

DEGRADATION ANALYSIS IN TENSILE PROPERTY AFTER ACCELERATED MOISTURE DIFFUSION IN GLASSFIBRE REINFORCED COMPOSITES

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Abstract— Moisture diffusion is one of the phenomenon observed in Fibre reinforced composites exposed to marine ambience or water body structures. The materials are exposed to variations in temperatures and humidity. Moisture diffusion depends upon the nature of the resin, porosity, temperature, humidity, salt water concentrations, fibre orientation, fibre volume fraction, void content, resin matrix interface, interfacial bonding. Moisture absorption produces debonding of the fibre matrix interface and this deteriorates the mechanical properties of the composites. The amount of degradation depends upon the percentage of moisture absorption which may cause swelling of the matrix phase and weakening/breaking of the matrix/fibre bond. This affects the short term and long term durability of the composites. In this study three types of Glassfibre reinforced composites, Glassfibre/epoxy, Glassfibre/vinylester, Glassfibre/polyester resin laminates are fabricated by hand layup process and compacted in a hot press. Tensile test experiment is performed in UTM on the cured specimens to study the degradation in Tensile property after moisture diffusion at different conditions of accelerated elevated temperatures in hot wet resin matrix and theoretically evaluated and analysed by finite element model.

Keywords— Accelerated testing, Finite element model, Marine ambience, Moisture diffusion, Tensile strength.

1. INTRODUCTION

Moisture absorption is a draw back in Fibre reinforced composites. Fibre reinforced composites are Characterized for moisture absorption due to ordinary plain water immersion, sea water immersion, humidity exposure, etc., as these ageing processes tend to degrade their mechanical properties by weakening the fibre/matrix bond. The water absorption and matrix debonding will vary with the type of resin systems. The degradation is mainly because of the polymeric resin. Most of the water absorption takes place due to resin matrix and water absorption by fibres is very less considering its diffusivity properties and diffusion co-efficients. Therefore the rate of water absorption in fibre reinforced composites depends upon resin matrix, temperature of exposure, humidity and orientation of fibres in composites.

The deterioration in mechanical properties of the composites depends upon the level of moisture absorbed. Saturation moisture levels and the time required for water absorption to reach saturation vary with temperature. Fibre/matrix bonding is very important as the applied load will transfer from matrix to fibre through this interface bond and distribute throughout the area.[4-10] Accelerating the test to a constant controlled temperature, increases the diffusivity coefficients and thereby increases the water absorption dependent on time. Thus the saturation levels can be determined in a shorter time. Moisture absorption behavior depends on temperature, applied load, medium type, time and resin matrix. Of the many factors, temperature influences the moisture diffusion and hence the

degradation levels. Accelerating the temperature to a higher value than room temperature, determines the percentage of moisture content absorbed and the time taken to attain saturation level can be lessened.

II. EXPERIMENT

In this study the three types of laminate specimens, Glass fibre/polyester, Glass fibre/vinylester and Glass fibre/epoxy resin are immersed in ordinary water at different elevated temperatures, and in room temperature at 23°C, and in seawater at elevated temperature, in a climatic chamber, till it attains moisture saturation level and is tested for Tensile Strength degradation in a Tensile test set-up in UTM of 10 ton capacity*. Fibre reinforced composites of Glass fibre/polyester, Glass fibre/vinylester and Glass fibre/epoxy resin are fabricated using Hand lay-upprocess and compacted in a 5 ton Hot press [1].

The composite laminates of 60:40 weight percentage of fibre/matrix ratio was fabricated following the rule of mixtures. 2D woven glass fabric of 360 gsm was used to interlay between the resin matrix till a 9 layered composite laminate structure was developed. This was cured in a Hot press maintained at 115°C for 2 hours and kept in a Thermal chamber for post curing maintained at 115°C for 3 hours. After curing, the specimens were cut according to ASTM D 3039 standard (230x20x3mm) and the edges were coated with a Teflon sealant. The moisture absorption was determined by the weight gain method, at saturation level, till no weight gain was observed. A sample size of three was taken for the experiment.

2.1. Observations and Results

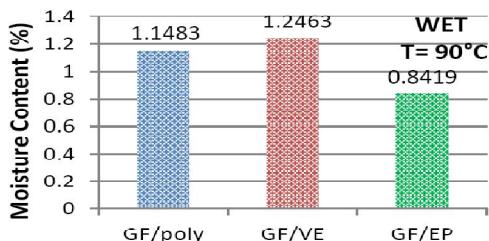


Fig.1. Moisture content(%) of different types of laminates in freshwater 90°C .

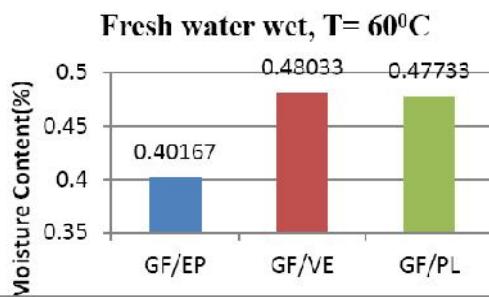


Fig.2. Moisture content(%) of different types of laminates in freshwater 60°C .

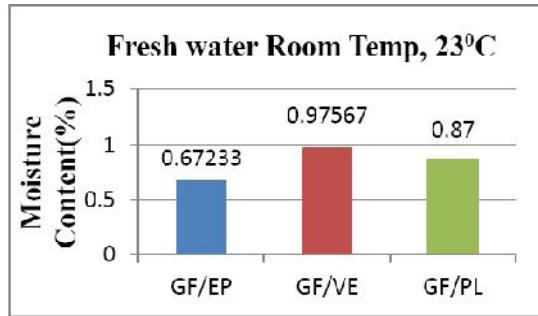


Fig.3. Moisture content(%) of different types of laminates in freshwater at room temperature 23°C .

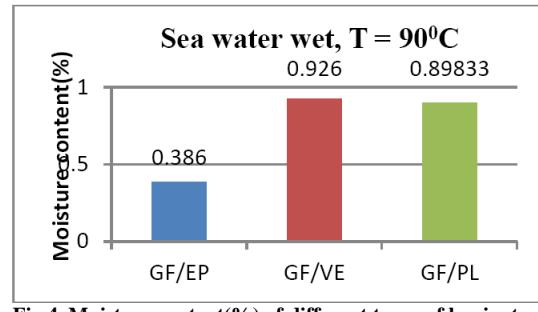


Fig.4. Moisture content(%) of different types of laminates

Figure 1 to Figure 4 shows the maximum Moisture content(%) of the three types of laminates at different temperature conditions.

III. TENSILE TEST IN UTM

The Tensile test to ascertain Tensile strength was conducted as per ASTM D 3039 standard, with specimen dimensions (230x20x3)mm. A 10 ton capacity UTM was used for testing purpose. The test specimens were gripped by wedge grippers, maintaining a guage length of 180 mm and loading

rate of 1mm/min. The load is applied till the peak load is reached. Figure 5 to Figures 28, shows the graphs for the three laminates for dry and wet specimens before and after moisture diffusion respectively. The amount of degradation of each type of laminate were studied and tabulated as shown in Table 1.

3.1. Observations and Results

Load Vs Displacement, GF/EP (FW 60°)

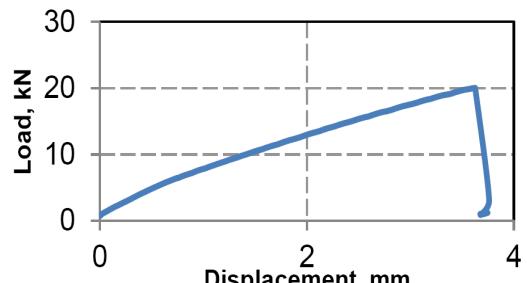


Fig.5. Load vs Displacement graph of Glassfibre/epoxy in freshwater 60°C .

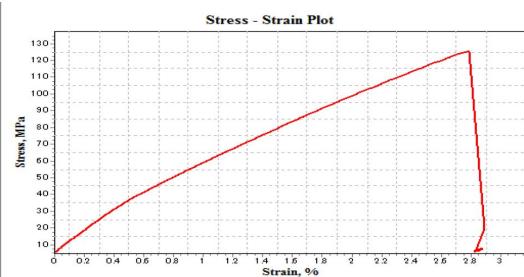


Fig.6. Stress vs Strain graph of Glassfibre/epoxy in freshwater 60°C .

Load Vs Displacement, GF/PL (FW 60°)

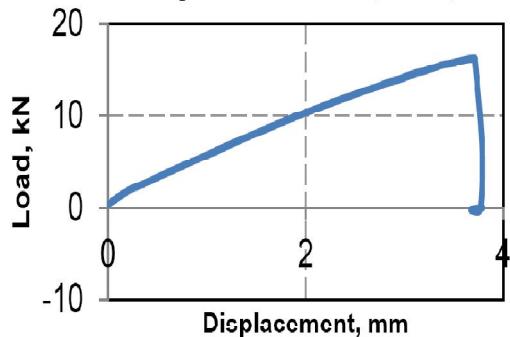


Fig.7. Load vs Displacement graph of Glassfibre/polyester in freshwater 60°C .

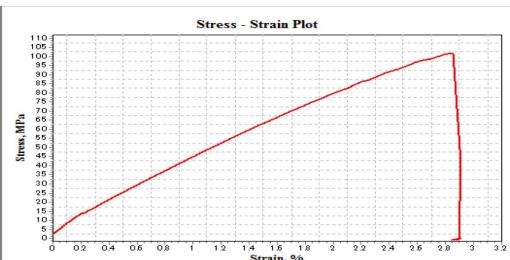


Fig.8. Stress vs Strain graph of Glassfibre/polyester in freshwater 60°C .

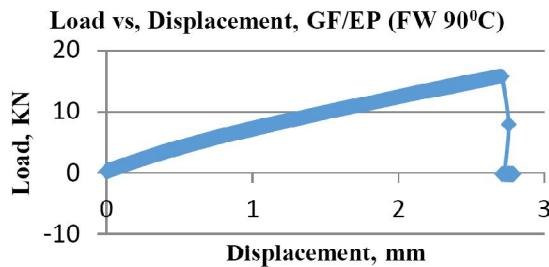


Fig.9. Load vs Displacement graph of Glassfibre/epoxy in freshwater 90°C.

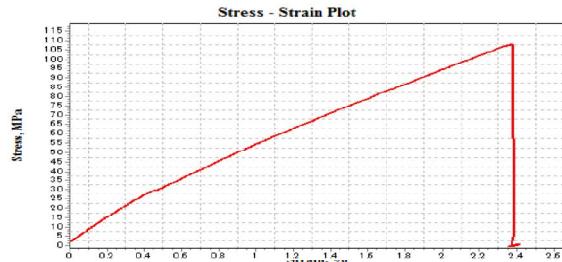


Fig.10. Stress vs Strain graph of Glassfibre/epoxy in freshwater 90°C.

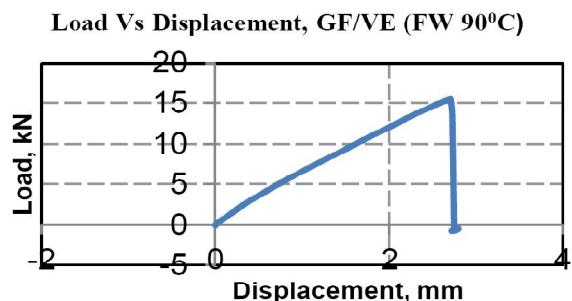


Fig.11. Load vs Displacement graph of Glassfibre/vinylester in freshwater 90°C.

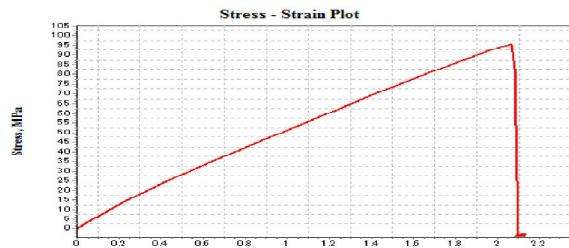


Fig.12. Stress vs Strain of Glassfibre/vinylester in freshwater 90°C.

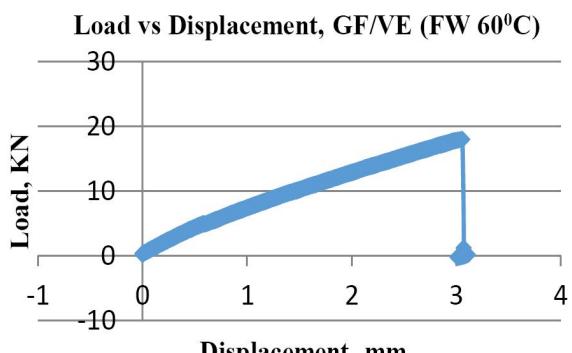


Fig.13. Load vs Displacement of Glassfibre/vinylester in freshwater 60°C.

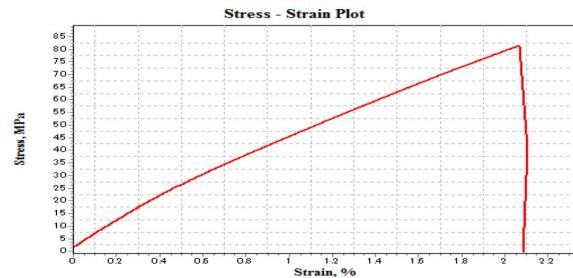


Fig.14. Stress vs Strain of Glassfibre/vinylester in freshwater 60°C.

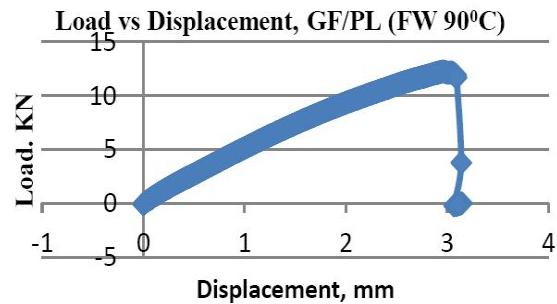


Fig.15. Load vs Displacement of Glassfibre/polyester in freshwater 90°C.

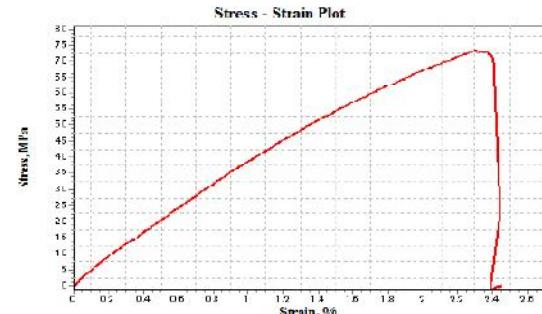


Fig.16. Stress vs Strain of Glassfibre/polyester in freshwater 90°C.

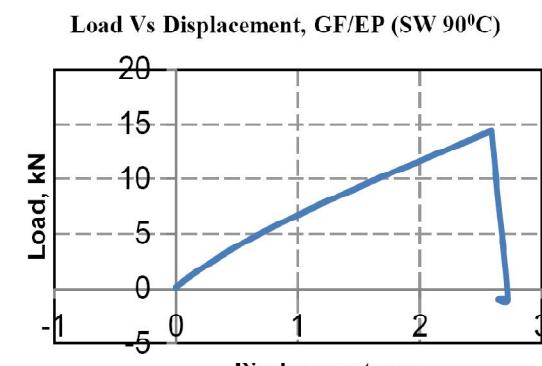


Fig.17. Load vs Displacement of Glassfibre/epoxy in seawater 90°C.



Fig.18. Stress vs Strain of Glassfibre/epoxy in seawater 90°C.

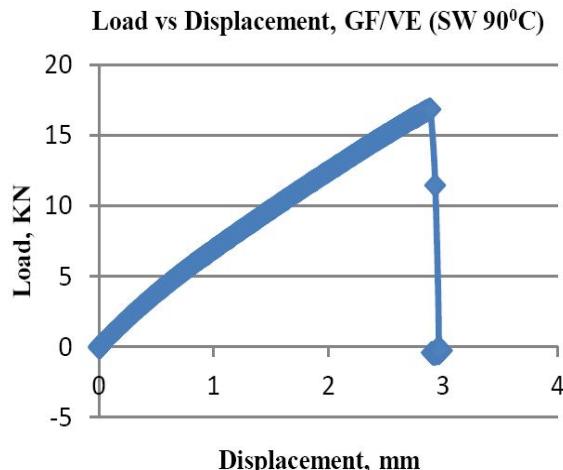


Fig. 19. Load vs Displacement of Glassfibre/vinylester in seawater 90°C.

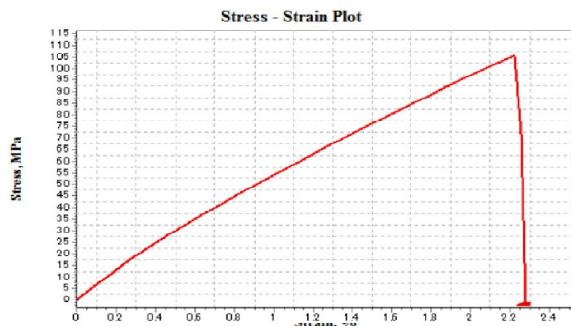


Fig. 20. Stress vs Strain of Glassfibre/vinylester in seawater 90°C.

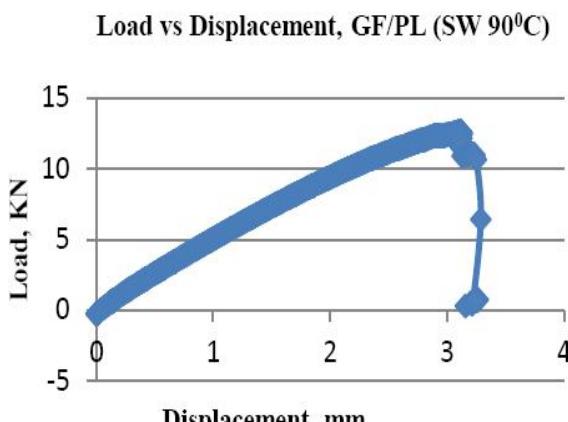


Fig. 21. Load vs Displacement of Glassfibre/polyester in seawater 90°C.

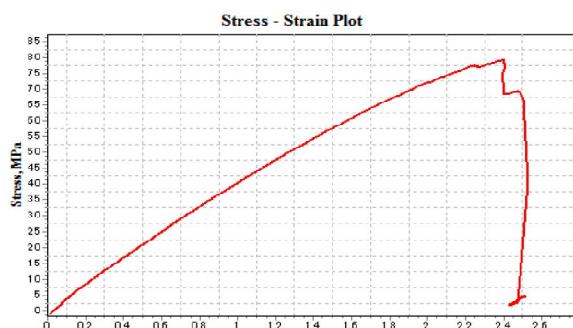


Fig. 22. Stress vs Strain of Glassfibre/polyester in seawater 90°C.

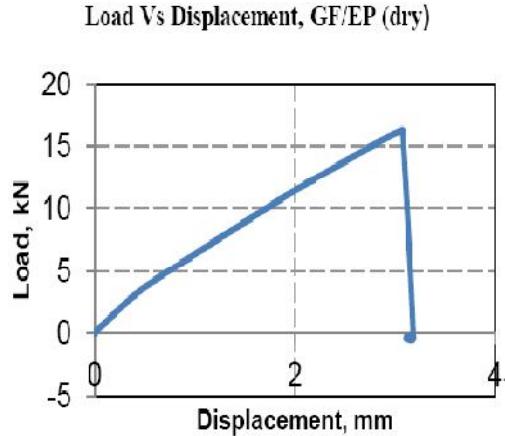


Fig. 23. Load vs Displacement of Glassfibre/epoxy dry.

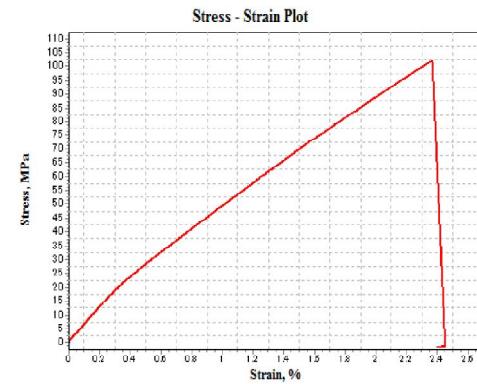


Fig. 24. Stress vs Strain of Glassfibre/epoxy dry.

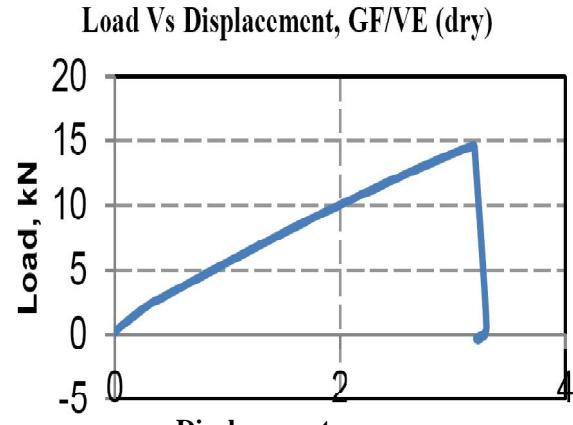


Fig. 25. Load vs Displacement of Glassfibre/vinylester dry.

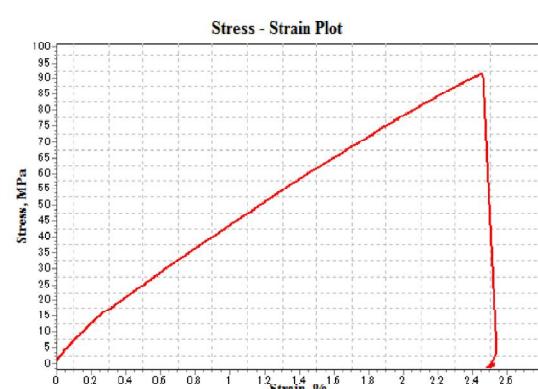


Fig. 26. Stress vs Strain of Glassfibre/vinylester dry.

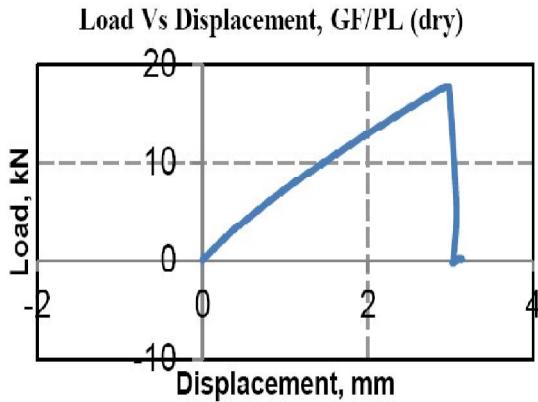


Fig. 27. Load vs Displacement of Glassfibre/polyester dry.

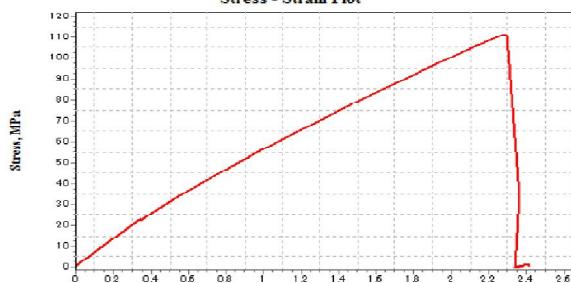


Fig.28. Stress vs Strain of Glassfibre/polyester dry.

Sl.No	Specimens	Peak load(KN)	Peak stress(MPa)	Strain	Young's Modulus(MPa)
1	GF/EP (FW60)	17.771	296.18	0.02289	12939.27
2	GF/VE (FW60)	16.302	271.7	0.02371	11459.3
3	GF/PL (FW60)	14.609	243.48	0.0245	9938.1
4	GF/EP(SW90)	16.858	280.97	0.02229	12605.05
5	GF/VE(SW90)	14.343	237.38	0.01992	11916.83
6	GF/PL(SW90)	12.648	210.8	0.02395	8801.67
7	GF/EP(dry)	20.034	333.9	0.0279	11967.74
8	GF/VE(dry)	18.039	300.65	0.02379	12637.66
9	GF/PL(dry)	16.252	270.86	0.02856	9484.12
10	GF/EP(FW90)	15.781	263.01	0.02066	12730.4
11	GF/VE(FW90)	15.502	258.36	0.02067	12499.59
12	GF/PL(FW90)	12.255	204.25	0.02300	8880.43

IV. DISCUSSION

4.1. Macro scale analysis (Laminate level).

Some current finite element software packages such as ANSYS analyse a composite structure by computing the stiffness matrix for a laminate with a given stacking order, and use it as input for analysis. This kind of analysis is adequate to calculate the deformation response for buckling or dynamic loads, however, void content, inadequate cure, fibre misalignment, etc., cannot be accounted for the stiffness matrix computations.

ANSYS R15.0 finite element software package is used for Tensile test, analysis type static structural with the following procedure.

→ Element is added in element type, new material is created in Engineering data (as GF/EP(dry)), using Young's modulus and Poissons ratio.

→ Sample material is generated inside geometry according to ASTM standard (230 x 20 3)mm, by setting Metric as standard units.

→ Suitable boundary conditions are set to carry out the tensile test.

→ Automatic mesh is generated, controlled by the program.

→ Load magnitude is defined in newtons.

→ Solution is run to get Total deformation, equivalent (von-mises) stress, and equivalent (von-mises) strain.

→ Finally, report is generated, and same procedure is carried out for all other materials by changing the material values and solution is generated.

→ The experimental and ansys results correlate with each other.

4.2. Observations and results

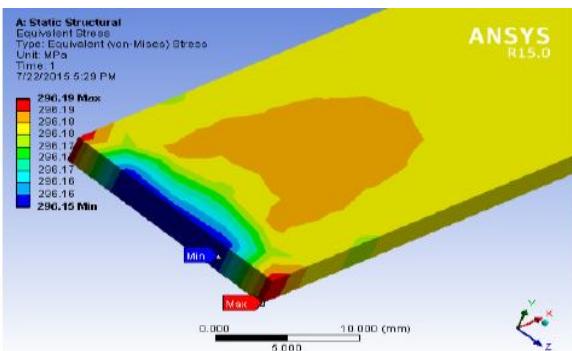


Fig. 29. Stress distribution of Glassfibre/epoxy in freshwater 60°C.

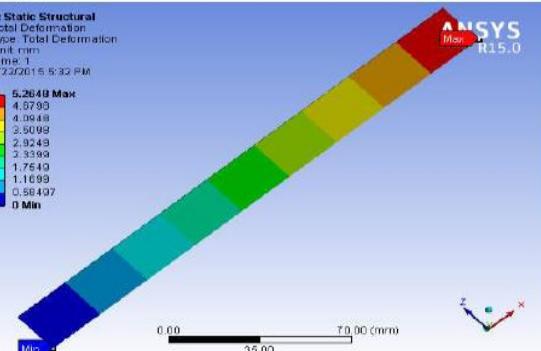


Fig.30. Total deformation of Glassfibre/epoxy in freshwater 60°C.

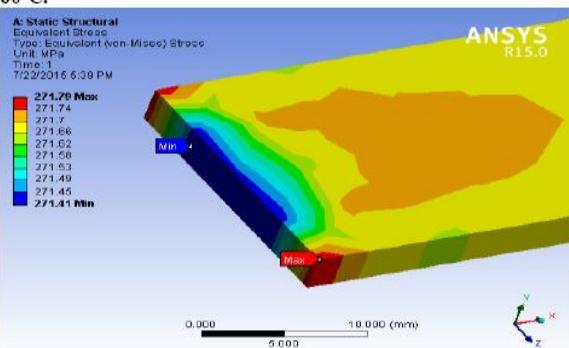


Fig.31. Stress distribution of Glassfibre/vinylester in freshwater 60°C.

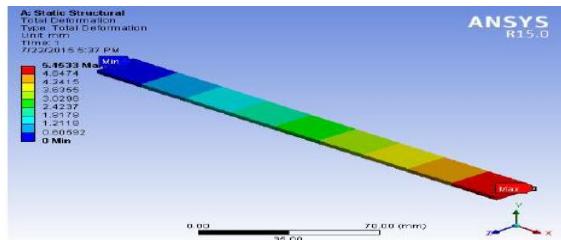


Fig.32. Total deformation of Glassfibre/vinylester in freshwater 60°C.

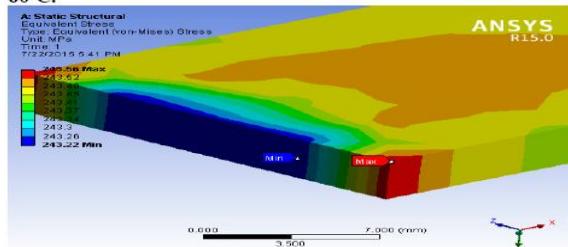


Fig.33. Stress distribution of Glassfibre/polyester in freshwater 60°C.

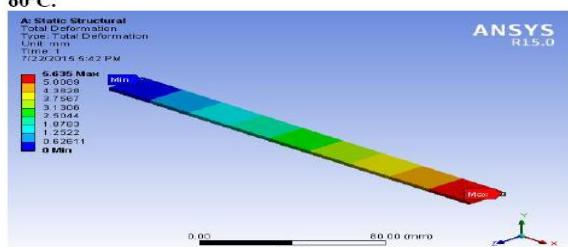


Fig.34. Total deformation of Glassfibre/polyester in freshwater 60°C.

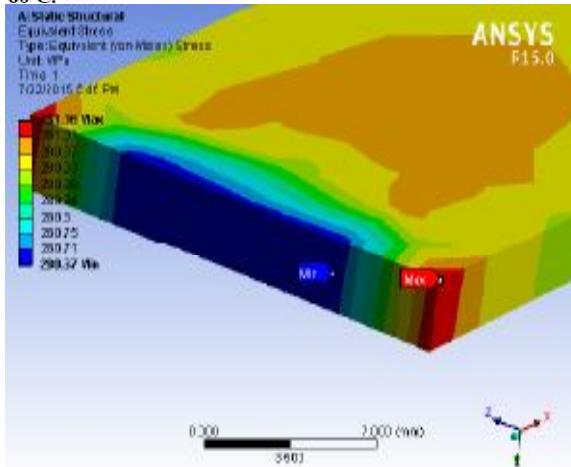


Fig.35. Stress distribution of Glassfibre/epoxy in seawater 90°C.

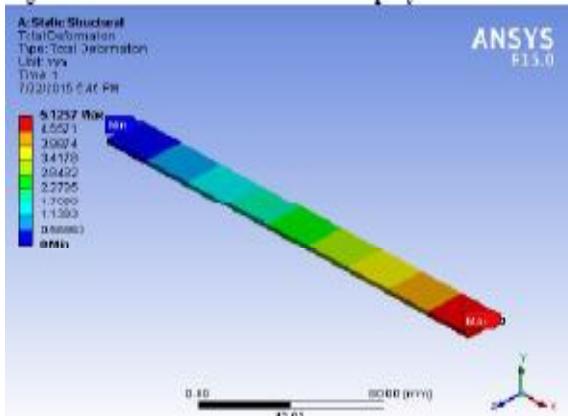


Fig.36. Total deformation of Glassfibre/epoxy in seawater 90°C..

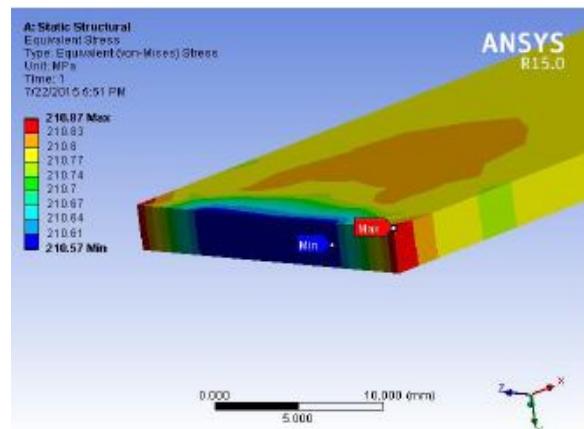


Fig.37. Stress distribution of Glassfibre/polyester in seawater 90°C.

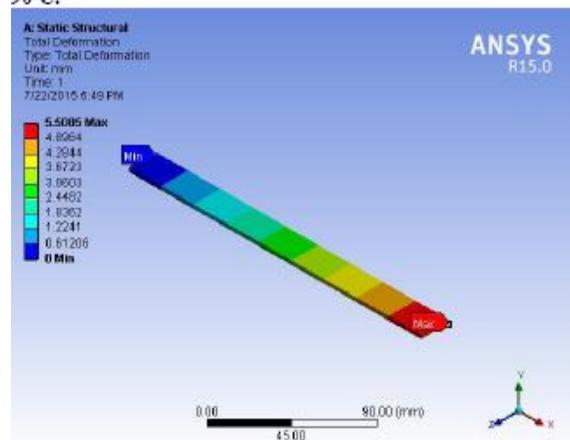


Fig.38. Total deformation of Glassfibre/polyester in seawater 90°C.

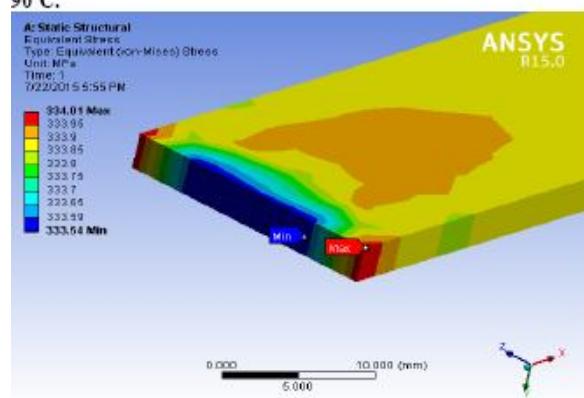


Fig.39. Stress distribution of Glassfibre/epoxy dry.

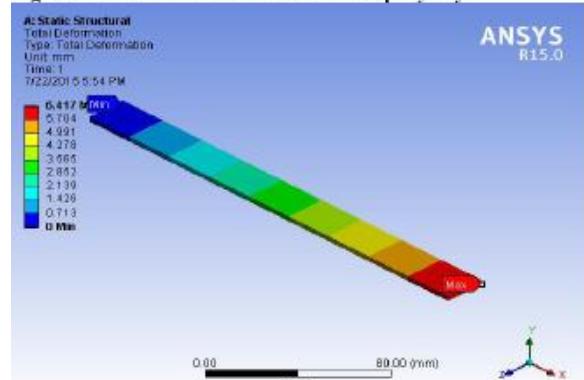
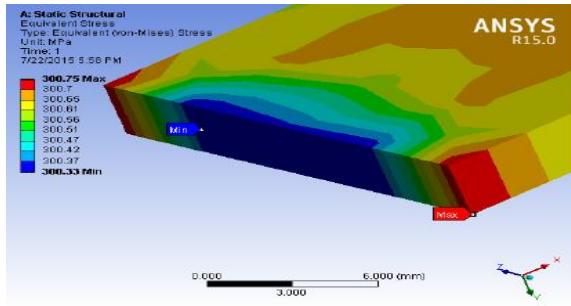
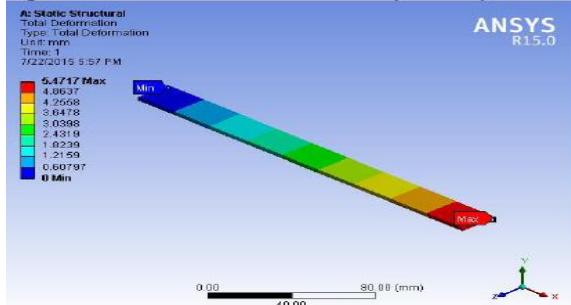
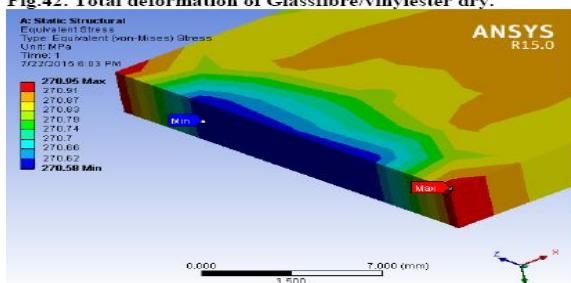
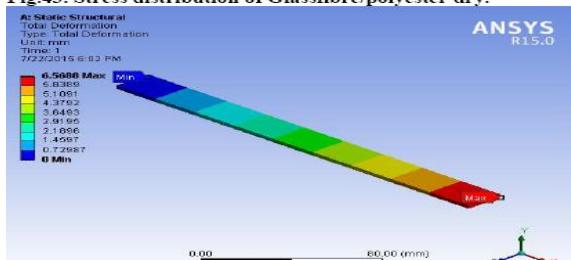
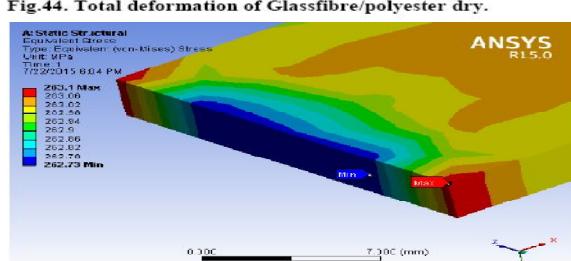
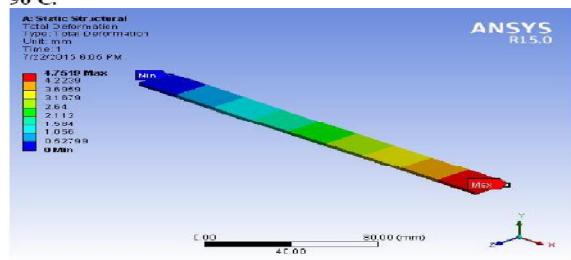
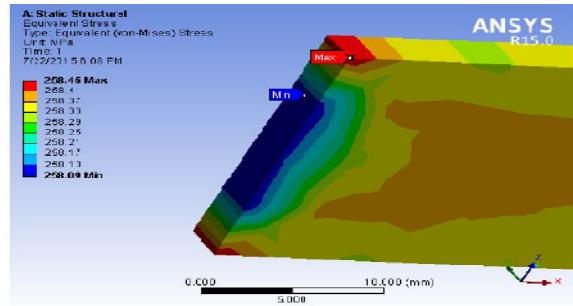
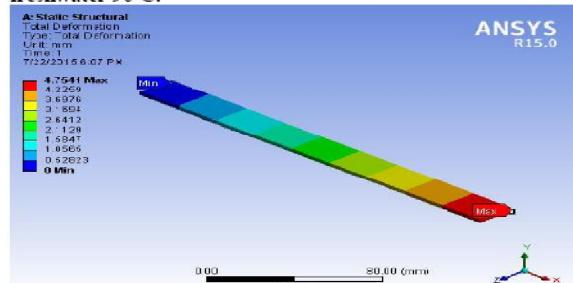
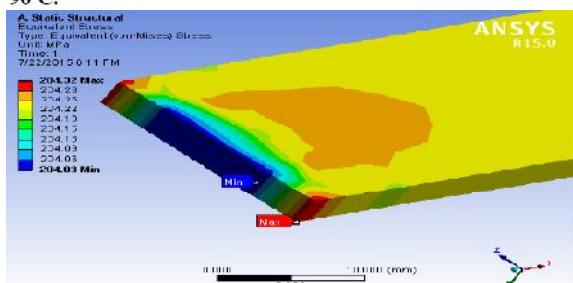
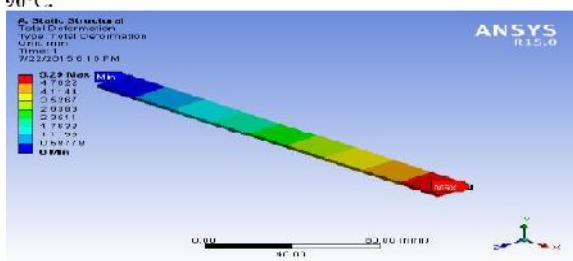


Fig.40. Total deformation of Glassfibre/epoxy dry.

**Fig.41.** Stress distribution of Glassfibre/vinylester dry.**Fig.42.** Total deformation of Glassfibre/vinylester dry.**Fig.43.** Stress distribution of Glassfibre/polyester dry.**Fig.44.** Total deformation of Glassfibre/polyester dry.**Fig.45.** Stress distribution of Glassfibre/epoxy in freshwater 90°C.**Fig.46.** Total deformation of Glassfibre/epoxy in freshwater 90°C.**Fig.47.** Stress distribution of Glassfibre/vinylester in freshwater 90°C.**Fig.48.** Total deformation of Glassfibre/vinylester in freshwater 90°C.**Fig.49.** Stress distribution of Glassfibre/polyester in freshwater 90°C.**Fig.50.** Total deformation of Glassfibre/polyester in freshwater 90°C.

4.2. Activation energy

Activation energy of the degradation process increases with increasing cure temperature and thereby increasing the cross-link molecules, raises the amount of thermal energy required to degrade the structure. Degradation of cured specimens is a multistep process consisting of chain breaking, char formation or carbonization and char stabilization[11]. Degradation begins at the points containing the aromatic ring structures and network cyclic structures. In this study the degradation mechanics is performed by isothermal heating rate method. The other method is by varying the heating rate.

The Arrhenius equation gives the quantitative basis of the relationship between the activation energy and the rate at which a reaction proceeds. From the

Arrhenius relationship, the activation energy can be expressed as:

$$K = Ae^{-E_a/RT} \quad (1)$$

A is the frequency factor for the reaction, R is universal gas constant = 8.314 J/cal, K is reaction rate coefficient. The equation suggests that activation energy depends on temperature, valid within the range of the Arrhenius equation and is cancelled by the temperature dependence of K. Thus Ea can be evaluated from the reaction rate coefficient at any temperature within its validity. Reaction rate constant can be extended with the diffusion coefficient constant, and thus can be written as:

$$D = Ae^{-E_a/RT} \quad (2)$$

This can be generalised for two different temperatures as:

$$\ln\left[\frac{D_2}{D_1}\right] = \left[-\frac{E_a}{R}\right] * \left[\frac{1}{T_1} - \frac{1}{T_2}\right] \quad (3)$$

Ea can be evaluated from (3). Where, D1 and D2 are the diffusion coefficients at temperatures T1(90°C) and T2(23°C). Thus, the fraction of molecules given by ($e^{-E_a/RT}$) able to react has increased with increase in temperature as shown in Table 2.

Table 2. E_a fraction of molecules.

Specime ns	E _a (J/mol)	Exp(- E _a /RT) at 23°C	Exp(- E _a /RT) at 90°C	% incre ase of fracti on
GF/EP	45037.8	51.93	133252.3	99.9
GF/VE	45751.2	35.87	28282.5	99.8
GF/PL	80.321.7	55.7	47572.0	99.8

When the surface of the fibre reinforced composites is exposed to moisture, it reacts chemically on the exposed surface and propagate through microstructured voids and cracks present in the material. The propagated water will be stagnated at the interface region and it reacts chemically at the interface region. The chemical composition of the resin affects the equilibrium content of water. Larger the water content absorbed in the initial stages, the greater the hydrolysis due to high controlled temperature and large amount of the stresses produced due to swelling in a shorter duration. This is due to water affinity with special functional groups of polymer matrix. Water absorption causes hydrolysis and physical ageing and changes in the resin may be either reversible like plasticizing and swelling or irreversible like hydrolysis and microcracking. Due to this irreversibility secondary cross-linking in the matrix may take place between the hydrogen bond of water and the resin matrix. This phenomenon is dependent on the chemical structure of the resin matrix. These alterations in the fibre/matrix interface which are generally destructive may lead to

degradation of the physical properties and interactions of fibres and resin matrix. Due to this, displacement of fibres may occur causing delamination at the interface when loaded. Thereby it is found that the reduction in mechanical and physical properties takes place due to the conditioning of temperature. Significant reductions are bound to occur in the mechanical properties in matrix like tensile strength is one of them [12].

The theoretical values are calculated using the relation:

$$\sigma = P/A \quad (4)$$

P is peak load in N, A is area of cross-section of specimen in mm².

It is seen from the Tensile test, the results obtained are agreeable with the theoretical values, and correlated with ansys results. After degradation there is a reduction in Tensile strength in fresh water elevated temperature (90°C) by 21% for glass fibre/epoxy laminate specimens, 14% for glass fibre/vinylester specimens, and 24.5% for glass fibre/polyester specimens. Also there is a reduction in Tensile strength in sea water by 15.8% for glass fibre/epoxy specimens, 21% for glass fibre/vinylester specimens and 22% for glass fibre/polyester specimens. This shows that glassfibre/vinylester has better water resisting properties and good in fresh water, and glass fibre/ epoxy has better tensile strength in sea water.



Fig.51. specimens after Tensile test.

The varying diffusion coefficients at different time intervals of exposure to hot water temperature signifies that the quantity of the moisture absorption will vary depending upon the saturation levels of moisture content for each type of laminates, but will remain constant after it reaches equilibrium state with the surroundings at saturation levels. Therefore after exposure to accelerated elevated temperature below the matrix Tg although spontaneous, delamination does not occur, the decrease in apparent tensile strength property is due to the damage or residual stresses generated as a result of thermal activation.

CONCLUSION

The three types of fibre reinforced composites, glass fibre/epoxy, glass fibre/vinylester and glass fibre/polyester resin were fabricated by Hand lay-up process and compacted using a hot press. Experimentation was conducted for the hot wet resin matrix and tested for tensile strength. Degradation mechanisms were analysed theoretically and the experimental results obtained were agreeable and correlated with ansys results.

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