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Investigation on Mechanical Properties and Life of GFRP Laminates by Employing Thin Film Layer

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Abstract- **Fibre composites are being used in various applications from aerospace, military, marine boats and submarine to renewable energy generation. The reinforcement materials are highly hygroscopic nature and exposed to environment, water molecules travels along the reinforcement and affects the performance of the materials. This study includes preparation and testing of unpainted and painted with thin layer GFRP Specimens under different environmental conditions. The present investigation has been carried out for the effect on mechanical properties by employing thin film layer on GFRP composite laminates under combined action of temperature and humidity, subjected to flexural loading . The experimental and mathematical analysis results reveal that the coated GFRP laminates shows small deteriorations in mechanical properties compared to unpainted GFRP laminates.**

Keywords: GFRP (Glass fibre reinforced polymer); The Resin transfer moulding (RTM); Environmental conditions; Flexural modulus; retention ratio.

I. INTRODUCTION

Polymer matrix composites (PMCs) are increasingly being used in a wide range of applications such as blades for wind turbines, construction structures, boat hulls, etc where long-term service required in different environmental conditions. In recent years GFRP/Polyester resin was received considerable attention as alternatives to steel and aluminum due to their high strength-to-weight ratio, competent mechanical properties, low cost and ease of processing and handling.

The above factors make E-glass fibers a better choice for naval composites despite their reduced tolerance to aqueous environments in comparison with carbon fibers **[1].**The marine environment is very unique due to dynamic tidal loading and moisture which make it a challenge to design composites for ship structures. Constant exposure to moisture prone environments makes durability and dynamic failure properties critical for naval composite ships **[2].** It is important to ensure that marine composites do not degrade significantly under constant exposure to sea water. However, fiber composites with vinyl ester matrices have been shown to lose interfacial mechanical properties due to Hydrolysis reaction of unsaturated groups within the matrix resin [3]. But, many previous approaches and measurements have significantly underestimated the actual durability of a composite structure without proper coating.

Accelerated environmental ageing study of polyester/glass fibre reinforced composites were studied based on two kinds of alternating cycles, which provided humidity, temperature and ultraviolet radiation. The study dynamic mechanical analysis, for a range of temperatures and frequencies under tensile and three-point bending loadings, revealed that the aged materials gained in stiffness, whereas a small deterioration in strength was found [4] because of the post-curing of the material, caused by temperature and ultra violet radiation, secondary cross-linking via hydrogen bonding, the occupation of the voids of the materials. Tensile and flexural strength of bamboo fiber reinforced polypropylene composite ,bamboo-glass fiber reinforced polypropylene hybrid composite were reduced [5] and hybrid approach of blending more durable glass fiber with bamboo fiber is an effective way to improve the durability of natural fiber composite under environmental aging. On similar way experimental work has been done with polyester-glass fiber reinforced composites. When GFRP subjected to Water and Moist Environment the bending strength of the GFRP was also found to be reduced [6]. The rate of weight decrease and the reductions in bending strength were greater in a 60°C water-immersion condition compared to both a 60°C moist-atmosphere condition and a 40°C water-immersion condition. Moisture does not only affect the adhesive bond of the bonded system in service, but also during the application of FRP on concrete surface. Tests on CFRP bonded to concrete with initially damp surface using a modified cantilever beam indicated reduction in bond strength when compared to specimens with initially dry concrete surface [7]. Since the failure under effect of moisture generally occurs by either concrete delaminating or concrete–epoxy interface separation. The effects of variable moisture conditions on the fracture toughness of concrete/FRP bonded system are studied by means of the peel and shear fracture toughness determined from the conditioned test specimens. The degradation of the reinforcements plays an important role in strength reduction of fiber-reinforced composite as they are the major load-carrying constituents [8] and moisture conditions can result in strength degradation [9].

The glass fiber reinforced plastics subjected to different environmental conditions and results show that the tensile strength affected at different levels of environmental conditions for various exposure periods [12]. The tensile

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strength and flexural modulus were reduced significantly, of the GFRP laminates specimens subjected to water soaking and varying temperature [13].

The objective of this work is to investigate the effects of hydro and hydrothermal loading based on combined parameters of moisture and temperature on the performance and durability of unpainted (uncoated) and painted (coated) glass fiber reinforced polymer materials under flexural loading. For this number of specimens are prepared, some of specimens are exposed to accelerated hydrothermal environmental conditions and some of specimens are painted with resin and exposed to same conditions .To know the changes of material properties due to absorption of water particles at room temperature and elevated temperature. For this series of experiments are conducted and results are interpreted to know behavior of the materials. Based on the experimental results, mathematical equations has been developed and life the materials was estimated.

II. EXPERIMENTAL METHODOLOGY

2.1 Production of laminates using Resin transfer molding

The materials used for GFRP laminates are polyester resin with density 1.35 g/cm^3 and glass fibre mats of woven fabric glass fibre with density 450 g/cm^3. The laminates were produced by mixing 60% of polyester resin and 40% of glass fibre using Resin transfer moulding (RTM) machine which has a closed mould process and consists of resin injection equipment as shown Fig.1.The parameters considered in RTM for producing the laminates were (i) injection pressure range of 30-40 psi (ii) curing temperature – room temperature.

The glass fibre mats were placed in-between the mould plates and clamps. The resin was mixed with 2% of accelerator (cobalt nathylene) and 2% of catalyst (methyl ethyl keypricperoxide) then poured into the cylinder through the valve. The valve was closed immediately then air pumped into hollow cylinder such that pressure should reach 40 Psi. The bottom valve of the cylinder was slowly released so that pressurized chemical resin enters in to the mould and it has to spread equally in to all directions. The laminates were kept for 4 to 5 hours idle time in the mould to get required shape. After curing the laminate, the mould was unsealed and separated the lower and upper mould parts. The laminate was removed from the mould then sliced into test samples according to standards ASTM-D-790 as shown Fig. 2 and some of test samples were converted in to coated specimens by surfaces and edges are painted with thin of polyester resin.

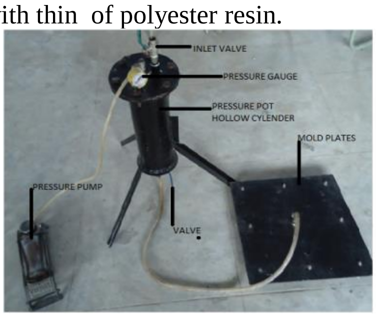

Fig.1 Resin transfer molding machine

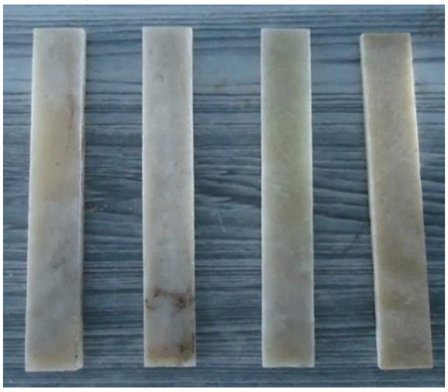
Fig. 2 Specimens of GFRP laminate with dimensions of 250 mm × 30 mm × 8 mm

2.2 Testing of the Laminates

The coated and uncoated laminates were tested under combined conditions of humidity and elevated temperature (60^{0}C). In total 120 specimens coated and uncoated specimens were exposed in constant temperature water bath tub at 60^{0}C over period of 60 days. Every 10 days interval 10 samples of each uncoated and coated were taken from the bath and tested with three point bending tests on universal testing machine.

2.2.1 Three point bending test

Specimen dimensions as per the standard ASTM-D-790: Specimen Length=250 mm, Specimen Gauge Length=220 mm, Width b=30 mm, Thickness h=8 mm

Three point bending tests were performed at a nominal cross-head speed of 1mm/min and at room temperature on conventional universal testing machine attached with data acquisition systems and repeated thrice for each set to check the reproducibility test data. The same test samples as per ASTM-D-790 standard were used for these tests. The loading direction was in transverse direction for all three point bending tests of GFRP samples. The load-stroke behavior obtained from the bending test. It was converted into load verses deflection relation and calculated the flexural modulus. The flexural modulus was calculated using equation 1.

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

Where E_f = Flexural modulus; L = Support span (Specimen gauge length) in mm; *b* = Width of specimen in mm; *d* = Depth or thickness of specimen in mm and *m* = the gradient of the initial straight-line portion of the load deflection curve in N/mm**.**

2.2.2 Model calculation for Flexural modulus

Flexural modulus of elasticity is calculated from the figures, Load v/s Deflection curves for the test results of coated and uncoated specimens exposed in water at constant temperature 60^{0}C with defferent exposure schedules by using the equation-1 and the calculated results are shown in table1. Example calculation for flexural modulus of painted specimen exposed in water at 60^{0}C for 10days

$$E_f = \frac{L^3 m}{4bd^3}$$

$$= 220^3 X 0.04 X 10^3 / 4 X 30 X 8^3$$

$$= 6.932 GPpa$$

This calculation procedure applied for all the test results with help of load v/s deflection curves and tabulated in table1.

2.3 Performance Prediction Analysis

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.

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

Where Y(X) is dependent parameter; X is exposure time in terms of days; Y_0 is minimum strength property after long exposure of time; t_1 is the degradation coefficient or decay constant, A_1 is Exponential coefficient which was determined by using experimental data

The GFRP composite materials exposed in water constant temperatures, 60^0C the mathematical equations for flexural modulus was established by experimental data are given in equations 3 and 4 and graphically represented as shown in Figures. 3 & 4.

The life prediction equation at 60^0C temperature for unpainted or uncoated specimen is

$Y(x)=2.12489+3.695exp-(x_i-9.3152)/62.251$—(3)

The life prediction equation at 60^0C temperature for painted or coated specimen is

$Y(x)=5.3202+1.747exp-(x_i-6.915)/28.62$—(4)

By using above equations calculated the predicted values of flexural property and compare with experimental values as shown table1.

III. RESULTS AND DISCUSSIONS

3.1 Results of three point bending test:

3.1.1 Three point bending test - Uncoated Specimens exposed in water at constant temperature 60^0C:

The numbers of uncoated specimens of dimensions $250mm X 30mm X 8mm$ are exposed to water bath at constant temperature 60^0C, and same tested with three point bending test. This is repeated for every 10days interval and the results are noted and the same was displayed in the graphs as shown in Fig3. From the graphs flexural modulus was calculated and shown in table1.

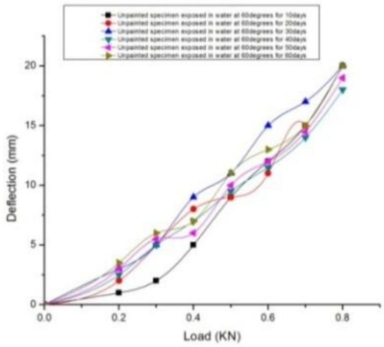

Fig. 3 Uncoated Specimen exposed in water at 60^0C (10 to 60 days)

3.1.4 Three point bending test - Coated Specimens exposed in water at constant temperature 60^0C:

The numbers of coated specimens of dimensions $250mm X 30mm X 8mm$ are exposed to water bath at constant temperature 60^0C, and same tested with three point bending test. This is repeated for every 10 days interval and the results are noted and the same was displayed in the graph as shown in Fig4. From the graphs flexural modulus was calculated and shown in table1.

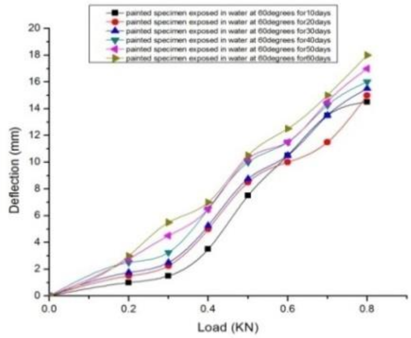

Fig. 4 Painted Specimen exposed in water at 60^0C (10 to 60 days).

3.2 Discussions:

The GFRP (E-Glass/Polyester) uncoated and coated test samples were subjected to aging in water at 60^0C constant temperature for 60 days and tested with three point bending test, the results are noted in table1. From the test results rapid reduction in mechanical properties is observed in uncoated specimens and gradual decrease is observed in coated specimens over the exposure schedule as shown in table.1. As per the experimental results of uncoated specimens and coated specimens (surfaces and edges are layer with polyester resin) exposed in water at constant temperature 60^0C, the strength degradation (Flexural modulus) is more in uncoated samples. The retention ratio (ratio of flexural modulus of exposed specimen to unexposed specimen) has been calculated for flexural modulus and presented in graphs as shown in Fig.5 that shows steady decreases in the coated specimen compared with uncoated specimen. From the results of uncoated and coated specimens exposed in water at elevated temperature, initially strength appear to be rapidly decrease then gradually decreased as soaking(exposure) time is increasing this is because of cross linking reaction in polyester resin is still in progress up to 2 weeks of laminate preparation. By comparing the test results of coated(same GFRP material coated on edges and surfaces with polyester resin) and uncoated specimens exposed at elevated temperature, coated specimens shows positive results because less moisture induced at the interference of fiber matrix. The samples subjected to aging at the constant temperature water bath (60ºC) showed a hyperbolic decrement in the flexural strength. On the whole it was observed that less reduction of flexural modulus in coated specimens than uncoated specimens with the presence of moisture and temperature. 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.

The regression analysis is performed for each of the time steps and this yield a set of exponential linear relationships between the flexural modulus and exposure time at constant temperatures were developed. The relationships so obtained are shown in equations 3, and 4 can be used to determine the flexural modulus of the composite material at different time steps under different conditions. For predictions of response due to immersion in water at 60^0C the values of flexural modulus at each time step are obtained by substituting the exposure time in days in the equations 3, & 4 the values are listed in Table 1.The relation between the experimental and predicted values and life of the material was estimated from the data in Table1.

The prediction values of flexural modulus, for the specimens immersed in water at temperature and 60^0C slightly variation was observed at temperature and higher variation at elevated temperatures when compared to the experimental values. It has to be noted that as temperature increases the predicted values are increases that indicate rate of degradation increase. The life estimation of composite materials is possible with prediction models.

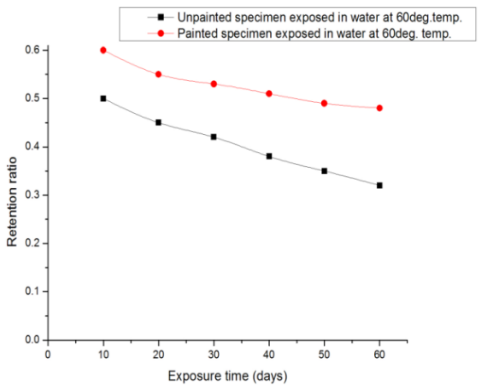

Fig. 5 Retention ratio v/s Exposure time for specimens exposed in water at 60^0C temperature

IV. CONCLUSIONS

The investigation showed a remarkable reduction in flexural strength (flexural modulus) of uncoated and coated GFRP composite laminates which are subjected to different environmental conditions over exposure time schedules. The flexural strength values of the uncoated specimens are rapidly decreased when compared to coated specimens over exposure period of 60 days in water at 60^0C constant temperature. As per the test results the retention ratio for the coated specimens exposed at 60^0C constant temperature it was about 0.60 to 0.43 in case of coated specimens but in case of uncoated specimens it was 0.50 to 0.32.This results shows that strength deterioration of GFRP composite laminates under flexural loading subjected to exposure tests. The following points drawn from test results.

i). The presence of moisture particles in fiber-matrix interface and also attack on the glass fibers are all the reason for reduction of properties due to environmental impact.

ii) In this investigation different environmental conditions were used with coated and uncoated specimens in testing, the coated specimens showed small changes in some mechanical properties.

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

iv) Based on test results of coated and uncoated specimens, the surface and edge coatings have a protective against changes of mechanical properties of GFRP composite laminates. Therefore coated laminates are recommended for aggressive environmental applications.

v) Theoretical results are similar when compared to experimental results. Therefore life of the laminate has been estimated.

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Table1: Predicted values of flexural modulus in comparison with experimental values of GFRP Composite laminates at different conditions

Flexural modulus of unpainted and painted specimens with exposure time				
Specimens exposed in water at 60^0C temperature				
Exposure Time days	Unpainted specimen		painted specimen	
	Predicted values in Gpa	Experimental value in Gpa	Predicted values in Gpa	Experimental value in Gpa
0	11.553	11.553	11.553	11.553
10	5.780	5.7764	6.882	6.932
20	5.238	5.1995	6.428	6.308
30	4.776	4.852	6.100	6.152
40	4.382	4.332	5.870	5.926
50	4.047	4.0436	5.708	5.720
60	3.762	3.773	5.593	5.550
70	3.519	-	5.513	-
80	3.312	-	5.456	-
90	3.135	-	5.416	-
100	2.986	-	5.387	-
110	2.858	-	5.367	-
120	2.749	-	5.353	-
130	2.656	-	5.343	-
140	2.577	-	5.336	-
150	2.510	-	5.332	-
160	2.453	-	5.324	-
170	2.404	-	5.322	-
180	2.404	-	5.322	-