=270 MPa**	**σ= 300 MPa**	**σ = 420 MPa**	**σ= 350 MPa**	**σ=490 MPa**
0.85	5500	4888	7000	4666	12708	10404
0.80	6974	6226	7500	5000	14044	12209
0.75	8578	7624	10000	6666	17154	14913
0.70	10,997	9775	15000	10000	20952	17854
0.65	14,984	13319	18000	11612	24834	19732
0.60	25,899	16666	27000	16129	34544	28282

4.1. S-N Curves

The SN curves are plotted using power law and it can be seen that as the load decreases the number of cycles tend to increases. All the curvese are plotted on two different percenta on the utlimate tensile strength at 50 and 70 cent of the ultimate tensile strength(UTS). The same preceipt is followed for the modified samples also. The UTSfor the un modified sample was 500 MPa while for that of 1 % MWCNT modified samples was 600 and for 3% MWCNT was found to be 700 MPa. The MWCNT enhanced the tensile strength of the samples and it can be sttributed to the fact that the filler materials reduced the brittle nature of the resin and therefore strengfthned the polymer composite on the whole.The SN curves are plotted using power law fit for diffrenet UTS. At each UTS two stress levels are considered namely 50 and 70 percent of the ultimate stress. Further tests were conducted by considerinring the ratio minmum to maxmimum stress as 0.1 which lead to choose the maxmimum ans minimum loads cases .

The unmodified SN curve is shown for two different sttress levels of 250 MPa and 270 Mpa demeonstrated in Figureure 3 and 4 resectively. While Figureure 5 and 6are for the MWCNT modified SN Curve for 300 MPa and 420 MPa respectively. While at 700 MPa the Figureures and 7 shows the Variation of the SN curve for 3 % MWCNT distribution. It can be observed that the R^2 for all the curves vary between 0.90 to 0.97 incading that the importance of the dispersion of the life times and represinting the scatter in testing the samples, its also due hectrogenous nature of the samples.

4.2 Weibull parameters

The failure data is assesed by the two parameter weibull distributionfor the failure data using equation 4 and 5. The failure data for the un modified samples are shown in table 2-4 and for the modified samples shown in table 2. The median rank for a sample size of six can be obtained from the data.

Table 2. Faulure data for un modified sample

Load	**Number of cycles to failure at 500 MPa**		**Median Rank**
	$\sigma = 250\ MPa$ Ln (NF)	$\sigma = 270\ MPa$ Ln (NF)	
0.85	8.615	8.490	10.910
0.80	8.850	8.730	20.444
0.75	9.050	8.940	47.141
0.7	9.305	9.187	57.559
0.65	9.615	9.496	73.556
0.6	10.116	10.010	89.090

Table 3. Failure data for 1 % MWCNT modified sample

Load	**Number of cycles to failure at 600 MPa**		**Median Rank**
	$\sigma = 300\ MPa$ Ln (NF)	$\sigma = 420\ MPa$ Ln (NF)	
0.85	8.850	8.440	10.910
0.80	8.922	8.517	20.444
0.75	9.210	8.800	47.141
0.7	9.615	9.210	57.559
0.65	9.798	9.36	73.556
0.6	10.203	9.688	89.090

Table 4. Failure data for 3 % MWCNT modifiedsample

Load	Number of cycles to failure at 700 MPa		Median Rank
	$\sigma = 350\ MPa$ Ln (NF)	$\sigma = 490\ MPa$ Ln (NF)	
0.85	9.450	9.250	10.910
0.80	9..550	9.410	20.444
0.75	9.750	9.610	47.141

0.7	9.950	9.790	57.559
0.65	10.120	9.890	73.556
0.6	10..450	10.250	89.090

The propability of survival is plotted by using equation 5, and the weibull parameters are estimated by least squares method. The weibull distribution is fit to the failure data.

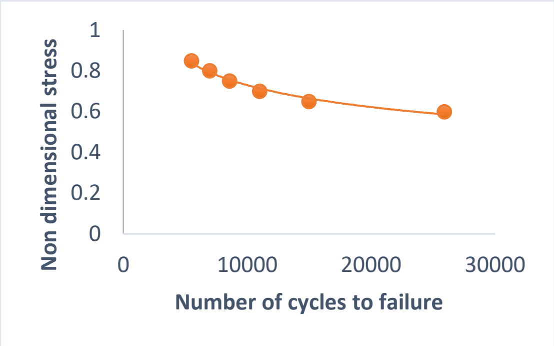

Figure. 3. SN curve for GFRP at 250 MPa

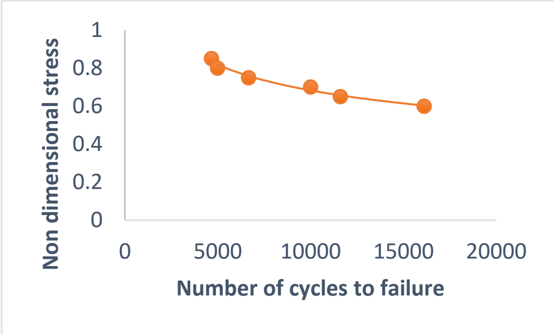

Figure. 6 SN curve for GFRP+ 1 % MWCNT for 420 MPa

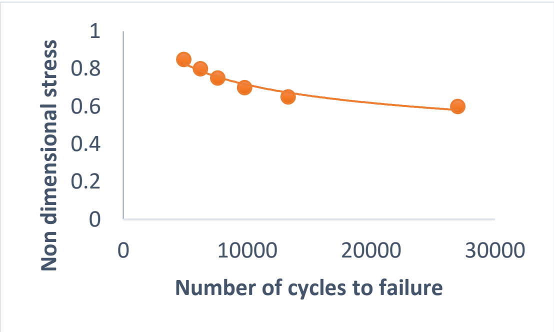

Figure. 4 SN curve for GFRP at 270 MPa

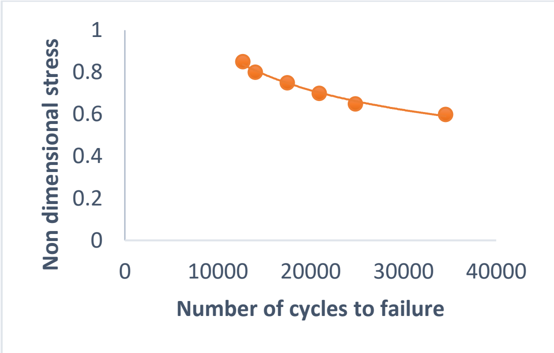

Figure. 7. SN curve for GFRP + 3 % MWCNT at 350 MPa

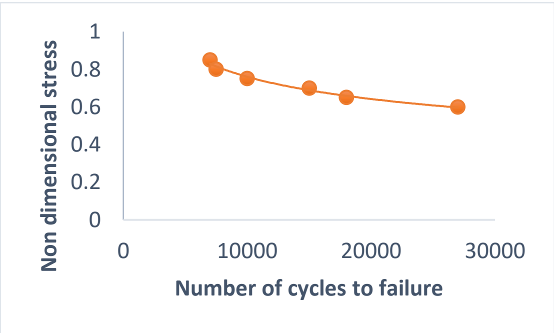

Figure. 5 SN curve FOR GRFP + 1 % MWCNT at 300 MPa.

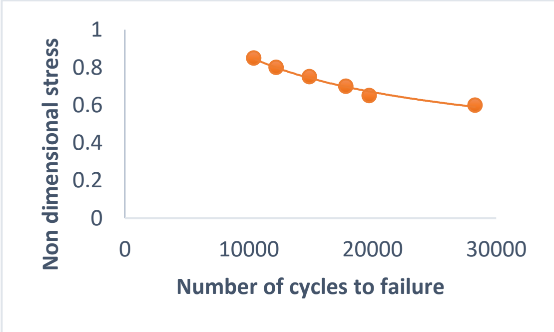

Figure. 8 SN curve for GFRP+ 3 % MWCNT at 490 MPa

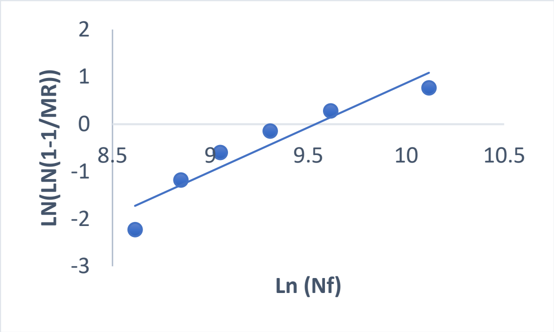

Figure. 9 Weibull fit for fatigue data : GFRP at 250 MPa

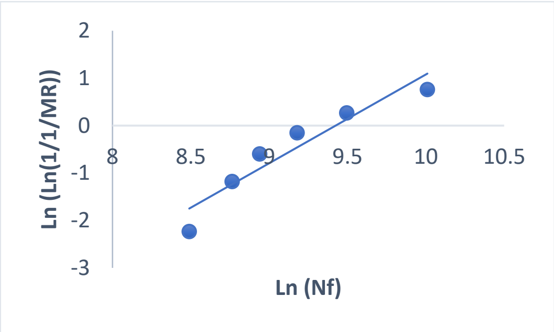

Figure. 10 Weibull fit for fatigue data: GFRP at 270 MPa

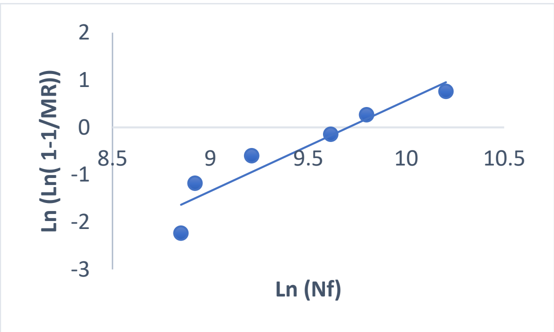

Figure. 11. Weibull fit for fatigue data: GFRP + 1% MWNT at 300 MPa

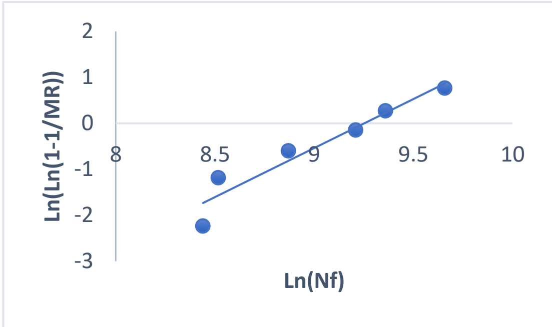

Figure. 12. Weibull fit for fatigue data: GFRP + 1% MWCNT at 420 MPa

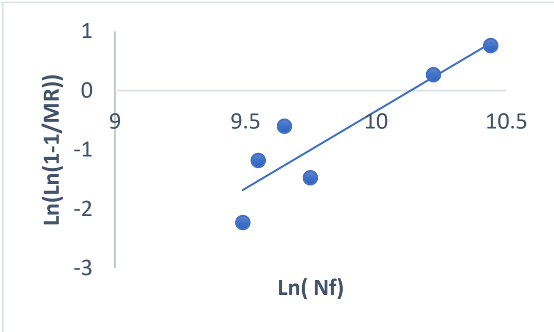

Figure. 13. Weibull fit for fatigue data: GFRP+ 3% MWCNT at 350 MPa

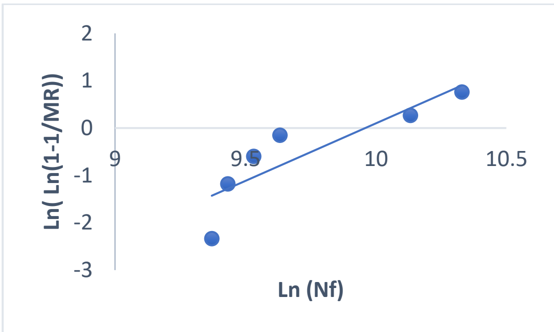

Figure. 14,. Weibull fit for fatigue data: GFRP +3 % MWCNT at 490 MPa

The Weibull distributions are fitted to the failure data using the equations outlined in above sections at different stress levels for both un modified and modified specimens represented by the Figureures 9-14. The values of the slope and the scale parameters are represented in table 5, along with MTTF, other statistics.

Table 5. Weibull parameters at each stress level.

Sample	Stress Levels (MPa)	β	η	R^2	MTBF	Median	Mode

GFRP Unmodified	250	1.8706	19, 148	0.9023	16,999	15690	12736
	270	1.8856	9595	0.9034	8521	7478	6320
GFRP +1% MWCNT	300	1.9118	20743	0.8924	18402	17122	14084
	420	2.056	15367	0.9035	13,612	12858	11120
GFRP +3 % MWCNT	350	2.736	26108	0.9050	23,229	23089	22110
	490	2.895	22359	0.9312	19898	19666	19288

The reliability index, R^2 is more than 0.89 and hence the failure data adequately follows the Weibull distribution, thus making it possible to calculate the slope and the scale parameters by using linear regression. It can also be observed that the values of β are greater than 1, indicating that these samples experience wear out. The shape parameter is a measure of variability of the data, a high value of β implies a low variability. Then this trend should not be cause for worry so long as the its counterpart η is sufficiently high to allow the product to achieve its overall reliability.

Hence its more important to analyse the data rather than solely focus on one value, in other words its sufficient if the product meets the requirements. In our case it's the reliability of the sample and it does. Observing from the table 5, R^2 is varying from 0.89 to0.93 indicating a decent reliability index. The failure data does follow the Weibull distribution.

4.3. Goodness of Fit

There were six samples tested at each stress level but for consistency, three samples were tested at each load case, and at any one stress level its 18 samples and all were tested till failure, none of the tests were suspended. Though the failure data followed the Weibull, Kolmogorov-Smirnov test was conducted, to verify the acceptance of the hypothesis at 0.05 % significance level. The value of the expected outcome was calculated by modifying the expression 21 for two parameter Weibull distribution, the acceptance of the hypothesis at each stress level of the failure data is given in table 6.

Table 6. K-S test of acceptance of the hypothesis at 0.05 significance level

Sample	**Stress Level MPa**	**Max of Absolute Difference**	**D_{cr} at 0.05 significance level**	**D_{cr}>max [Abs difference]**	**Acceptance of hypothesis**
GFRP Unmodified	250	0.310	0.521	0.521>0.310	Accepted
	270	0.2003	0.521	0.521>0.2003	Accepted
GFRP +1 % MWCNT	300	0.318	0.521	0.521.>0.318	Accepted
	420	0.4027	0.521	0.521>0.4027	Accepted
GFRP +3% MWCNT	350	0.415	0.521	0.521>0.415	Accepted
	490	0.4227	0.521	0.521>0.4227	Accepted

The distribution parameters were within the significance level. Only the principal values are indicated in the above table. But these values are calculated at each stress level and against the failure data and only the max absolute difference that can be obtained from the equation 20.

4.4. Effect of Nano Materials and SEM Imaging

One of the most sought-after methods in polymer composites is to introduce the nano, micro sized fillers into the polymer resins and study its effect on the various mechanical properties. In the current study the MWCNT were introduced into the polymer to study its effect on fatigue properties. Definitely the tensile strength improved by 20 % and 40% for 1 % and 3 % of MWCNT infusion. The improvement in the tensile strength can be attributed to the fact that these particles participate in the failure mechanism and acts as the crack arrestors, causing a arduous path for the crack propagate, thus leading to the increase in the values of the tensile loads.

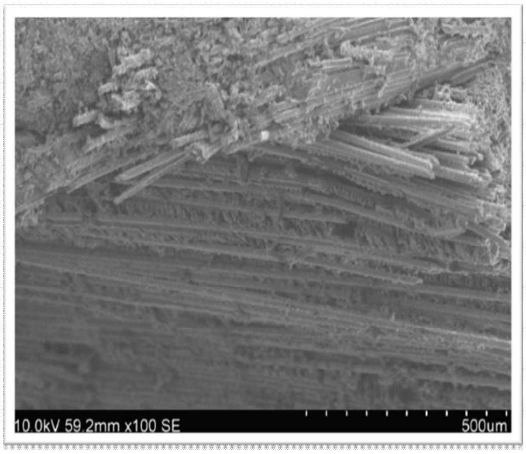

Figure. 15 SEM micrograph of the failed sample

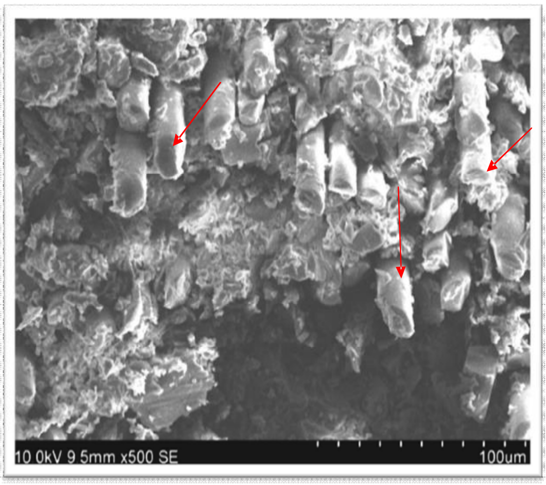

Figure.16 Broken fiber bundles

The broken cross ply sample in Figureure 15, and another characteristic feature of broken fiber stubs in Figureure 16. And the glassy pieces are the matrix cracking, while the nano tubes are very well dispersed in the resin.

5. Conclusions

A GFRP laminate was cast using hand-lay up technique having dimensions of 400 mm x 400 mmx 5 mm the sample had 7 layers and it was a cross-ply. The tensile samples were tested till failure in fatigue rated UTM till failure. The polymer resin was modified with multiwalled carbon nano tubes and its fatigue data was obtained. All failure data were obtained at 50% and 70% of the ultimate tensile strength for all samples.

The ultimate strength of the unmodified sample was found to be 500 MPa while for modified polymer was 600 MPa and 700 MPa at 1 % and 3 % MWCNT dispersion into the polymer resin. The strength of the sample increased by 20 and 40% for 1 % and 3% MWCNT dispersion. This perhaps one reason why the failure data improved at each stress level. The failure data was fit to power law at each stress level to obtain the S-N curve and the failure data also fit toe the Weibull distribution.

The failure data was fit to Weibull distribution and the un known parameters were estimated using least squares regression. The slope parameter was greater than 1 signifying that the samples were failing and at wear out stage, arguably the other parameter η was sufficiently high and thus the reliability of the sample was ensured, from the R^2 values point to the fact that the reliability index is fairly decent and the samples did fit the distribution and were reliable.

Kolomogrov-Smirov goodness of fit was administered to the failure data even though the data set was small, while χ^2 distribution can be used for large data. The K-S statistic was modified to accommodate the two parameters and the from the null hypothesis, the significant value was determined as the absolute difference between the observed and the expected phenomenon. This maximum absolute difference was compared with the critical value and it was found that at all stress levels, the parameters passed the goodness of fit.

Acknowledgements

The author wishes to thank the management to for conducting this work.

Conflict of Interest:

The author states that there weren't any competing interests.

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