Proceedings of MUCEET2009
Malaysian Technical Universities Conference on Engineering and Technology
June 20-22, 2009, MS Garden, Kuantan, Pahang, Malaysia

MUCEET2009

Effect of Adverse Environment on Buckling of Composite Laminates

Z.Ahmad@Manap, M.R.M.Rejab, M.M.Noor, R.Daud, M.S.M.Sani and K.Kadirgama

Abstract — This paper examine how the critical load of Glass Fibre Reinforce Plastic (GFRP) changed if exposed to the ordinary water. The exposure duration is for four (4) week. Buckling test is the type of experiment had been done for this project. The experiment analyzes for two (2) types of boundary condition; both ends fixed and ends pinned. The reinforcement had been used are woven and chopped strand mat (CSM) types. The specimens were prepared by hand lay-up technique. ASTM D 3039-76 for tensile test was used to obtain the properties of specimen such as strength (σ), strain (ε), poison ratio (v) and Modulus Young (E). The actual volume fraction (V_f) of the composite comply the ASTM D2584-02 for burn-out test. The results from the buckling test method will compared the results from theory. After immersed the specimens in water, buckling critical load for CSM laminate is higher than woven type laminates and the composite experienced significant reduction of the strength. From results also, the long period of specimen exposed in the water will reduce the strength and decrease the critical point for buckling as well.

Keywords: GFRP, fibre volume fraction effects, mechanical properties, buckling.

I. INTRODUCTION

Composite materials consist of two or more materials which together produce desirable properties that cannot be achieved with any of the constituents alone [1]**.** Fiber reinforced composite materials, for example consist of high strength and high modulus *fiber* in a *matrix* material. Reinforced steel bars embedded in concrete provide an example of fiber reinforced composites. In these composites, fibers are the principal load carrying members and the matrix material keeps the fibers together acts as a load transfer medium between fibers and protects fibers from being exposed to the environment.

Author is with the Faculty of Mechanical Engineering, Universiti Malaysia Pahang, Kuantan, 25000 Pahang, Malaysia. (e-mail: kifli@ump.edu.my)

Composite have unique advantages over monolithic materials such as high strength, high stiffness, long fatigue life, low density and adaptability to the intended function of the structure. Additional improvements can be realize in corrosion resistance, wear resistance, appearance, temperature – dependent behavior, thermal stability, thermal insulation, thermal conductivity and acoustic insulation.

Fiber reinforced materials are not an invention of this century. Applications date back of composite is quite far [2]. The use of fiber reinforced polymer composites in the marine industry has been studied for more than two decades. The applications range from surface vessels, offshore structures, underwater vehicles, to special military uses [3]. Although composites have been used in marine and waterfront applications, they are still fairly new compared to the traditional materials. Water absorption of fiber composites in humid environments or submerged in water has been studied mainly for the aerospace industry, military vessels, and surface boat industry [4].

As a general, the extent of strength reduction was found as a function of the water absorbed. When saturation was reached, no further loss would occur [5].

Recently, glass-fiber-reinforced polymers ~GFRP! are being increasingly used in construction applications because of a number of advantageous characteristics, such as light weight, high strength, and anticorrosion properties [6]. Pultruded GFRP is suitable for construction applications because it is possible to form long parts in various cross sections at relatively low cost. The main environmental factors for the deterioration of GFRP are temperature, sunshine, water/moisture, and load. Among these factors, water/moisture is well known and studied to influence the mechanical properties of the material.

Hence, the aim for this project is to determine the critical load of composite laminates due to buckling when the specimens were exposed to the ordinary water. Chopped strand mat (CSM) and woven will be used as specimens. Actually this study just used three layer of laminate for experiment. Universal testing Machine (INSTRON) was used to perform tensile test as well as buckling test. The value of strength, modulus of elasticity, poisson ratio and so on will get from tensile test. Buckling test had examined in order to get the critical load from the specimen. The results from the experimental will compared to the theoretical values for validation.

II. MATERIALS AND METHODS

2.1 Materials

The raw materials had been chosen to be used to fabricate the specimens of the project is polyester with 1%

of hardener and two types of glass fibre chopped strand mat (CSM) and woven.

Chopped strand mat (CSM) is a non-woven material which, as its name implies, consists of randomly orientated chopped strands of glass which are held together. In some processes such as hand lay-up, it is necessary for the binder to dissolve. In other processes, particularly in compression molding, the binder must withstand the hydraulic forces and the dissolving action of the matrix resin during molding. Thus, two general categories of mats are produced and are known as soluble and insoluble. Now, chopped strand mat is rarely used in high performance composite components as it is impossible to produce a laminate with high fiber content or by definition a high strength to weight ratio.

Woven type was used for application where more than one fibre orientation required. A fabric combining 0^o and 90^o fibre orientation is useful. Woven fabric is produced by the interlacing of warp 0^o fibres and weft 90^o fibres in a regular pattern or weave style. The fabric's integrity is maintained by the mechanical interlocking of the fibres. Drape (the ability of a fabric to conform to a complex surface), surface smoothness and stability of a fabric are controlled primarily by the weave style.

Properties of the glass fibre used are given in Table 1 while the properties of polyester resin are given in Table 2.

Table 1 Mechanical properties of E- Glass fibre

Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)
2.50	1750	73

Table 2 Mechanical properties of polyester resin (23°C)

Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Poison's Ratio
1.1 – 1.4	34.5 – 103.5	2.1 – 3.45	1 - 5

2.2 *Composite Sample Preparation*

A total of sixty specimens of glass fiber reinforced polymer (GFRP) laminates were tested for buckling test. The numbers of controlled samples were twelve. In case of water exposure, thirty specimens were tested by using both ends fixed and thirty specimens were tested by using both ends pinned. Six specimens have been used to obtain the maximum stress, maximum strain, and young modulus from tensile test. **Table 2.1** is summary the number of samples had been prepared.

Table 2.1 Summary of number of samples had been prepared.

Test	Boundary	Control	Soaked water
Tensile		6	0
Buckling	both fixed	6	24
	both pinned	6	24

Installation of rig is very important because it will hold the specimen during the testing in order to obtain better result or at least to make sure the testing perform successful without any failure. Before the buckling test, make sure that the test-rig and the shape of specimen are in correct condition. The rig design as shown in **Figure 1** before attached to the INSTRON Machine. There are two types of design, left one for fixed and the right for pinned.

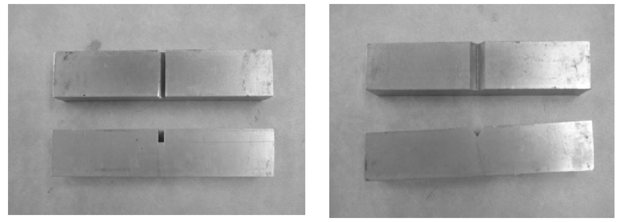


Figure 1 The rig design had fabricated

There are two types of dimension were cut out for composite laminate fabrication purpose. The first dimension is 700mm x 300mm for buckling test condition and second is 100mm x 25mm for tensile test. All the specimens were fabricated with three layers.

In order to produce good samples, make sure that the surface of the plastic was clean out before fabrication process had started. Polyester adhesive was mixed with hardener (about 1%) from polyester resin mixture. Then, the polyester resin mixture was applied on the fibers by using a brush. It is then spread on the glass fibers and accomplished by roller. This process was carry-on until the resin was covered and adhere the whole ply of fibre. The steps were repeated until the third layer and covered by plastic. The specimens left 1 to 2 days for curing process under room temperature.

After the specimens had been cut to specific testing dimension for each test whether buckling test or tensile test, it will be exposed into water condition. The specimens that exposed in the water will divide to the four groups for 4 weeks. Each group represents week of soaked.

2.3 *Burn out Test*

This test method covers the determination of the ignition loss of cured reinforced resins. It means that the resins were removed from the reinforcement. This ignition can be considered to be the resin within the limitations. There are two test method of testing but in this project applied ASTM D2584:-

a) ASTM D2584 - Test method for ignition loss of cured reinforced resins.(burn-off test in a furnace at 500ºC)
b) ASTM D3171 - Test method for fiber content of resin matrix composites by matrix digestion.(chemical digestion)

From the burn-off test data, the volume of fiber and resin matrix was analyzed. Fiber volume is the volume of fiber in a cured composite.

$$V_f = \frac{\rho_m W_f}{\rho_f W_m + \rho_m W_f} \tag{1}$$

Where,

V_f = volume fraction of fibers ρ_f = density of fibers
W_f = weight of fibers ρ_m = density of matrix
W_m = weight of matrix

2.4 *Tensile Test*

Tensile test was conducted to obtain the properties of specimen for this project such as of Strength (σ), Strain (ε), Poisson ratio, percent elongation and Modulus Young (E). The test is based on ASTM standard D 3039-76. This is the standard which is specially to be used to determine the tensile properties of polymer composite materials. The machine used to conduct tensile test is 50 kN INSTRON Machine.

The ultimate tensile strength of the specimen can be determined from the stress-strain curve plot by the raw data of test results. The initial portion of the curve where stress is proportional with strain before yield occurred is used to determine the specimen modulus of elasticity. From the x-axis stress and y-axis stress plot, the slope of graph represents the poisson ratio value.

The speed of testing or cross head speed is set at 1mm/min. The speed of testing is set at 1mm/min and remains constant for all specimens during the test, so that the test carried out is in static condition. This is to ensure the consistency and accuracy of the experiment.

2.5 Buckling Test

The objective of this project is to find the critical load when soaked to the water in certain duration of weeks. In order to proceed with the test, guidance from technician needs to make it easy in a short time. Firstly, make sure the right or appropriate load frame to use. Clamp both rigs to the load frames at the top and bottom whether for fixed or pinned condition. The speed for this project set up at 10 mm/min because if using slow speed the specimen can't shows the affect (i.e. less than 10 mm/min). After that, insert the specimen into the groove of rig and then set the crosshead speed. In order to obtain good results, the specimens must be rigidly fixed the rigs. **Figure 2** shows the position of rig and specimen before start the testing.

.

Figure 2: The position of rig before start the buckling test

2.6 Theoretical Results

To estimate the mechanical properties of composite materials, the formulas given below are needed for comparison with experimental data. These formulas are considered the types of fibre and types of resin. The formula used to calculate the modulus of elasticity in first direction. The steps of formula are given below:

$$W_f = \frac{w_f}{w_c} \tag{2}$$

$$W_m = \frac{w_m}{w_c} \tag{3}$$

After get the weight of fibre and resin, the density of composite was calculated using the formula.

$$\rho_c = \frac{1}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}} \tag{4}$$

The formulas to determine the volume fraction of fibre and resin are as follows.

$$V_f = W_f \frac{\rho_c}{\rho_f} \tag{5}$$

$$V_m = W_m \frac{\rho_c}{\rho_m} \tag{6}$$

Finally, E_{11} and E_{22} can get from the formula given below.

$$E_{11} = E_f V_f + E_m V_m \tag{7}$$

$$\frac{1}{E_{22}} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \tag{8}$$

Where,

W_f = weight fraction of fibre.
W_m = weight fraction of matrix
ρ_c = density of composite (specimen)
V_f = fibre volume fraction
V_m = matrix volume fraction
E_{11} = Modulus of Elasticity in first direction.
E_{22} = Modulus of Elasticity in second direction.

Then, formulas from buckling test should be considered.

$$I_{xx} = \left[\frac{b \times d^3}{12}\right] \tag{9}$$

$$I_{yy} = \left[\frac{d \times b^3}{12}\right] \tag{10}$$

Therefore, $I_{min} = I_{xx}$ because $I_{xx} < I_{yy}$, So;

$$P_{critical} = \beta \frac{\pi^2 E I_{min}}{L^2} \tag{11}$$

Where,

I_{xx} = Second Moment of Inertia in x direction
I_{yy} = Second Moment of Inertia in y direction
β = boundary coefficient factor

β for each condition is different. For example, β for both pinned is 1 and β for both fixed is 4. Choose the right coefficient before determine the critical load.

III. RESULTS AND DISCUSSION

3.1 Burn out Test Results

The result obtained from burn out test shows that the relative proportions of the matrix and the reinforcing materials. Volume fraction of fibre (V_f) and volume fraction of matrix (V_m) using formula as follows: -

$$V_f(\%) = \frac{M_f \times \rho_c}{M_c \times \rho_f} \times 100 \quad (12)$$

$$V_m(\%) = \frac{(1-M_f) \times \rho_c}{M_c \times \rho_m} \times 100 \quad (13)$$

Table 3.1 presented the weight of specimens before and after burn out test and percentage of volume fraction. The fibre fraction for woven is higher than CSM because the structures are rigid. So, it's hard to allow the resin absorbed through the structure.

Table 3.1: weight of specimens before and after burn out test and percentage of volume fraction

Specimens	Weight of Fibre, W_f(g)		% Fibre Volume Fraction, (V_f)
	Before	After	
Woven	2.7726	1.6012	41.16
CSM	3.4706	1.0696	18.56

3.2 Water Uptake

The exposure sets were carefully wiped before measuring the specimens. The formula to obtain the percentage water uptake as follows: -

$$\text{Water Uptake } (\%), M = \frac{w - w_d}{w_d} \times 100 \quad (7)$$

The results for this activity are summarized in **Table 3.2**. The material which is absorbing water, in these specimens is resin. So, CSM was absorbed much water than woven due to the resin volume fraction for CSM is high.

Table 3.2 Summary of experimental result for water uptake

Category	Weight increased (g)	% Water Uptake
W1	0.2042	0.4733
W4	0.5921	1.3018
C1	0.5602	0.8656
C4	1.0193	1.5699

W1 = woven specimen soaked for 1 week.
C4 = CSM specimen soaked for 4 weeks.

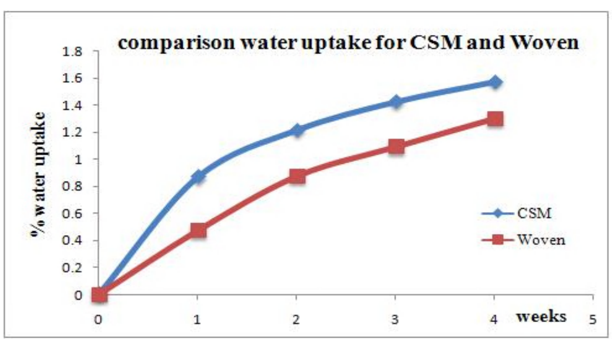


Figure 3 Comparison water uptakes for CSM and Woven

It is highly probable that the polyester, which is polymeric themselves, could absorb water. The water entered the composite specimens on their edge side and this situation called edge effect. This side occurred due to cutting process after hand lay-up technique

3.3 Tensile Test Results

The mechanical properties of two types of reinforcement forms, woven and CSM were summarized in **Table 3.3.** This table shows a listing of the average properties for the GFRP in the control condition.

Table 3.3 Mechanical properties from tensile test.

Category	Modulus Young (GPa)	Tensile Stress (MPa)	Poison Ratio
Woven	17.11	198.94	0.1424
CSM	6.6	106.49	0.3814

When these two types of reinforcement forms are compared, it was found out that the woven is stronger than the CSM. Similar, the Young Modulus for woven is higher than CSM and it has the same trend for tensile stress which is two (2) times bigger than CSM. This means that the maximum strain of the CSM reinforcement forms are greater than woven polymer composites.

Table 3.4 Longitudinal Young Modulus, E_{11} by calculation.

Category	W_f	W_m	E_{11}
Woven	0.5775	0.4225	16.4649
CSM	0.3082	0.6918	9.3477

Table 3.4 is the Longitudinal Young Modulus, E_{11} which is determine by calculation using the formula given. This Young Modulus only for one direction (along the fibre) and it shows that woven is greater than CSM in terms of E_{11}. This value is very important to complete the next step in this experiment.

3.4 Buckling Test Results

The results from this test are as table and figure below. The trend of these data shows decreasing of critical load for both pinned and fixed. The phenomena were occurred due to water decrease the specimen strength. The decreasing trend is not only for CSM, but it will happen for woven reinforcement forms as well.

Table 3.5 CSM critical load for both fixed and pinned.

Category	Water Uptake %	Fixed (N)	Pinned (N)
CSM0	0.0000	35.895	9.13
CSM1	0.8656	35.595	8.79
CSM2	1.2129	35.465	8.53
CSM3	1.4215	34.235	8.46
CSM4	1.5699	30.340	7.79

The graph shows that critical load for CSM-polyester is higher than woven-polyester. This is because CSM is assume to be the isotropic type and woven as an orthotropic type. So, CSM can we considered as a unidirectional GFRP. Unidirectional GFRP can hold high load in 1-direction (i.e. along the fibre) but not in 2-direction (transverse to the fibre). In this case, the buckling load is assumed to be applied in the 1-direction.

From the **Figure 4** also, the graph presents the strength of specimens reduces every week. The critical load will decrease after specimens soaked to the water. It proved that the water uptake will decrease their strength. The water uptake will the debond specimens and by this way the failure will occur much faster. The specimens are not broken, but it will buckle until the specimens become unstable. Failure of the microstructure can be clearly seen by using microscope.

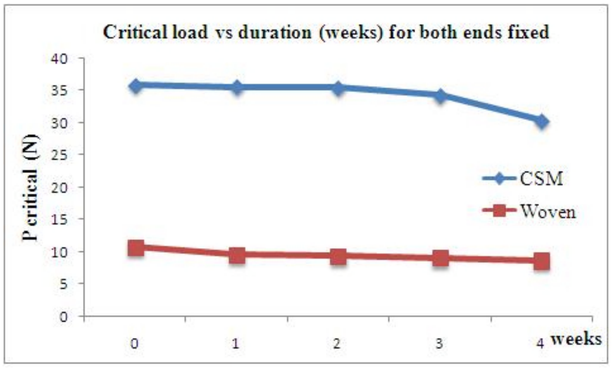


Figure 4 Critical load vs duration for both ends fixed

Figure 5 shows that the structure of woven before load is taken on specimens. Obviously, from the side view shown the structure for woven is already buckling. So, in this case the woven structures already buckle the specimens before the buckling test is performed. For this reason, the critical buckling load for woven is lower than the chopped strand mat (CSM) samples. The results of critical load by experiment proved that CSM-polyester is higher than woven-polyester.

Figure 5

Table 3.6: Effect of water uptake to Critical Load for woven.

Category	Water Uptake %	$P_{critical}$ (N)	Weight increased (g)
W0	0.0000	3.385	0
W1	0.8656	2.960	0.2042
W2	1.2129	2.755	0.3644
W3	1.4215	2.620	0.4577
W4	1.5699	2.150	0.5921

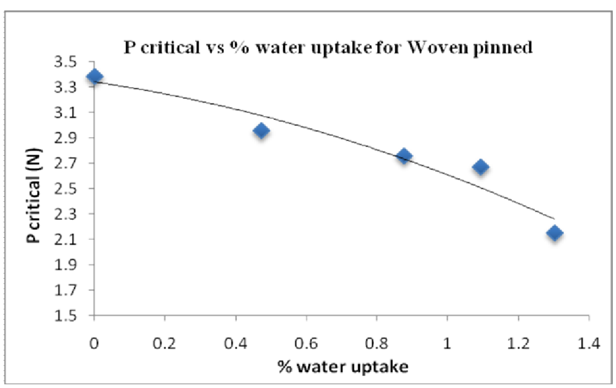


Figure 6: Critical Load vs Water Uptake for Woven

From the table and graph above shows that the critical load for woven will decrease when the percent of water uptake is increase. The critical load will decrease to a constant value when specimens in saturated condition. In conclusion, water uptake in specimen will decrease the strength of structure in terms of critical load.

3.5 Validity Theoretical Results

In order to evaluate the validity of theoretical result, comparison is made between theoretical value and experimental value. **Table 3.7** shows the comparison modulus of elasticity between using calculation and experiment from tensile test.

Table 3.7 Comparison between theoretical and experiment for modulus of elasticity.

Types of fibre	Theoretical	Experimental	Error
Woven	16.46	17.11	0.65
CSM	9.35	6.60	-2.75

Table 3.8 shows the comparison between experimental and theoretical strength of critical load. The table also summarized the relationship between type of fibre and type of ends.

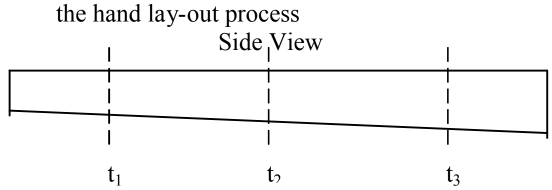
Table 3.8 Theoretical and experimental comparison for critical load.

Types of ends	Types of fibre	Theoretical (N)	Experimental (N)	Error
Fixed	Woven	8.0806	10.74	2.659
	CSM	39.4502	35.895	3.555
Pinned	Woven	2.0202	3.385	1.365
	CSM	9.8625	9.13	0.733

3.6 Speculated Factors Affecting Experimental Result

Throughout the experiments, a few factors have been short-listed as plausible explanation contributing to the errors between experimental derived results to those obtained through theory analysis. They are follows by:

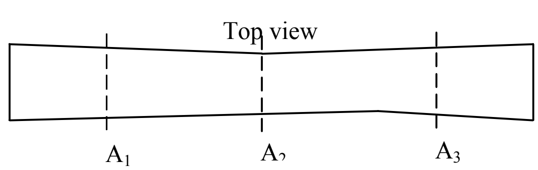
a. Non-uniform thickness, t of the specimen (see **Figure 7**)
Reason: due to human factors while carrying out the hand lay-out process



$t_1 \neq t_2 \neq t_3$

Figure 7 Thickness of specimens

b. Non-uniform effective area (A) of specimen (see **Figure 8**)
Reason: occurred during the cutting process of specimens into desired dimensions



$A_1 \neq A_2 \neq A_3$

Figure 8 Non-uniform of area

As a result, the non-uniform effective area of specimen had displayed the different value of tensile strength and modulus Young.

c. Non-uniform distribution of fiber and resin phases during the hand lay-up process (see **Figure 9**).
Reason: due to the fraction to polyester resin weight fraction is not uniform at several portions of the specimen.

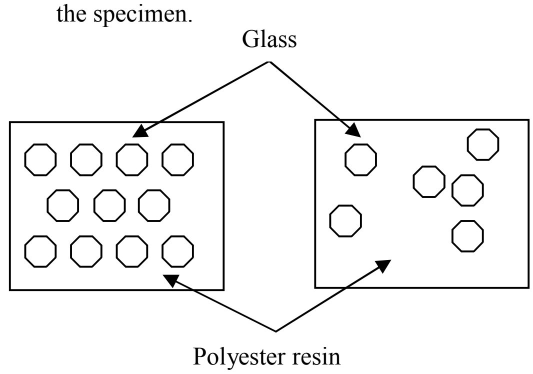


Figure 9 Non uniform distributions of fibre and resin

IV. CONCLUSION

Water uptake was found to have significant effects on critical load of composite as well as on mechanical properties. From experiment or Euler theory shows that the critical load will decrease with increasing duration of specimen exposed in water. It is because; water uptake will debonding the specimen laminates.

CSM reinforcement forms has higher critical load than woven due to the structure of the CSM is more rigid if compared to the woven structure which is already buckle before testing. Water absorption of specimens is depending on quantity of resin in structure. So, that's why water uptake for CSM is higher than woven. Volume fraction of fibre, V_f for woven is higher than CSM due to harder for resin enter through the structure of specimen.

This study is carried out in order to investigate the critical load of chopped strand mat (CSM) and woven reinforced forms when exposed to the water. Buckling test is subjected to the compression load. Woven type was weakening in compression load. So, the critical load for woven is lower than CSM. In other hand, the structure of CSM type is more rigid than woven.

Overall, we can say that the factors which contribute to buckling effect of column are as follows:-

a) Geometry of the column; if $I_{xx} > I_{yy}$ then the buckling will probably occur in x direction while if $I_{xx} < I_{yy}$, buckling in the other way, y direction. [11]
b) Fixed support will give high critical load than pinned support because existence moment that resist the deflection specimens.
c) Young's Modulus is also a factor that contributes to the phenomenon of buckling.

When the glass/polyester composites are immersed in the water, water uptake would happen. This is the results of capillarity of the materials and the water absorption of the hydrophilic groups in the glass fiber and the unsaturated polyester. The weight uptake would increase with prolonged immersion time until the water uptake in the composite is unsaturated. The reaction between the water molecules and the matrix would deteriorate the interphase as a result the material become weak.

The effect of moisture or water uptake on the properties of polymer composites is an important issue, further studies are necessary.

ACKNOWLEDGEMENT

The authors would like to express their thanks to the Universiti Malaysia Pahang for funding this project.

REFERENCES

[1] Reddy, Junuthula Narasimha, (1997), "*Theory and analysis of Composite Plates*", Texas, Department of Mechanical Engineering Texas A&M University, college station, texas, USA
[2] Dr. Amran Alias, Dr. Yob Saed Ismail, 2003 "*Composite Materials*", Faculty of Mechanical Engineering, UTM Skudai, Johor.
[3] Davies, P. (1996) ''Application of composites in a marine environment: Status and problems'', Durability analysis of structural composite systems.
[4] Choqueuse, D., Davies, P., Mazeas, F., and Baizeau, R. (1997)''Aging of composites in water: Comparison of five materials in terms of absorption kinetics and evolution of mechanical properties.'' West Conshohocken.
[5] Pritchard, G., and Speake, S. D. (1987) ''The use of water absorption kinetic data to predict laminate property changes.''
[6] Meiarashi, S., Kishima, T., Nishizaki, I., and Sasaki, I. (1998). ''Application of fiber reinforced plastics to construction structural materials. Volume 1: Examples of application of FRP as a primary structural material.'', Public Works Research Institute, Ministry of Construction, Tsukuba, Japan.
[7] Shahruzaman B. Md. Hamdani, (2003), "*Ledingan Topang Bahan Komposit*", UTM Skudai, Fakulti Kejuruteraan Mekanikal.
[8] Itaru Nishizaki & Seishi Meiarashi, "*Long-Term Deterioration of GFRP in Water and Moist Environment*",Journal of Composites for Construction, Vol. 6, ©ASCE 2002.