

Damage Tolerance Analysis of Composite Laminate Subjected to Stress-Corrosive Environment

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ABSTRACT: Research presented in this paper provides an overview on long-term physical degradation of polyester-fiber glass composite material immersed for a duration more than 1400 hours in a saline medium under the service stresses. Mechanical characterization of composite material exposed for a longer period in sea water conditions was determined. Under bending load conditions, composite material specimens were loaded with stresses both in elastic and plastic domains. Results obtained under the stressed conditions were characterized in a flexural mode and the resulting decrement in characteristics was incorporated in an exponential model. From the experiments conducted, flexural strength losses obtained within the range 3.6 % - 13.73 % and compressive strength losses obtained within the range of 7.06 % - 25.48 %. The most substantial losses were observed in composite material specimens subjected to continuous load stresses while being submerged in natural sea water, which is analogous to the plastic behaviour of the composite material. Even though the existence of plasticization of matrix is uncertain. Presence of microcracks, osmotic diffusion effects on the junction and matrix of the composite fibers, and the chemical ion effects in the medium on the composition of the surface fiber clearly depicts the strength degradation of the composite material.

KEYWORDS: Polyester fiber glass composite, Hand lay-up, C-channel fabrication, Water jet cutting.

I. INTRODUCTION

In modern era, high strength and lightweight materials have emerged satiating the soaring requirements from the industries and the domestic applications. Majority of the components used in aerospace, automobiles, packaging, and domestic appliances industries demands for water resistant, corrosion resistant, and fairly good strength materials to withstand the environmental impact. Polymeric composite materials play a vital role in such applications due to its reasonable high strength, light weight, water, corrosion, and crack resistant characteristics in comparison to conventional materials.

GFRP fiberglass reinforced polymeric matrix composite materials allows the design of light weight component and equipment, which offer substantial resistance when subjected to load conditions. One of the most compelling feature of such material is its chemical resistance which is attained at an acceptable cost and, in this context, it demonstrates to be superior to conventional metals in numerous cases. The applications related to the marine environment, ship hulls, naval, sports gears, military, commercial, and industrial equipment are of exponentially increasing economic importance.

When exposed to saline and aqueous mediums, such materials exhibit changes in characteristics and structural degradation such as blister formation on the surface of the material, plasticization of the material matrix, increase in material fragility due to increased internal tensions, and impact on the matrix, or fiber, or the fiber-matrix interface, thus, resulting in dissolving of fiber components in diffused sea water.

The main objective of this research is to determine the stress degradation effect on glass fiber and polyester manufactured GFRP composite materials subjected to prolonged exposure in a saline and aqueous medium under the bending load conditions. Mechanical properties such as hardness, stiffness, compressive strength, tensile strength, etc.,

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along with the ageing phenomenon of the glass fiber reinforced epoxy polymer composite material subjected to stress corrosive environment, will be determined. Experimental technique is used in determining damage tolerance of the composite fiber material which will be compared with theoretical results for qualitative analysis.

The work in this paper is divided in two stages. 1) Manufacturing and Fabrication 2) Machining and Testing. The first stage is carried out by manufacturing E-glass fiber composite laminates through Hand-layup technique in an open moulding method. Thereafter, composite laminates were machined through waterjet cutting methodology using a mixture of water and an abrasive substance. Later, composite laminates were loaded by bolting them in C-channel devices under the constant load by applying same deflection through dial gauge. At last, loaded specimens were placed in sea water saline medium. For testing phase, sea water submerged specimens were withdrawn, in a batch of 2 specimens, after 20 days, 40 days, and 60 days which were tested under digital universal testing machine (UTM) in metallurgical laboratory and results were compared with standard unsubmerged specimen.

Paper is organized as follows. Section II describes manufacturing and fabrication of composite laminates. Machining process was carried out on fabricated composites which were uniformly loaded, submerged in sea water, and finally tested using UTM over a period of predefined test duration, is presented in Section III. Section IV presents comparison results of experimental specimens with respect to standard specimens. Finally, Section V presents conclusion.

II. MANUFACTURING AND FABRICATION

For manufacturing E-glass fiber composite laminates, hand layup technique, which is an open moulding method, was applied. This method is more suitable for making a wide variety of composite products for a wide variety of sizes. E-glass fiber is a low alkali glass fiber with a typical composition of SiO_2 - 53-57% w/w, Al_2O_3 - 12-15% w/w, $CaO + MgO$ - 22-26% w/w, B_2O_3 - 5-8% w/w, F_2 - 0-0.6% w/w, $Na_2O_3 + K_2O < 1%$ w/w, and Fe_2O_3 - 0.5% w/w and miscellaneous material present at impurity levels. E-glass or electrical grade glass fiber was chosen due to its high susceptibility to stress corrosion cracking when exposed to acids. Universal plain weave electrical grade glass of thickness 0.25 mm was selected for glass reinforcements having ortho-normal orientation ($0/90^\circ$). Bisphenol-A based Araldite LY556 epoxy resin was applied on the fibers thoroughly for high performance composite FRP application as it has good fiber impregnation characteristics as well as high standard thermal, mechanical and dynamic characteristics. Along with epoxy resin, low viscosity hardener HY951 was used for curing at room temperature as it offers good mechanical strength, good resistance to atmospheric and chemical degradation, and offers outstanding electrical characteristics. During fiber production phase, the fibers are normally treated with coupling and sizing agents in order to reduce fiber-fiber abrasion effects which can considerably degrade the individual fibers mechanical strength. For promoting, wetting and adherence of the composite matrix material to the fiber, other treatments can also be used.

To produce a high-quality surface, Mylar sheets, which were completely wetted by epoxy resin, was first applied to the mould. In order to make sure fabricated composite gets separated from Mylar sheet, wax polish was applied which is hydrophobic in nature. For surface cleaning, an organic compound, acetone was used.



Fig. 1. Manufacturing and Fabrication (a) Unidirectional plain weave (b) Mylar sheet used as mould releasing agent

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Fiber glass reinforcements was manually placed on the Mylar sheets in the mould. Steel roller and steel scale was used for rolling out the voids or air bubbles between glass fibers and Mylar sheets. The composite laminates were kept under the load of 20 Kgs for 24 hours for curing at room temperature. Thereafter, the composite laminates were removed by detaching Mylar sheets.

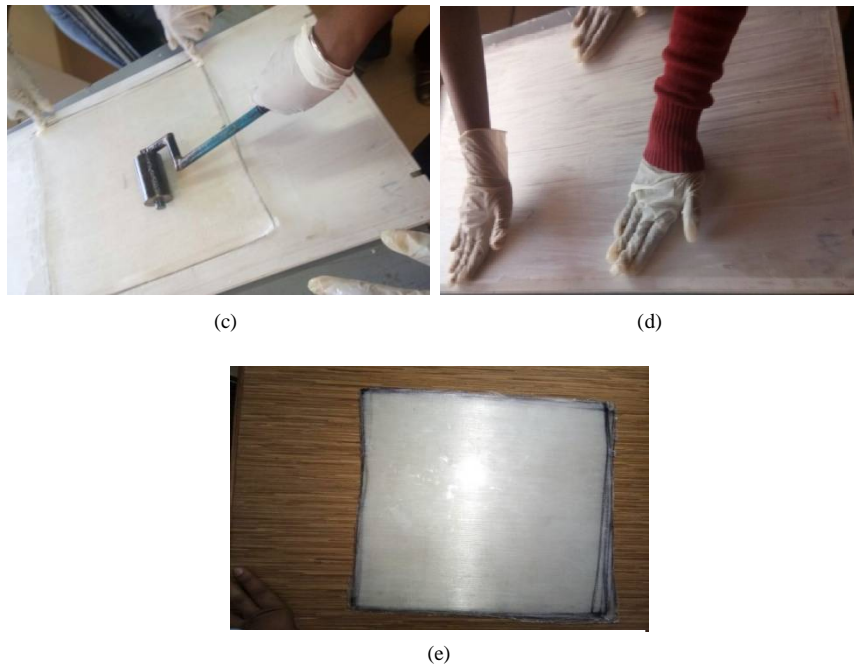


Fig. 1. Manufacturing and Fabrication (c) Rolling process (d) Application of wax (e) Composite laminate specimen on removal of dead weights and Mylar sheet.

III.MACHINING AND TESTING

Water jet cutting technique was used for machining fabricated composite laminates. A high-pressure mixture of water and an abrasive substance such as abrasive garnet sand or Al_2O_3 was used for this method mainly due to the reason that waterjet cutting produces the intricate cuts in the composite laminate materials without interfering with its inherent structure. Also, use of abrasive substance during machining process allows smoothening of composite laminate edges. Finally, composite specimens of fiber glass of thickness 3.20 mm and width 24.4 mm were prepared for testing.

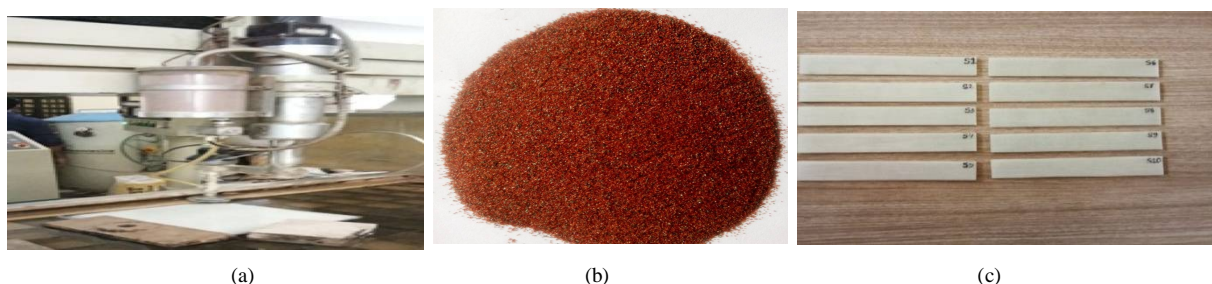


Fig. 2. Machining (a) Waterjet cutting (b) Garnet sand (c) Composite specimen of fiber glass after water jet cutting

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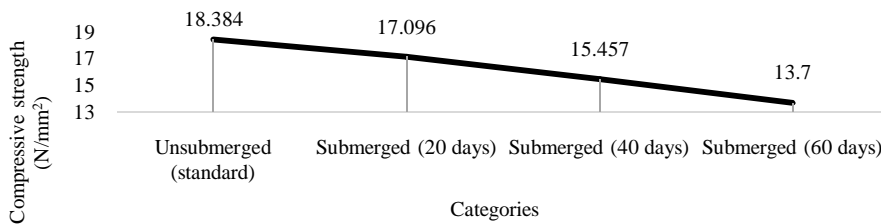
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Table 1. Bend strength test results

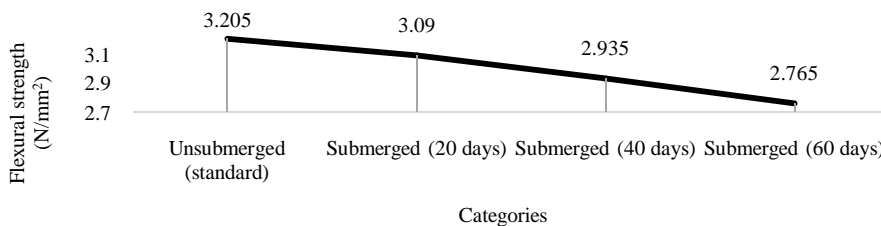
Categories	Peak load (kN)	Compressive strength (N/mm ²)	Flexural strength (N/mm ²)
Unsubmerged (standard)	1.57	18.384	3.205
Submerged (20days)	1.46	17.096	3.09
Submerged (40 days)	1.32	15.457	2.935
Submerged (60 days)	1.17	13.700	2.765

Table 2. Tensile strength test results

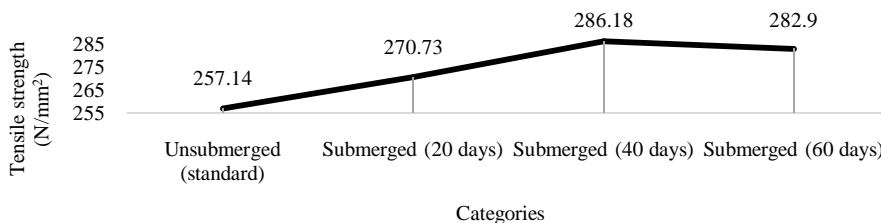
Categories	Peak load (kN)	Tensile strength (N/mm ²)	Yield strength(N/mm ²)
Unsubmerged (standard)	21.96	257.14	243.56
Submerged (20days)	23.12	270.73	241.22
Submerged (40 days)	24.44	286.18	263.93
Submerged (60 days)	24.16	282.9	257.14



(a) Compressive strength results



(b) Flexural strength results



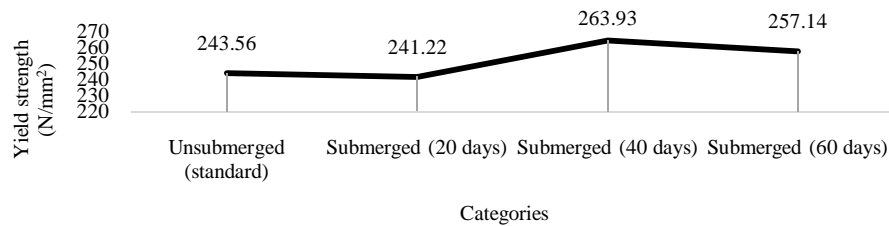
(c) Tensile strength results

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(d) Yield strength results

Fig. 4. Experimental results

V. CONCLUSION

Based on the current investigation it is concluded that, in comparison with the standard specimen the compressive strength and the flexural strength, when subjected to load, for the E-glass fiber composite laminate decreases substantially over a range of 7.06%-25.48%, and 3.6%-13.73% respectively, when exposed to saline sea water over a duration range of 20-60 days. Thus, resulting in strength degradation of composite materials.

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