DETERMINATION OF DAMAGE TOLERANCE OF COMPOSITE LAMINATE SUBJECTED TO STRESS-CORROSIVE ENVIRONMENT

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Abstract— **Composite materials are widely used in aerospace and other fields, mainly due to their light weight, high strength to weight ratio, chemical resistance and high fatigue life. Polymer matrix composites find extensive applications in aerospace industries. Currently fiber reinforced polymer matrix composites constitute more than 90% of the total composite used in aerospace industry. This research presents the recent trends in the mechanical characterization of composite systems exposed to sea water environments. This work provides an insight on very long-term degradation of epoxy and polyester-fiber glass composites immersed more than 720 hours in saline medium under service stresses. Samples were loaded under bending conditions with stresses both in the elastic and plastic fields, the result that characteristics in a flexural mode were able to be determined and the ensuing decrease in characteristics was fitted to an exponential model. The degree of losses ranged from 28% to 35% for the flexural strength. The most notable losses were for specimens immersed in natural sea water under a continuous stress of some load, corresponding to the plastic behavior of the material. First, a testing protocol for environmental effects has been developed for resin infused in-house fabricated laminates. Unidirectional ([0] and [90]) mechanical test samples were submerged in synthetic sea water at 24°C and 25°C, with the weight recorded at time intervals over the entire period. The fatigue resistance of environmentally conditioned samples is reduced at high stress levels, but matches the un-conditioned samples at low stress levels. The Flexular strength after period of time has been decreased whereas the water absorption has increased slightly.**

Key Words:- Polyester, Sea water, Mechanical, Flexural Strength

I. INTRODUCTION

In recent times, light weight and high strength materials have been developed owing to soaring demands from industries and domestic applications. Most of the components of automobiles, aerospace, domestic appliances and packaging industries need waterproof, reasonably good strength and corrosion resistant materials to fight against environmental attack. Interior decorative materials, furniture's and fittings are also to be developed for better asthetic values. Under such circumstances, it is no doubt that polymeric composites play a very important role in such applications due to its light weight, high strength, moisture, crack and corrosion resistant properties. In exposures to aqueous and saline mediums, various effects and types of damage are presented, such as matrix plasticization, surface blistering, attack on the fiber, the matrix or the fiber–matrix interface, and internal tensions which increase the fragility of the material, as a consequence of the diffusion of sea water and the components dissolved within it. There are few cases in which the modification of the mechanical characteristics is due to exposure to saline mediums and other types of service conditions under load. Articles dedicated to the study of exposure periods of over 720 hours are very scarce.

The main objective of this research is to determine the effect of the prolonged exposure of GFRP materials made from polyester and glass fiber to a saline medium under bending load conditions, with regards to degradation under stress and to investigate the mechanical properties like tensile strength, compressive strength, stiffness, hardness, etc. and the age of glass fiber reinforced epoxy composites which is subjected to stress corrosive environment. The damage tolerance of the composite material is to be determined experimentally and compared with the theoretical values.

II. LITERATURE

Usage of Composite Materials in Aerospace industry is increasing rapidly, it is necessary to test the materials for damage tolerance before implementing in to respective applications, the following papers are the best literature for determination of damage tolerance in corrosive environment.

David Miller, John F. Mandell et.all [1]

This paper Presents the recent trends in the mechanical characterization of composite systems under consideration for Marine Hydro Kinetic (MHK) applications exposed to salt water environments. Tensile fatigue resistance was also measured at room temperature for the 0° samples. These results show trends of reduced tensile and compressive strength with increasing moisture and temperature in the 0° (longitudinal) direction.

A.M. Amaro, P.N.B. Reis et all [2]

This work studied the flexural and low velocity impact response of a glass fibre/epoxy composite after immersion in hydrochloric acid (HCl) and sodium hydroxide (NaOH). It was concluded that the corrosive environmental affects significantly the flexural strength and flexural modulus. The exposure time was determinant on the mechanical properties degradation.

The alkaline solution shows to be more aggressive than the acid solution, promoting the lowest flexural properties. Complementary tests were carried and the ultra micro indentation shows a decrease of the matrix mechanical properties. The impact bending stiffness showed to be an important property to assess the damage resistance of composites.

Selection of the material

The selection of the material is made by taking into account the need to keep the following inherent properties at the given performance specifications, hardness and monolithic character, strength in respect of mechanical and thermal loading, elongation at a particular strain, outdoor stability and waterproofing.

It is evident that the role of filler materials in aircraft applications has not been carried out so far. To start with, we would like to carry out a general study of the mechanism of mechanical behavior of Polyester based composites to process and correlate and compare the data to estimate the damage tolerance of a composite.

The materials to be used in this investigation are:

Polymers - Epoxy and Polyester

Reinforcement -Glass fiber, Filler material

III. FABRICATION AND MACHINING

A. Processing of PMC's

There are so many processing methods, the method of production and PMC's selected by a manufacturer will depend on factors such as cost, shape of component, number of components and required performance. In this experimental investigation we used hand layup method to prepare laminates.

B. Hand lay-up methods

In hand lay-up the reinforcement is put down to line a mold previously treated with a release agent to prevent sticking and perhaps a gel coat to give a decorative and protective surface. The reinforcement can be in many forms including woven rovings and chopped strand mat. The liquid thermosetting resin is mixed with a curing agent and applied with a brush or roller taking care to work it into the reinforcement.

C. Materials and experimental work

Materials

Materials which are used for producing PMC laminates with reinforcement are discussed in this part. PMC laminates are basically requires the matrix materials and reinforcement materials. Matrix materials are produced by using resin systems with accelerator and catalyst. In some cases it requires filler materials also with hardener material. Reinforcement materials are produced by using glass fibers.

Epoxy

Epoxy systems are the major composite material for low-temperature application [usually under 200ºF (93ºC)] and generally provide outstanding chemical resistance, superior adhesion to fibers, superior dimensional stability, good hot/wet performance, and high dielectric properties. Epoxy can be formulated to a wide range of viscosities for different fabrication processes and cure schedules. They are free from void-forming volatiles, have long shelf lives, provide relatively low cure shrinkage. They also have good chemical stability, flow properties, excellent adherence, water resistance, and low shrinkage during cure, freedom from gas formation, and stability under environmental extremes.

Polyester

Polyester resins are unsaturated synthetic resins formed by the reaction of dibasic organic acids and polyhydric alcohols. Maleic Anhydride is a commonly used raw material with diacid functionality. Polyester resins are used in sheet moulding compound, bulk moulding compound etc.

Filler materials

These are the materials most often added to polymers to improve tensile and compressive strengths, abrasion resistance, toughness, dimensional and thermal stability and other properties. Materials used as particulate fillers include wood flour (finely powdered saw dust), silica flour and sand, graphite, clay, talc, limestone.

Reinforcement

Woven mat

This is a bi-directional reinforcement, obtained by weaving or textile operations using strands running in both directions warp (longitudinal) and fill (transverse) and fibres remain parallel to each other. Woven roving may be specified by the end count (number of ends per centimeter in the warp and fill direction), thickness depends on the number of strands grouped to form one end.

Chopped strand mat

Chopped strand mat is probably the most widely used form of glass reinforcement. Strand of bonded filaments of about 50 mm long are themselves bound to one another in a random pattern to form a mat. Different binders are used to suit different applications, the main variable being the solubility of the binder.

Figure 1-Woven mat

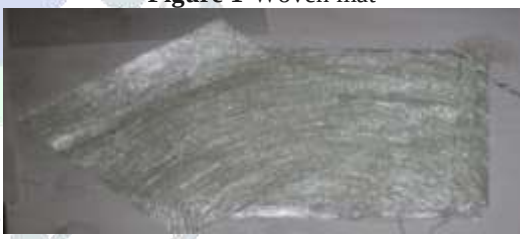


Figure 2- Chopped mat

4.3Mould used for preparing laminates

The mould used for the preparing laminates involves two mild steel plates, seven spacers and seven C- clamps. This mould is sufficient to carry out the fabrication process by using hand lay-up method and as well as by using compression molding method, figure 3 shows the mould assembly.

Figure 3-.Mould Assembly

Figure 4 -Spacers

Figure 5-Clamp

Mold plates

Two plates are having the dimensions of 250mm*250mm and 8mm thickness. These dimensions are selected according to the requirements of the fabrication process. The thickness of each plate is 8 mm, if it is less than 8mm then there may be chance of buckling of plates will takes place and laminates are not prepared well.

Milling and grinding process are carried out on the plates in order to get good surface finish.

Spacers

The spacers are made by using the mild steel material. It is having dimensions of 20mm*20mm with 2.5mm thickness. The dimensions are selected as per the fabrication process requirements. Thickness is selected in order to obtain the desire thickness of the laminates. Figure 4 shows the spacers.

C-Clamps

Clamps are used in the mold preparation is due to the load application process by using the screw threads. C-clamp means, it is having the C shape. It is having the dimensions of height 50mm and thickness 10mm. Milling and Grinding process are used to prepare the clamps. Figure 5 shows the C-Clamps.

The Following Figures shows the Acessories or Materials we used for fabrication.

Figure 6-Epoxy Resin

Figure 7-Polyester Resin

Figure 8- Wax

Figure 9-Steel Roller

Figure10:- Weighing of Resin and Fibers for Volume Fraction

Figure 6 and Figure 7 Shows the Epoxy and Polyester resin used for Laminate Preparation.

Figure 8 shows Wax which is been used for coating for an easy removal of laminate from the mould.

Figure 9 is a steel roller used to remove air gaps in a laminate while fabrication.

IV. LAMINATES AND MACHINING

Preparation of laminates

The plates used for the fabrication process is cleaned with acetone in order to remove the dust particles. The woven roving mats (reinforcement) are cut for required dimension (230×230mm) and it is cleaned at top and bottom surface which would affect the properties of laminates. Resin system (matrix) is prepared by taking a epoxy resin of 200ml in the beaker and the filler material Acetone is added into the resin slowly to avoid the air bubbles of 5%-10% of weight of resin and its is stirred well about 10 to 15 mins. After this process hardener, K-6 of 8ml (4% of weight of the resin) is added to the resin system in order to form chemical reaction and to give strength to the resin system and stirred well about 5 – 10 mins. For polyester laminate is prepared by taking 200ml of Polyester in the beaker and the filler material is added into the resin slowly to avoid the air bubbles of 5%-10% of weight of resin and stirred well about 2 to 3 mins.

Place the plate on the table and it is covered with a surface mat in order to remove the laminate easily. The resin system is coated on the mat by using brush and a woven mat is placed on it. Then again the procedure is repeated till 8 woven mats are placed between those mats where resin system is coated. The coated plies of glass fiber with the resign is placed one over the other are placed on one of the plates of the mould over which Teflon sheet coated with wax has been placed, The G.I sheet of gauge thickness also coated with wax is placed and finally the top plate of the mould is carefully located over the laminate and securely clamped

using the clamps. After the curing process the mold is taken out from the compression molding press and the laminate is removed from the mold. The laminate, which is placed inside the mould, is allowed to cure at room temperature for 24 hours.

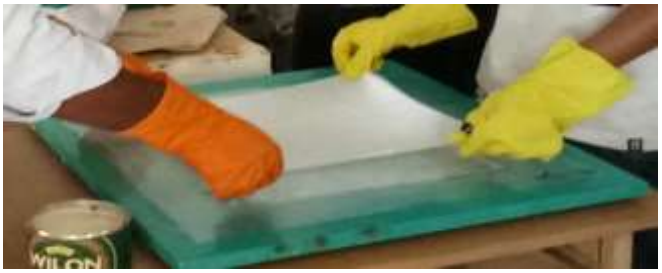


Figure 11:- Preparation of Laminates

Figure 12:- Chopped mat & Woven mat Laminate

MACHINING PROCESSES

The Prepared Laminates are cut as per ASTM Standards; the specimen was prepared according to the dimension by water jet cutting.

WATER JET CUTTING

All water jets follow the same principle of using high pressure water focused into a beam by a nozzle. Most machines accomplish this by first running the water through a high pressure pump. There are two types of pumps used to create this high pressure; an intensifier pump and a direct drive or crankshaft pump.

Figure13:- Water Jet Cutting

Figure14:- Specimens as per ASTM standards

V. RESULTS AND DISCUSSION

The Specimens are cut in to ASTM standards and that specimens are used for testing.

SPECIMENS ARE IMMERSED IN SEA WATER

Figure14:- Specimens Submerged in Sea Water

Deflection test is done in Structure lab applying load by point load as shown in below figure Dial gauge shows reading of deflection where as Load Cell indicate load in Kgs. The setup is arranged in such a way that load is applied on middle of specimen.

Figure15:- Deflection Set up

The Load vs Deflection test results formulated in below table

TABLE-1 Load vs Deflection test

S.N.	Load(kgs)	Deflection(mm)
1	0.5	0.37
2	2.5	0.97
3	4.5	1.48
4	6.5	1.96
6	10.5	2.82
7	12.5	3.26
8	14.5	3.63
9	16.5	4.12
10	18.5	4.57

Take out one batch 2 specimens from water after 10 days, 20 days and 30 days and then go Test the Specimen. Take Standard specimen for testing to compare with other days specimen result and finally analyze it from result output.

Figure16:- Digital UTM

Digital Universal Testing Machines Capacity **100 kN - 2000 KN** Mechanical, Electronic & Computerized versions available Capable of tensile, compression bend & shear tests.

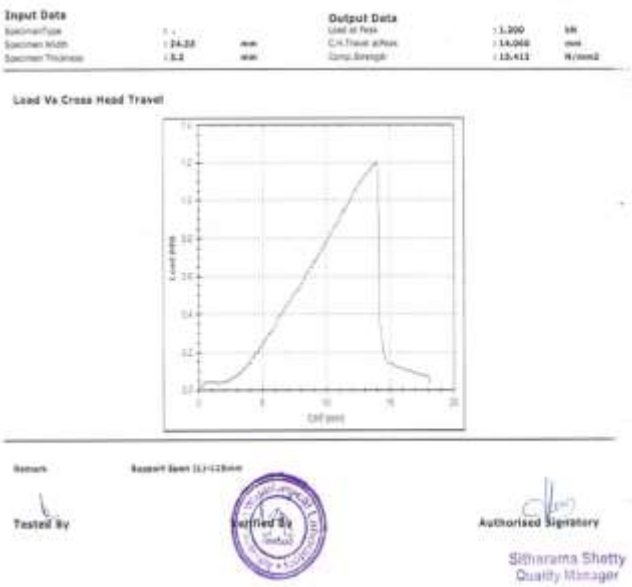


Figure17:- Test Report without submerging in sea water

Figure18:- Test Report 10 days submerging in sea water

Figure19:- Test Report 20 days submerging in sea water

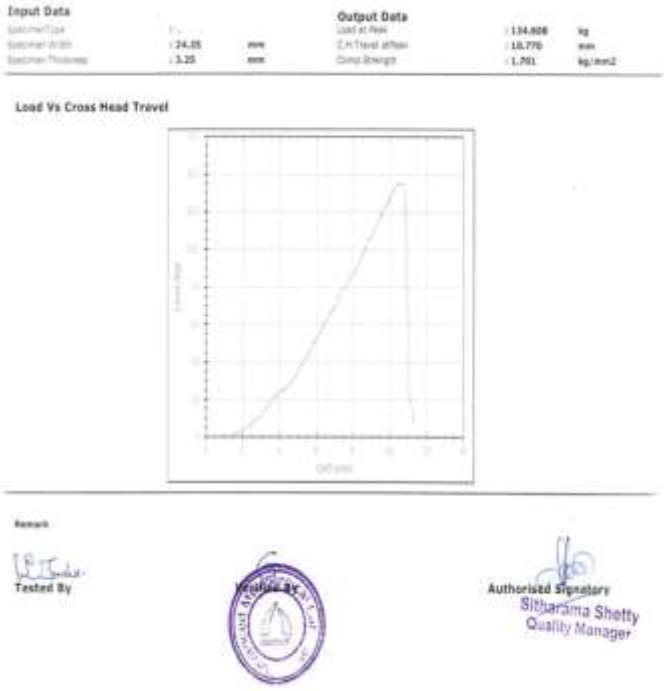
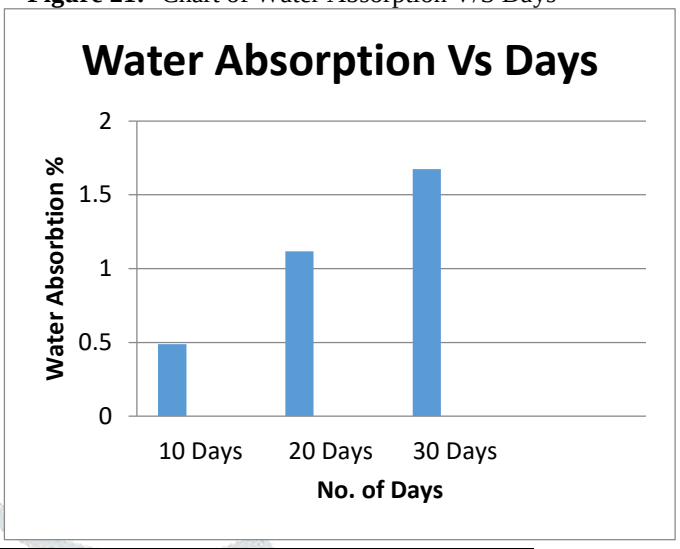


Figure 20:- Test Report 30 days submerging in sea water

Figure 21:- Chart of Water Absorption V/S Days



WATER ABSORPTION DATA

Water absorption has been increased in different interval of time but at very minimum rate. Only 0.5 % has been increased in 10 days and1.12% at 20days and 1.67% at 30 days.

Sample Nos.	Categories (Days)	Weight of samples	Average Weight	Increased Weight	Water Absorption (%)
S8	Unsubmerged (standard)	18.572	18.568	……	…….
S9	Unsubmerged (standard)	18.565		……	……..
S1	Submerged (10 Days)	18.650	18.6615	0.093	0.488
S2	Submerged (10 Days)	18.673			
S3	Submerged (20 Days)	18.774	18.778	0.21	1.118
S4	Submerged (20 Days)	18.783			
S6	Submerged (30 Days)	18.874	18.884	0.316	1.673
S7	Submerged (30 Days)	18.895			

TABLE-2 Water Absorption Data

Sample Nos.	Categories (Days)	Width(b) (mm)	Thickness(t) (mm)	Maximum load (kN)	Average Maximum load (kN)	Maximum deflection (mm)	Average Cross Head Travel(mm)
S8	Unsubmerged (standard)	24.33	3.2	1.2	1.25	14.06	13.2
S9	Unsubmerged (standard)	24.36	3.3	1.3		12.34	
S1	Submerged (10 Days)	24.1	3.05	1.19	1.22	13.47	13.15
S2	Submerged (10 Days)	24.3	3.23	1.25		12.84	
S3	Submerged (20 Days)	24.5	3.3	1.49	1.52	11.04	10.85
S4	Submerged (20 Days)	24.5	3.3	1.55		10.67	
S6	Submerged (30 Days)	24.32	3.36	1.3	1.31	9.89	10.33
S7	Submerged (30 Days)	24.35	3.25	1.32		10.77	

TABLE-3 Different Samples Data of Flexural Test

The above table 3 explains result obtained from lab testing of samples including their specification such as width and thickness. Maximum Load of each samples at different days were tested on lab and average is taken from two samples readings. Different width and thickness are measured in lab for different samples and accordingly tests are done.

The Maximum Load withstand capacity has decreased initially at 10 days and slightly increased and again decreased due to unequal pressure distribution in specimen during hand layup process and due to improper application of load on the specimen.

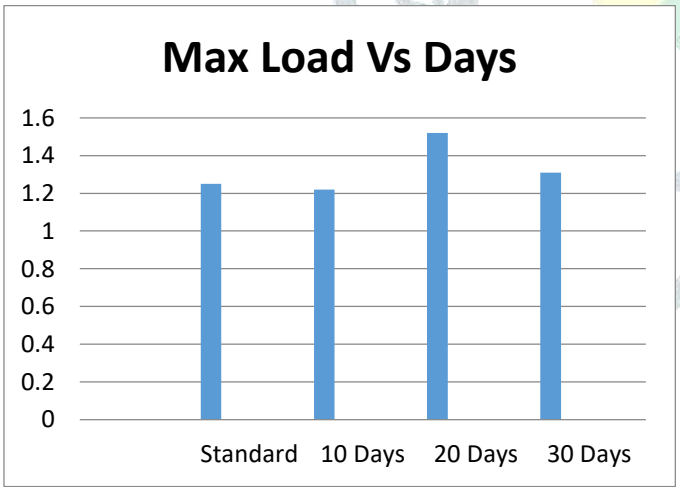


Figure 22:- Maximum Load V/S Days

The deflection is decreasing as the number of days is increasing which indicates that the material gets stronger and stiffer as the composite is exposed for a longer period of time. Therefore after certain time it the corrosive environment does not affect the strength of composite material.

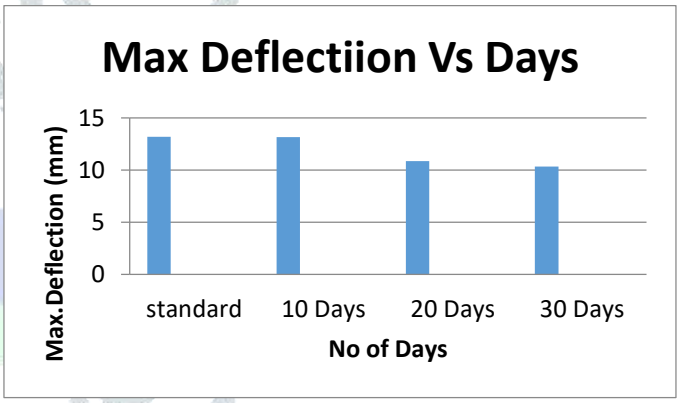


Figure 22:- Maximum Deflection V/S Days

VI. CONCLUSION

This research describes the influence of synthetic sea water (SSW) on the static and cyclic strength of epoxy and Poly-ester composites. The Maximum Load withstand capacity has decreased initially at 10 days and slightly increased and again decreased due to unequal pressure distribution in specimen during hand layup process and due to improper application of load on the specimen. Prolonged exposure to saline media which imitates sea water produces significant deteriorations in the mechanical properties of the composite materials of polyester and fiberglass. The exposure to this medium together with continuous working stress contributes to the increase in the losses within the different mechanical properties with regards to flexure. Whereas the diffusion of water reaches values near saturation point relatively quickly in prolonged exposures and with a low level of working load, the penetration of the marine medium on the material is continuous when high working tensions operate and does not reach saturation even after such an extended period as 720h. All this indicates that the reduction in the properties is mainly due to the degradation of the matrix–fiber bonding. This is helped by the existence of internal tensions in this area, by the osmotic effect which produces the presence of water which is mainly distributed by hydrolytic attack on the matrix–fibre bonding, primarily on the fibre.

Hence due to negligible moisture absorption capacity, these composites can be used in Amphibian Sail Plane, Navyship and Submarine. Based on analysis on the result, it can be well predicted that the E-glass fibre composite underwent reduction for a small period of time initially and then oxidation. These changes inferred from results suggested that these composites may be fully suitable for use in marine environment.

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