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Experimental and Prediction Evaluation of the Flexural behavior of GFRP Laminates

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Abstract: **Fibre reinforced polymer composites are being used replacement material in various applications like marine boats aerospace, military and renewable energy generation because of high strength-to-weight ratios and high corrosion resistance in relation to conventional metal. The reinforcement materials are highly hygroscopic nature and exposed to environment, water molecules travels along the reinforcement and affects the performance of the materials. In the present work an attempt has been made in establishing the investigation procedure to assess influence of moisture absorption coupled with temperature. And to estimate life cycle time of polymer composite components such as marine boats and submarine applications and under water applications. The results of the experimental investigation showed that the GFRP Composite laminate tested in different environmental condition under flexural loading. From the experimental results and numerical analysis, it was clear that the tensile behavior of the salt water conditioned specimens were significantly reduced. The results of the analytical predictions and numerical simulations are in good agreement with the experimental results.**

Keywords: Glass fibre reinforced polymer, Environmental conditions, Resin transfer molding, and Flexural modulus

1. INTRODUCTION

In recent years, Glass-fiber reinforced polymer (GFRP) have received considerable attention as structural materials due to their high strength-to-weight ratios in relation to conventional metals such as steel and aluminum. The advantages over conventional structural materials, composites are susceptible to heat and moisture when operating in harsh and changing environmental conditions. The main benefit of using the sandwich concept in structural composite components is its high bending stiffness and high strength to weight ratios [1]. In addition, composite materials are preferred over conventional materials because of its high corrosion resistance [2]. With its many advantages, composite structures have been widely used in the automotive, aerospace, marine and other industrial applications. This composite material also draws a lot of interest in the construction industry and is now beginning to be in use for civil engineering applications [3].

The researchers investigated on hygrothermal effects on composite laminates and they stated the hygrothermal effect causes a reduction of in-plane properties of laminates, where the ratio of the moisture absorption in composite laminates is accelerated by the presence of cracks and voids in the laminate. For example, a study by Hertz et al. [4] in 1972 has shown that moisture absorption leads to changes in the thermophysical, mechanical, and chemical characteristics of the resin matrix by plasticization and hydrolysis. [5] Bao and Yee[6] investigated the moisture diffusion and hygrothermal aging in bismaleimide matrix carbon fiber composites and found that short-term moisture diffusion interface has little effect on the fiber–matrix interface. However, after prolonged moisture absorption, interfacial cracks develop in the composites. Vaddadi et al. [7] analyzed the evolutions of internal stresses within fiber-reinforced composites subjected to transient hygrothermal deformation. It was found that the stresses gradually increase from the exposed surface to the interior, as the moisture tends to expand the epoxy phase. The degradation of the reinforcements played an important role in strength reduction of fiber-reinforced composite as they are the major load-carrying constituents [8] and also the moisture conditions resulted in strength degradation. Karbhari and Zhang[10] investigated the durability of 2 and 4 layered specimens of E-Glass/Vinylester material and it was shown that the highest levels of tensile strength and modulus degradation for the deionized water immersed samples.

The objective of this work is analysis on the performance and durability of glass fiber reinforced polymer materials under bending loading for different environmental conditions with varying temperature from room temperature to elevated temperature. In this investigation study the flexural behavior of glass fibre reinforced polymer composite material due to water absorption. Also life prediction analysis has been carried out by mathematical modeling.

2 EXPERIMENTAL SETUP

2.1. Preparation of Test Samples

The specimens for the present work are prepared using RTM Machine as shown in fig.1. The specifications for the laminate preparation are (i) injection pressures, 30-40 PSi. (ii) Curing Temperature – room temperature. The laminates obtained by RTM is the size 300mm x 300mm x 8mm.These laminates are sliced to standard ASTMD 638 tensile specimens of dimensions 250 mm x 30 mm x 8 mm as shown fig.2.

Raw materials used in the composite laminate: Matrix: General purpose polyester resin (commercial Grade) Glass fibre: Saint Gobain makes E-Glass Chopped strand mat (stitched) 450g/s-m, the laminates are prepared with RTM process . The volume fraction of the reinforcement loading about 40% which is found by Burn test the remaining is matrix about 60%

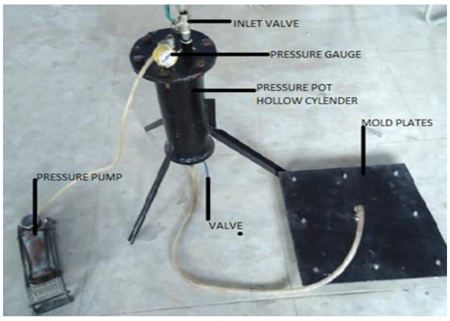


Fig. 1 Resin transfer molding machine

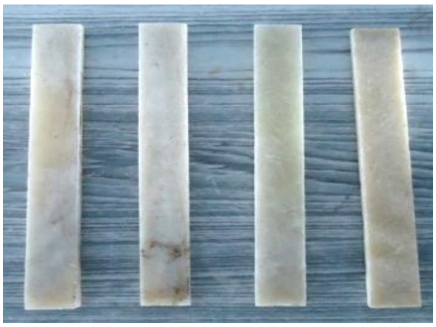


Fig. 2 Specimens of GFRP laminate with dimensions of 250 mm×30 mm×8 mm

2.2 Testing of the Laminates

The laminates were tested under different environmental conditions at room temperature and constant elevated temperature in both water and salt water bath tubs. In total 120 specimens were soaked in water bath over period of 360 days at room temperature and 120 specimens were soaked in water bath over period of 60days at each constant temperature of 60ºC and 75ºC. Similarly way totally 120 specimens were soaked in salt water bath over period of 60days at each constant temperature 60ºC and 75ºC. Every 30 days specimens are taken from bath which are exposed to room temperature and for every10 days specimens are taken from bath which is maintained at 60ºC and 75ºC constant temperature and carried out bending tests on universal testing machine. The load-stroke behavior obtained during testing was converted into load – deflection and calculated the flexural modulus was calculated using the below formulae

$$E_f = L^3 m / 4bd^3 \text{-------------} (1)$$

Where *L* is support span (specimen gauge length in mm), *b* is width of test specimen (mm), *d* is depth or thickness of test specimen (mm), *m* is gradient (i.e., slope) of the initial straight-line portion of the load deflection curve, (P/D), (N/mm).

2.3 Performance Prediction Analysis

An indirect indication of service life is obtained simply by comparison of the performance of materials under given test conditions, the one which shows the smaller change being deemed to perform better. To make a direct estimate of service life of materials, it is necessary to apply some form of extrapolation technique to their experimental data. The life estimation of GFRP composites in these environmental conditions were analyzed by employing exponential regression analysis life prediction mathematical models. The life predication equation was derived on the basis of experimental data in terms of the degradation coefficient (decay constant), soaking time, minimum strength and exponential coefficient for different environmental conditions. Exponential linear regression provides powerful technique for fitting the best relationship between dependent and independent variables based on this technique life estimation of composite materials was being established as follows.

$$Y(X) = Y_0 + A_1 exp - \left(X - X_0\right) / t_1 \text{........} (2)$$

3.0 RESULTS AND DISCUSSIONS

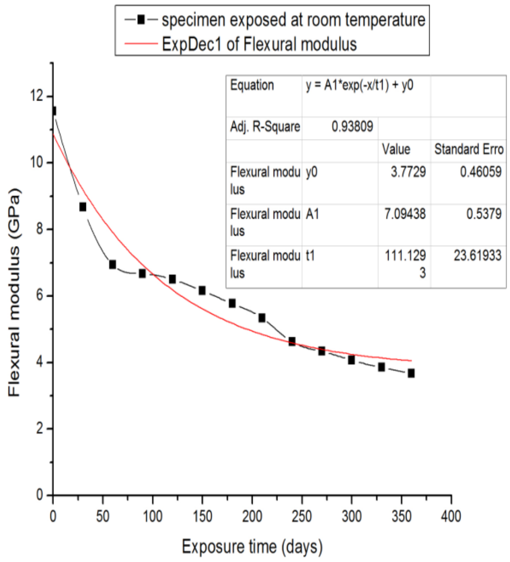
The laminates were tested under different environmental conditions at room temperature and constant elevated temperatures in both water and salt water bath tubs with bending test and noted the results. From the results load – deflection graphs are drawn and calculated flexural modulus of the specimens within the elastic limits choosing straight line portion of load – deflection relation. For example specimen soaked at RT in water for end of 30days flexural modulus is calculated as Flexural Modulus (30 Days), $E_f = L^3 m / 4bd^3$

$$E_{f1} = 220^3 \times 50 / \left(4 \times 30 \times 8^3\right) = 8.665 \text{ GPa}$$

The laminates are soaked to water bath at room temperature, and are tested with bending test. This is repeated for every 30 days, the final experimental and numerical results are noted and the same displayed in Fig.3.The laminates are exposed at constant temperatures 60^0C and 75^0C in water bath, tested with bending test. At each temperature this is repeated for every 10 days, the final experimental and numerical results are noted and the same displayed in Fig.4 and 5 and also shown in table.1. The laminates are exposed or soaked at constant temperatures 60^0C and 75^0C in saltwater bath, tested with tensile test. At each temperature this is repeated for every 10 days, the final experimental and numerical results are noted and the same displayed in Fig.6 and 7 and also shown in table.1.

The experimental results revealed mechanical properties of the GFRP (E-Glass/Polyester) samples subjected to aging at room temperature and elevated temperature in water as shown in fig.3,4 and 5 from the experimental results(shown in figure4 and 5), initially rapid reduction in mechanical properties is observed and gradual decrease is observed over the exposure time. The regression analysis is performed for each of the time steps and this yields a set of exponential linear relationships between the tensile modulus and exposure time based on the analysis derive the mathematical equation.

The results shows rapid reduction for the specimen soaked to salt water as compared to specimens exposed to water because of more moisture interference in fibre matrix in the saltwater than water. The samples subjected to aging at the constant temperature water bath (60ºC and 75^{0}C) showed a hyperbolic decrement in the flexural modulus. On the whole it is observed that flexural modulus decreased to some extent with the presence of moisture, temperature and reduction in flexural module is more salt water conditioned specimen then normal water. There is significant reduction in modulus because of loosing bonding strength of the polyester resin at temperature. It is clear that the modulus rapidly decreases due to hydrothermal aging because moisture generally affects any property which is dominated by the matrix and/or interface. However the bending strength being a fibre dominated property the strength reduction occurs only if the fibres themselves are affected by hydrothermal environmental conditions. The flexural modulus at end of 60 days exposed in sea water at constant temperatures of 60^0 C is 3.524 GPa and at 75^0 C is 3.324 GPa, but when it is exposed to the normal water under same conditions the resulted values are 3.973 GPa and 3.446 GPa. The results indicate that the flexural moduli of the environmental hydrothermal aging conditioned specimens are significantly decreased with exposure time.



Equation	y = A1*exp(-x/t1) + y0		
Adj. R-Square	0.93809		
		Value	Standard Erro
Flexural modulus	y0	3.7729	0.46059
Flexural modulus	A1	7.09438	0.5379
Flexural modulus	t1	111.1293	23.61933

Fig.3 Bending test - Numerical (predicted) and experimental flexural modulus of GFRP Specimens exposed to room temperature in water

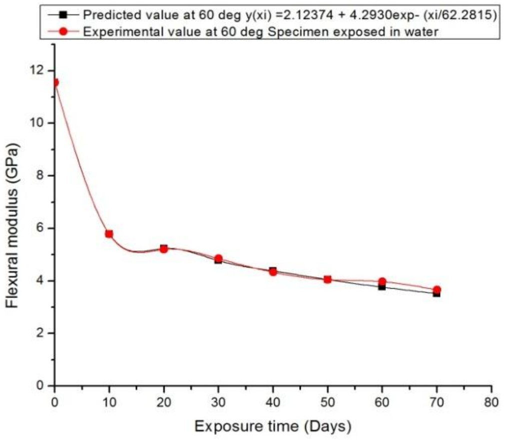


Fig.4 Bending test- Numerical (predicted) and experimental flexural modulus of GFRP Specimens exposed 60^{0}C in water

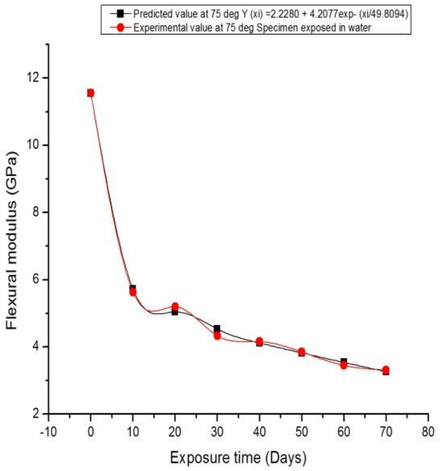


Fig.5 Bending test- Numerical (predicted) and experimental tensile modulus of GFRP Specimens exposed 75^{0}C in water

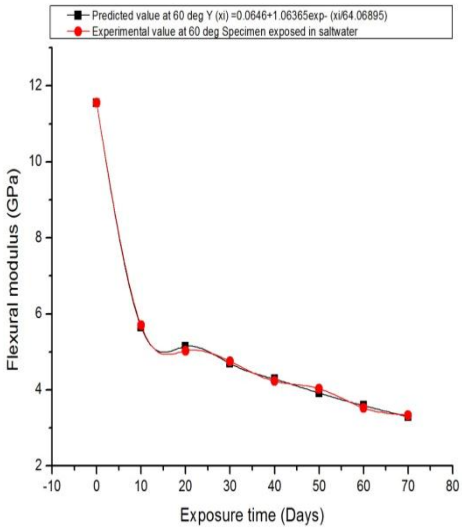


Fig.6 Bending test- Numerical (predicted) and experimental tensile modulus of GFRP Specimens exposed 60^{0}C in saltwater

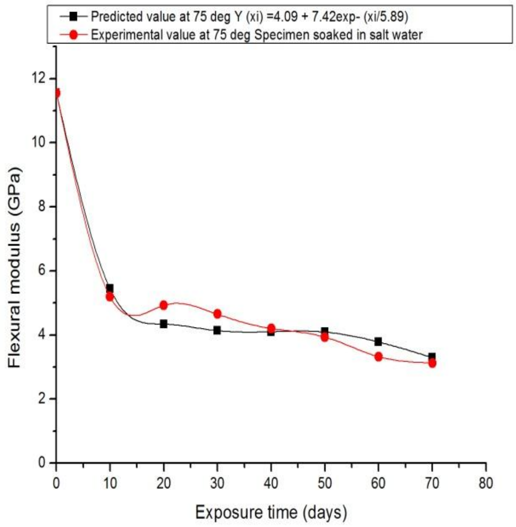


Fig.7 Bending test- Numerical (predicted) and experimental tensile modulus of GFRP Specimens exposed 75^{0}C in saltwater

The regression analysis is performed for each of the time steps and this yields a set of exponential linear relationships between the flexural modulus and exposure time at different conditions as shown table1 and figures 3, 4, 5, 6 and 7. The obtained predicted values are compared to experimental data and they are similar and good agreement between them. Based on this analysis it has to be noted that as temperature increases the predicted or numerical values are increases that indicate rate of degradation increase. The life estimation of composite materials has been possible by prediction models. It is expected to maintain minimum strength after 120 days over life cycle of period at 60^{0}C, 75^{0}C in water and saltwater under this environmental impact. According to prediction analysis at elevated temperatures predicted values and experimental values are comparable.

Table1 Flexural modulus of GFRP Composite laminates soaked to water and salt water at 60^{0}C and 75^{0}C

Exposure time (days)	Specimen exposed in water and salt water-Tensile modulus (GPa)							
	Specimen in water at 60^{0}C		Specimen in water at 75^{0}C		Specimen in salt water at 60^{0}C		Specimen in salt water at 75^{0}C	
	Predicted	Experimental	Predicted	Experimental	Predicted	Experimental	Predicted	Experimental
0	11.553	11.553	11.553	11.553	11.553	11.553	11.553	11.553
10	5.780	5.786	5.722	5.632	5.646	5.698	5.445	5.198
20	5.238	5.199	5.044	5.199	5.143	5.028	4.339	4.928
30	4.776	4.852	4.532	4.332	4.690	4.752	4.136	4.652
40	4.382	4.332	4.113	4.159	4.283	4.232	4.098	4.202
50	4.047	4.043	3.822	3.851	3.917	4.032	4.092	3.932
60	3.762	3.973	3.541	3.446	3.588	3.524	3.788	3.324
70	3.519	3.657	3.260	3.312	3.293	3.334	3.293	3.126
80	3.312	-	3.072	-	3.027	-	2.775	-
90	3.135	-	2.918	-	2.789	-	2.582	-
100	2.986	-	2.793	-	2.575	-	2.312	-
110	2.858	-	2.756	-	2.382	-	2.215	-
120	2.749	-	2.659	-	2.209	-	1.924	-
130	2.656	-	2.581	-	2.205	-	1.798	-
140	2.577	-	2.516	-	1.914	--	1.675	--
150	2.510	-	2.464	-	1.788	-	1.554	-
160	2.453	-	2.421	-	1.675	-	1.552	-
170	2.404	-	2.366	-	1.574	-	1.552	-

4.0 CONCLUSIONS

The investigation showed a remarkable reduction in mechanical bending strength (flexural modulus) of GFRP composite laminates which are subjected to different environmental conditions over soaking time. The strength values of the specimens are decreases over exposure period of 60 days in water and salt water at constant temperature. As per the results flexural modulus initially slightly increases and gradual decrease over long period and expected to maintain considerable minimum strength over service of the life cycle. The following points drawn from Experimental and theoretical results (numerical results obtained from mathematical modeling).

i). The presence of moisture or water particles in the matrix, fibre-matrix interface and also attack on the glass fibres are all the reasons for reduction of properties due to hydrothermal impact.

ii).The flexural modulus reduction is more in hydrothermal aging because of temperature is a key factor for accelerated aging in the processes of water diffusion and chemical degradation .

iii) The investigation noticed that aging at elevated temperatures, strength degradation is more in salt water exposure when compared to normal water.

iv) It is worth noticing that aging at elevated temperatures will also cause color change in samples.

v) Prediction analysis stated that the material posses minimum strength over the life cycle.

vi) The predictive mathematical models have showed good agreement between experimental data and theoretical values. The numerical results are similar when compared to experimental results. Therefore life of the laminate can be estimated reasonably.

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