Effects Of Hydrolytic Aging On Glass/Epoxy, Kevlar/Epoxy, And Hybrid (Glass/Kevlar/Epoxy) Composites

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Abstract

The primary objective of the research is to develop a fundamental understanding of the effects of hygrothermal exposure on Glass/Epoxy, Kevlar/Epoxy, and Hybrid (Glass/Kevlar/Epoxy) composites. Moisture absorption and its effects on the tensile and flexural strength of the above mentioned composite specimens have been studied. To study the effect of moisture on the Flexural strength 24 number of Glass/Epoxy and 24 number Glass/Kevlar/Epoxy ASTM D 790-02 Flexural Specimens is used. The specimens were conditioned by immersing them into collected sea water and tested for five different periods (every month). The aged and unaged specimens are tested under Uni axial tension and Flexure (3-Point bending) loads using Instron 3367 Universal Testing Machine (UTM). The amount of degradation and the mode of failures of the aged specimens are also investigated. The percentage reduction in tensile and Flexural strength of aged and unaged specimens is analyzed. Scanning electron microscope (SEM) micrograph is used to find out the degradation of the specimens immersed into sea water, and the EDAX results are used to estimate the changes in chemical composition , the atom percentage and weight percentage of the specimens immersed into sea water .

1. Introduction

The Environmental effects are known to cause degradation of the composite and consequent loss of mechanical properties. Considerable efforts were made by researchers to study the effects of moisture and temperature and to develop analytical models for the diffusion process in various composites. G, S.Springer [1] presented extensive work on the moisture absorption behavior of neat epoxy resin, glass and graphite fiber composites based on a Fickian diffusion model. R.Gopalan and M.V.V.Murthy [2] showed that experimental data for simple and hybrid composites comprising both permeable and impermeable fibres have good correlation with the analytical Fickian diffusion model and hence the Fickian model is adequate to characterize these composites for the through thickness moisture diffusion. Edge coating has significant effect on the saturated moisture content in the impermeable fiber composites.

As the properties of any composite depend on the behavior of the matrix, fibres and the interface, it seems essential to know the rate of water absorption in glass/epoxy composites in order to predict their long – term behavior. In many cases water absorption obeys Fick's law and diffusion is driven by the water concentration gradient between the environment and the material producing continuous absorption until saturation is reached [3].R.Gopalan, R.Somashekar and Dattaguru [4] revealed that the moisture absorption in a fiber-matrix composites is by the matrix and fiber -matrix interface in the case of impermeable fibres and fiber and fiber – matrix interface in the case of permeable fiber composite. The moisture absorption causes degradation of strength and stiffness of composites. The degradation is a function of fiber orientation and is quite significant on the matrix dominated properties. The failure process monitored by acoustic emission technique revealed that the effect of hygrothermal altering the failure mechanism from gradual to brittle and catastrophic. G.S.Springer and J.M.Tang [5] presented for accelerated environmental testing of composite which shows the test conditions required to achieve desired moisture content in the shortest time. Data obtained with fiberite T300/934 fabric show that the moisture contents and mechanical properties of the material are nearly the same after "regular" and "accelerated" environmental conditioning.

Testing of hydrothermal Effects on Durability and Moisture Kinetics of fiber-Reinforce Polymer Composites is done by Padmavathi Surathi Vistasp M. Karbhari. The kinetics of fluid sorption E-glass/vinyl ester composites is studied widely using The Fickian and Langmuir diffusion models. The time and temperature dependence of the rate of diffusion and maximum moisture content are analyzed and moisture kinetics data is assessed for performance predictions. It is seen that various processes of degradation, both reversible and irreversible, are induced in the composite materials on exposure to moisture. The durability characteristics of unidirectional E-glass-Vinyl ester composites under the influence of relative humidity and immersion in water at different temperatures are investigated. [6]

The Effect of Aging Environment on the Degradation of Glass Reinforced Epoxy by Somjai Kajorncheappungam; Rakesh R. Gupta and Hota V.S. Ganga Rao. The effects of immersing coupons of glass-reinforced epoxy in four different liquid media at two separate temperatures were investigated in this study aimed at examining the durability of fiber-reinforced plastics currently being used in the construction industry. Composite samples were soaked for up to 5 months in distilled water, a saturated salt solution (30g/100 cc NaCl), a 5 molar NaOH solution, and a 1 molar HCl solution Aging was conducted at room temperature and at 60 °C. Results show that commercial epoxy resins used in GFRPs are fairly durable. It was found that all the solutions marginally degraded the mechanical properties of the neat resin, especially at the higher temperature; this was mainly the result of polymer hydrolysis. The strength of the composites however, was reduced by more than 70% by the acid at room temperature and by the alkali at the elevated temperature. Water immersion was less damaging than either acid or alkali soaking, and immersion in brine had the least effect on mechanical properties. As evidenced by SEM micrographs, the worst cases of damage involved attack on the glass fibers in acid at 60oC compared to room temperature. Therefore, reinforcing glass fibers have to be protected from attack by liquid media to improve the durability of composites.[7]

The failure behaviour and determination of the effects of seawater on composites is carried out by Catherine A. Wood & Walter L.Bradley (1996) Specimens were tested in transverse tension in an environmental Scanning electron Microscope.[8].S.K.Rege, and S.C.Lakkad (1983) found the degradation in compressive, interlaminar and flexural strength is much more severe in salt water than in distilled water. The percentage weight gain is also higher in salt water. [9] Krystyna Imielinska and Laurent Guillaumat (2004) studied glass and aramid laminates are commonly used light – weight materials. The water immersion affected microstuctural integrity of the two composites causing numerous internal defects.[10].M. Akay, S. Kong Ah Mud & A. Stanley (1996) Moisture absorption behaviour and the influence of moisture on the thermal and mechanical properties of Kevlar-49/epoxy-resin laminates have been studied. The laminates were prepared by two different routes, namely autoclaving and oven-curing, and their properties were compared.[11]

Fiber-Reinforced Polymer (FRP) composites offer many advantages over conventional materials for applications in the marine and civil infrastructure areas. Their increasing widespread use emphasizes the need to predict their performance over long periods of time after being subjected to exposure to different environmental conditions. The effects of sea water exposure on Glass/Epoxy, Kevlar/Epoxy, and Hybrid (Glass/Kevlar/Epoxy) composites, moisture absorption and its effects on the tensile and flexural strength of the above mentioned composite specimens have been studied.

2. Experimental Procedure

2.1. Materials

The reinforcement fibres used in this work were Glass fibres and Kevlar fibres. The matrix material used was a home-formulated epoxy resin (bisphenol-A type). The physical properties of carbon fibres, Kevlar fibres, and epoxy resin employed in this study were presented in Table.1

2.2. Fabrication

The GFRP, Kevlar fiber mats were cut at a size of 30cm* 30cm from the fabric. Twelve such fiber mats are required for a Laminate. The epoxy resin is taken at a mass ratio of one to that of the fiber mats and hardener is mixed with the resin at a mass ratio of 0.1. The Laminates were fabricated by hand layup method using a compression moulding machine at a pressure of about 100bar for 24 hours. After curing the Laminates were removed from the mould and cut into tensile specimens as per ASTM D3039 by using Water Jet cutting machine. The Flexural specimens are cut from the laminate as per ASTM D790-02 by Using Water jet cutting machine.

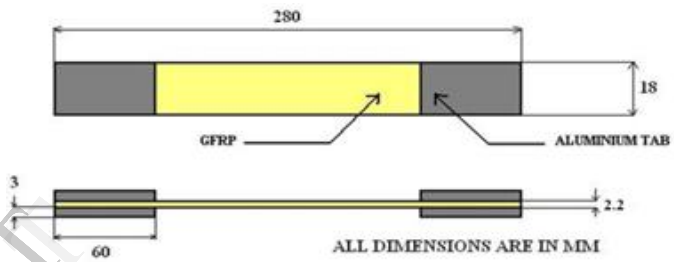

Fig.1 Schematic Representation of Tensile Test Specimen

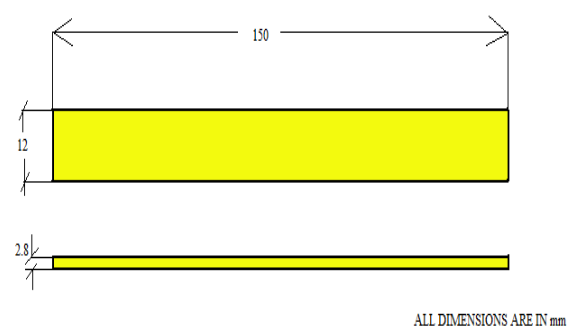

Fig.2 Schematic Representation of Flexural Test Specimen

The fabricated tensile, flexural specimens were immersed into collected sea water for period of 1month, 2months, 3months, 4months and 5 months duration.

2.3 Water absorption test

The initial weights of Glass/Epoxy, Kevlar/Epoxy and Glass/Kevlar/Epoxy tensile and flexural specimens are measured using a digital weighing machine. Then the specimens are immersed in sea water over different periods of time. The final weight of the samples is measured after taking out the specimens from sea water. The percentage of water absorption in the composites was estimated by finding out the difference in weights of the samples before and after aging using the following equation.

$$\Delta M\ (t) = \frac{m_t - m_0}{m_0}$$

Where,

ΔM(t) is moisture uptake,
Mo is the specimen before ageing
Mt is the specimen during ageing

2.4 Mechanical testing

The SPECIMENS were subjected to uni-axial tensile test 30kN INSTRON 3367 universal testing machine.

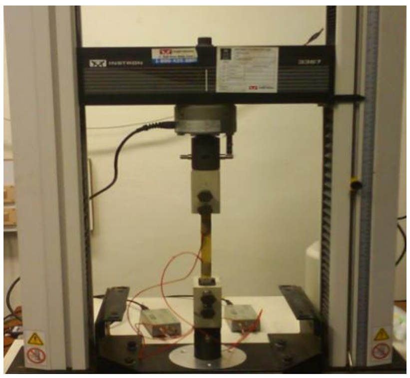

Fig.3. Uni-axial tensile test universal testing machine

The crosshead speed was limited to 0.1mm/min and sampling rate was set to 30pts/sec for tensile Specimens, and 0.5mm/min and sampling rate was set to 30pts/sec for flexural specimens (3 point bending).

3. Results and Discussion

The moisture absorption curves of the glass/epoxy, Kevlar/epoxy, and glass/Kevlar/epoxy hybrid composites are shown in fig 4a and 4b, where moisture uptake is plotted against the immersing time. The absorption is more in Kevlar and hybrid when comparing glass.

3.1. Influence of moisture on failure load

Table 1 represents the results of ultimate failure load of the tensile and flexural specimens for both unaged and sea water immersed specimen. It can be seen that moisture absorption causes the change in the ultimate failure load as determined in the tensile and flexural tests.

3.2. Influence of moisture on the modulus

The table 2 lists the percentage reduction in tensile modulus for Kevlar/Epoxy, Glass/Kevlar/Epoxy and Glass/Epoxy specimens immersed in sea water for a period from 1-5 months when compared with the tensile modulus of unaged Kevlar/Epoxy, Glass/Kevlar/Epoxy and Glass/Epoxy specimen.

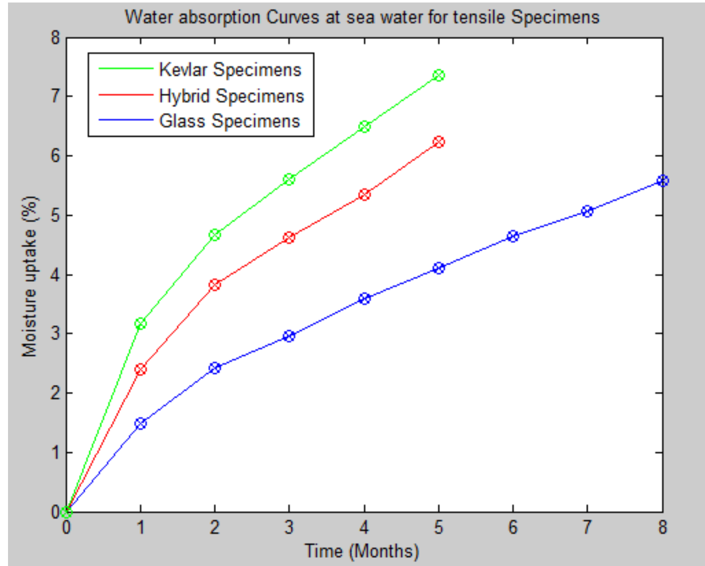

Fig.4a water absorption curve for tensile specimen

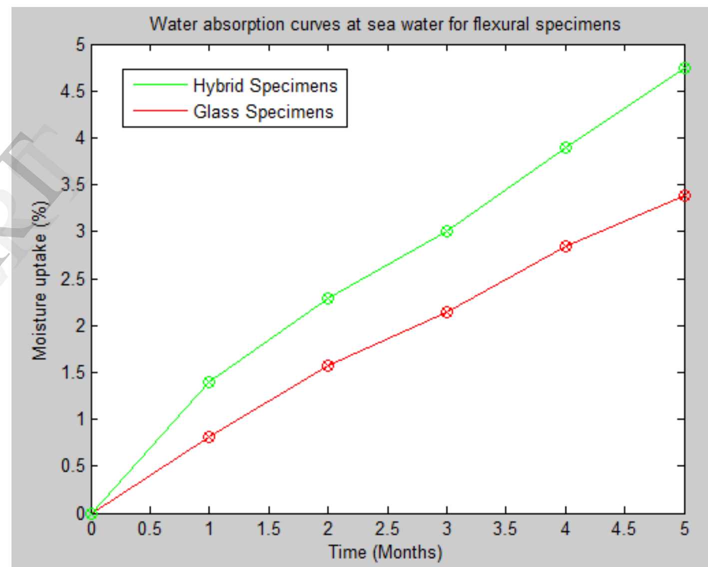

Fig.4b water absorption curve for flexural specimen

Table 1: Ultimate failure load of tensile specimens

ULTIMATE FAILURE LOAD					
	Tensile Specimens			Flexural Specimens	
Duration	Glass	Hybrid	Kevlar	Hybrid	Glass
Un aged	13.94	14.34	21.25	0.1239	0.1861
1 Month	12.57	12.09	19.45	0.1005	0.1327
2 Month	11.87	11.34	17.46	0.0908	0.1183
3 Month	8.338	10.87	14.4	0.0852	0.0989
4 Month	7.735	10.02	13.85	0.0749	0.0916
5 Month	6.174	7.398	12.38	0.0649	0.0854

Table 2: Percentage Reduction of tensile modulus

TENSILE MODULUS (MPa)						
Duration	Kevlar	% of reduction	Kevlar/Epoxy	% of reduction	Glass	% of reduction
Un aged	14450	0	12960	0	13170	0
1 month	13990	3.183	12560	3.086	12940	1.746
2 month	12860	11.00	12330	4.861	12580	4.479
3 month	11530	20.20	11630	10.26	11850	10.02
4 month	10345	28.40	10745	17.09	11260	14.50
5 month	9878	31.64	10320	20.37	10890	17.31

Table 3: Percentage Reduction of Flexural modulus for aged and unaged Glass/Kevlar/Epoxy and Glass/Epoxy

FLEXURAL MODULUS (MPa)				
Duration	Hybrid	% of Reduction	Glass	% of Reduction
Un Aged	11240	0	12460	0
1 month	9505	15.43594	11470	7.945425
2 months	9414	16.24555	10760	13.64366
3 months	9232	17.86477	10320	17.17496
4 months	8655	22.99822	9442	24.22151
5 months	8274	26.3879	9344	25.00803

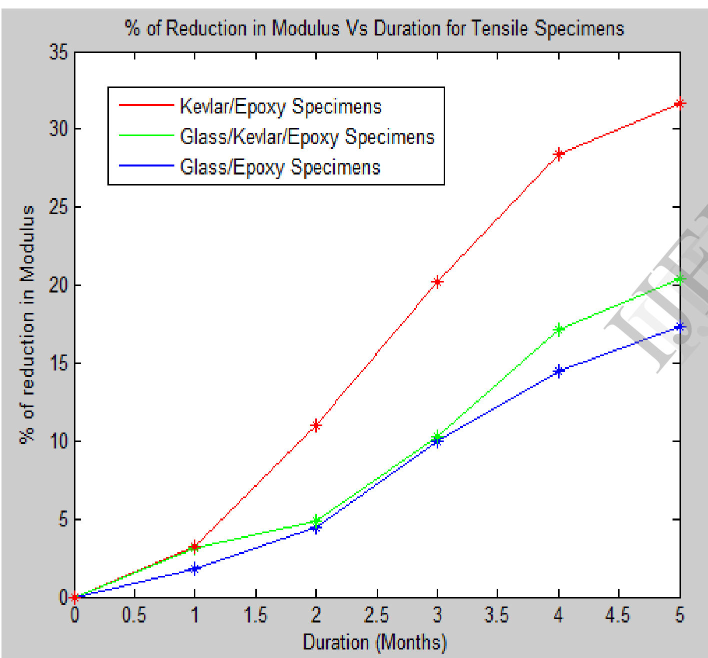

Fig.5: Percentage reduction in modulus with time for tensile specimens

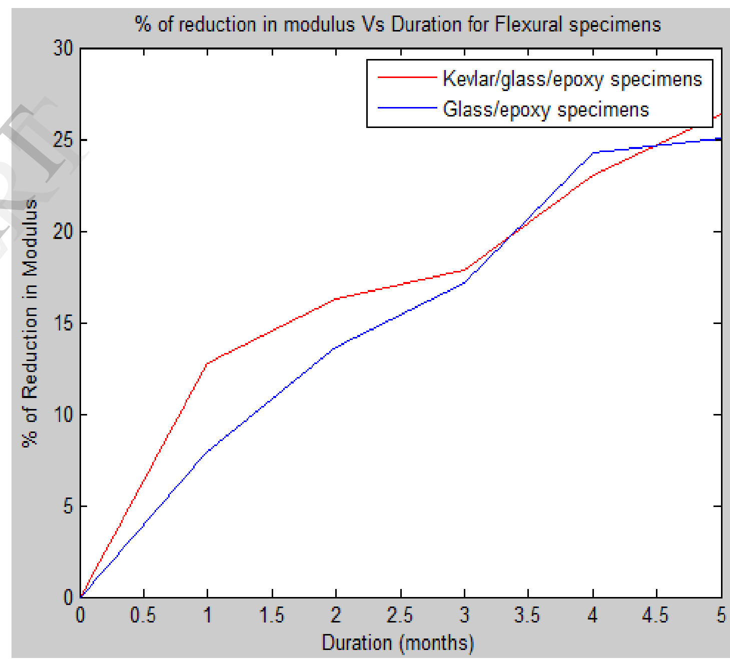

Fig.6: Percentage reduction in modulus with time for flexural specimens

Percentage of reduction in tensile modulus Vs Duration for aged and unaged Kevlar/Epoxy, Glass/Kevlar/Epoxy and Glass/Epoxy specimens

The percentage in modulus is very high for pure Kevlar/Epoxy specimens which is due to the reason that Kevlar absorbs more moisture. The difference in percentage reduction of tensile modulus for aged Glass/Epoxy, Glass/Kevlar/Epoxy specimens are found to be almost same.

Percentage of reduction in Flexural modulus Vs Duration for aged and unaged Kevlar/Epoxy, Glass/Kevlar/Epoxy and Glass/Epoxy specimens

The table 5.8 lists the percentage reduction in flexural modulus for Glass/Kevlar/Epoxy and Glass/Epoxy specimens immersed in sea water for a period from 1-5 months when compared with the tensile modulus of unaged Glass/Kevlar/Epoxy and Glass/Epoxy specimen.

The percentage reduction in flexural modulus is higher for Glass/Kevlar/Epoxy specimens which is due to the fact Kevlar is relatively higher tensile, high impact strength but weaker in Compressive, flexural strength.

4. EDAX RESULTS

Energy Dispersive X-ray Analysis (EDAX) is used to find out the chemical composition, net count, weight percentage, atom percentage and compound percentage. In this study the chemical composition, net count, weight percentage, atom percentage and compound percentage of un aged and aged Glass/Epoxy, Glass/Kevlar/Epoxy specimens for periods of two months and four months is being analysed. Effect of water absorption From that we inferred the absorption of the sea water in the immersed specimen data compared to the unaged data.

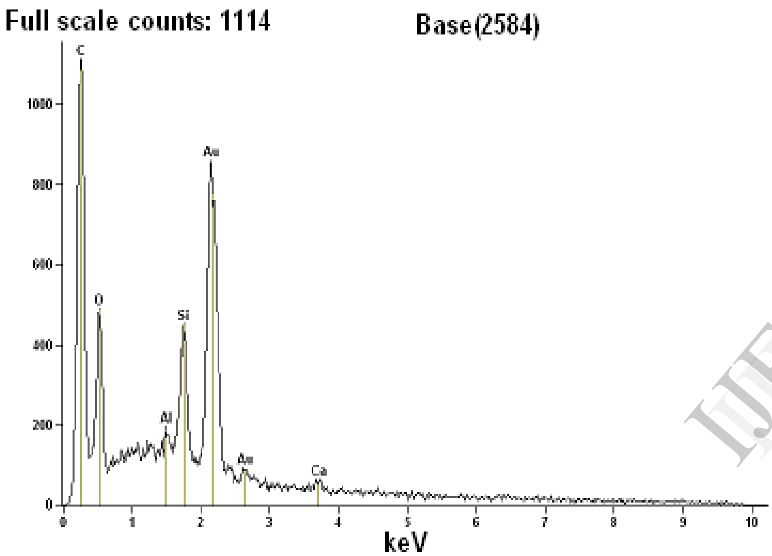

Fig.7: EDAX results for Glass/Epoxy unaged specimen

Table 4: the Element % for Glass/Epoxy unaged Specimen from EDAX test

Element	*Net Counts*	*Net Counts*	*Weight %*	*Atom %*	*Compo und %*
C	11719	+/- 432	58.47	83.09	58.47
O	3574	+/- 222	11.86	12.65	11.86
Al	430	+/- 195	0.31	0.19	0.31
Si	3366	+/- 252	2.45	1.49	2.45
Ca	329	+/- 138	0.70	0.30	0.70
Au	15361	+/- 3r2 900	26.21	2.27	26.21
Total			100.00	100.00	100.00

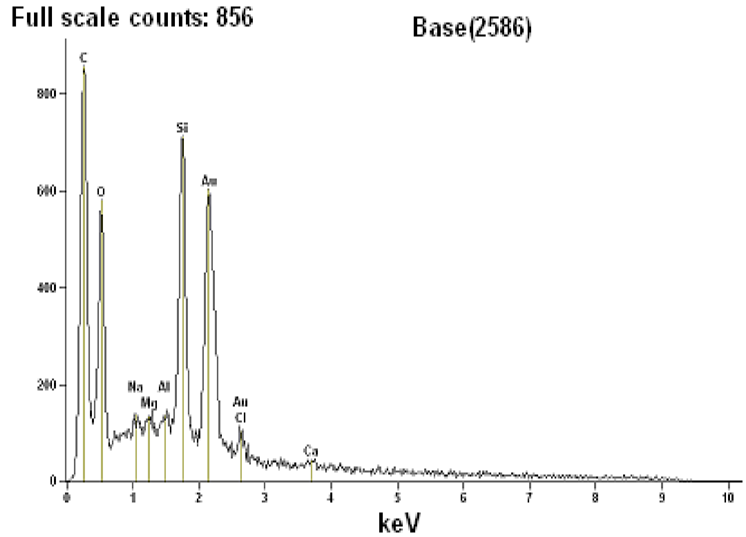

Fig.8: EDAX results for Glass/Epoxy specimen 2 months aged in sea water

Table. 5: the Element % for Glass/Epoxy 2 months aged specimen in sea water from EDAX test

Elem ent	***Net Counts***	***Net Counts Error***	***Weig ht %***	***Atom %***	***Compo und %***
C	7822	+/- 930	53.42	75.40	53.42
O	4540	+/- 390	16.95	17.80	16.95
Na	209	+/- 156	0.27	0.20	0.27
Mg	253	+/- 165	0.20	0.14	0.20
Al	355	+/- 183	0.30	0.19	0.30
Si	7183	+/- 474	6.19	3.73	6.19
Cl	668	+/- 159	0.92	0.51	0.92
Ca	198	+/- 120	0.50	0.21	0.50
Au	10399	+/- 834	21.27	1.83	21.27
Total			100	100	100

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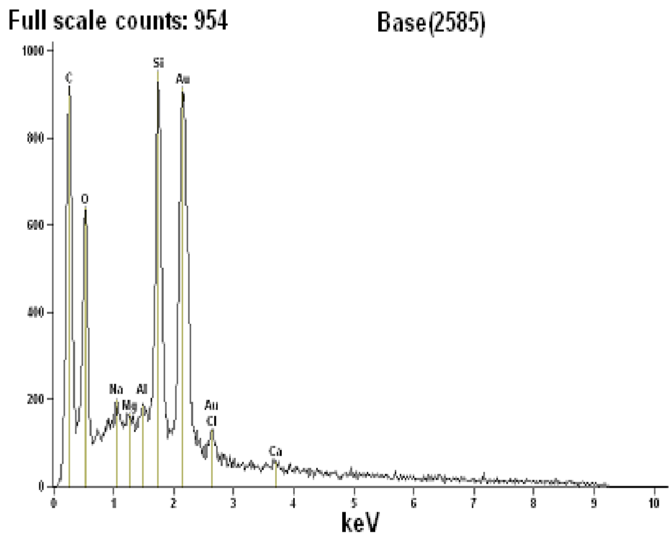

Fig.9: EDAX results for glass/epoxy specimens 4 months aged in sea water

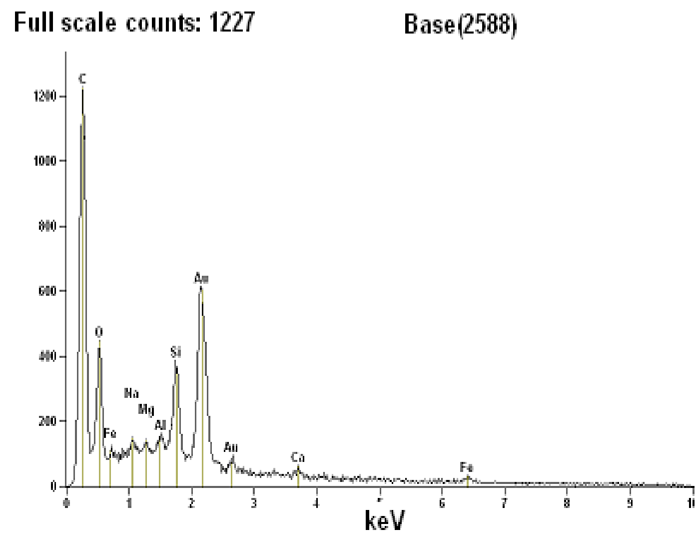

Fig.10: EDAX results for Glass/Kevlar/epoxy un aged specimen

Table 6: the Element % for Glass/Epoxy 4 months aged specimen in sea water from EDAX test

Element	***Net Counts***	***Net Counts Error***	***Weight %***	***Atom %***	***Compound %***
C	8519	+/- 981	49.83	75.39	49.83
O	4864	+/- 423	14.60	16.59	14.60
Na	446	+/- 183	0.46	0.37	0.46
Mg	221	+/- 189	0.14	0.10	0.14
Al	397	+/- 213	0.27	0.18	0.27
Si	9071	+/- 549	6.36	4.12	6.36
Cl	852	+/- 183	1.12	0.58	1.12
Ca	221	+/- 141	0.45	0.21	0.45
Au	16081	+/- 999	26.75	2.47	26.75
Total			100.00	100.00	100.00

Table 7: the Element % for Hybrid un aged specimen from EDAX test

Element	***Net Counts***	***Net Counts Error***	***Weight %***	***Atom %***	***Compound %***
C	12374	+/- 441	63.10	84.09	63.10
O	3180	+/- 234	11.65	11.55	11.65
Mg	285	+/- 168	0.20	0.13	0.20
Al	436	+/- 183	0.33	0.20	0.33
Si	3092	+/- 393	2.43	1.38	2.43
Ca	267	+/- 123	0.60	0.24	0.60
Fe	225	+/- 123	3.12	0.89	3.12
Au	10125	+/- 504	18.56	1.51	18.56
Total			100.00	100.00	100.00

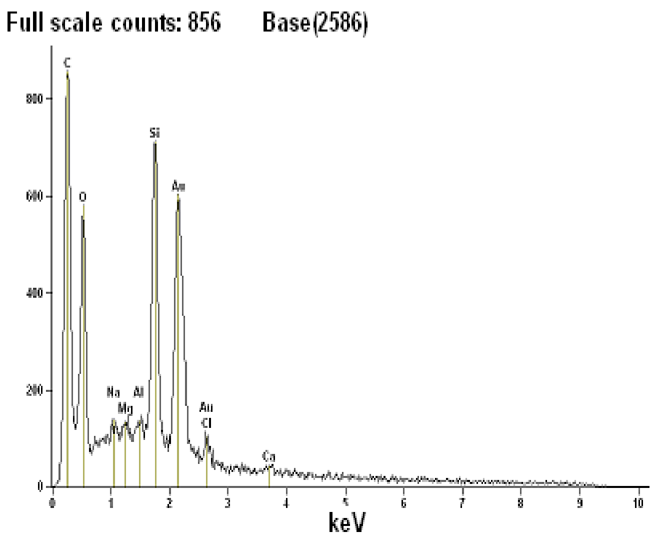

Fig.11: EDAX results for Glass/Kevlar/Epoxy 2 months aged specimen in sea water

Table 8: Element % for Glass/Kevlar/Epoxy 2 months aged specimen from EDAX test

Element	*Net Counts*	*Net Counts Error*	*Weight %*	*Atom %*	*Compound %*
C	7760	+/- 927	45.72	75.94	45.72
O	4102	+/- 243	12.36	15.41	12.36
Na	762	+/- 351	0.81	0.70	0.81
Mg	451	+/- 210	0.29	0.24	0.29
Al	411	+/- 222	0.29	0.21	0.29
Si	6176	+/- 531	4.38	3.11	4.38
Cl	688	+/- 384	0.92	0.52	0.92
K	223	+/- 144	0.38	0.19	0.38
Ca	173	+/- 144	0.36	0.18	0.36
Au	20715	+/-1098	34.49	3.49	34.49
Total			100	100	100

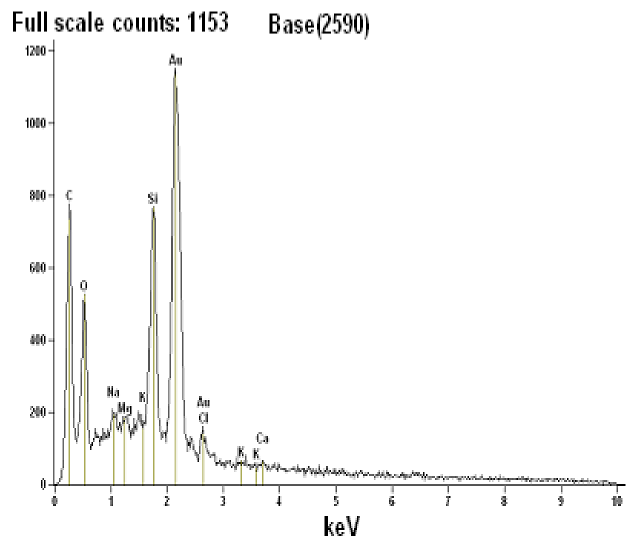

Fig.12: EDAX results for Glass/Kevlar/Epoxy 4 month aged specimen in sea water

Table 9: Element % for Glass/Kevlar/Epoxy 4 months aged specimen from EDAX test

Element	*Net Counts*	*Net Counts Error*	*Weight %*	*Atom %*	*Compound %*
C	6712	+/- 894	43.68	74.83	43.68
O	3775	+/- 399	11.94	15.36	11.94
Na	644	+/- 342	0.72	0.64	0.72
Mg	441	+/- 207	0.30	0.25	0.30
Si	7392	+/- 537	5.52	4.05	5.52
Cl	864	+/- 195	1.23	0.71	1.23
K	193	+/- 144	0.35	0.18	0.35
Ca	204	+/- 147	0.45	0.23	0.45
Au	20326	+/-1080	35.80	3.74	35.80
Total			100.00	100.00	100.00

From the EDAX results it was found that Na+ and Cl- , were not present in unaged specimens whereas for Glass/Epoxy specimens immersed in sea water for two months Na+ is 0.20 percentage by weight and Cl- is 0.92 percentage by weight and the percentage of Na+ has increased to 0.46 percentage by weight and Cl- 1.12 percentage by weight for 4 months aged specimens.

And the EDAX results it was found that Na+ and Cl- , were not present in unaged specimens whereas for Glass/Kevlar/Epoxy specimens immersed in sea water for two months Na+ is 0.81 percentage by weight and Cl- is 0.92 percentage by weight and the percentage of Na+ has increased to 0.72 percentage by weight and Cl- 1.23 percentage by weight for 4 months aged specimens.

CONCLUSSION

The effect of water absorption on the mechanical (tensile & flexural) properties of glass/epoxy, Kevlar/epoxy, glass/Kevlar/epoxy fibre reinforced polymer composites has been studied the immersion in sea water for the period of 5 months. The data presented in the present work show that the procedure adopted is suitable for environmental (sea water immersed) testing of composite materials. The environmental procedure introduces moisture into the material faster than the regular procedure. For many problems of practical interest, the conditions to be employed in the environmental tests can be determined from the simple charts obtained in this work. The investigation has revealed that the moisture absorption causes the degradation of strength and stiffness of the composites.

It shows the moisture uptake increase with Kevlar/epoxy composites than compared to glass/epoxy composites due to the aramid fibre. The water absorption pattern of these composites is found to follow Fickian behaviour. Water uptake behaviour is radically altered at higher duration due to significant moisture induced degradation. Exposure to moisture results in significant drops in tensile and flexural properties due to the degradation of the fibre matrix interface. The acoustic emission measurements reveal that moisture content plays a significant role in the behaviour of the material during the failure process. The SEM/EDAX results are used to validate the degradation and the absorption behaviour.

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