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Mechanical Charecterization Of Glass Fiber Reinforced Polymer (GFRP) Bars.

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ABSTRACT: The objective of the present work is to evaluate mechanical tests (tensile, compression and Flexural) of pultruded bars which are made up of E-glass reinforced with Epoxy resin in short-term aged test conditions. Experiment on 151 FRP pultruded bar samples with varying diameters (12, 16 & 20 mm) being carried out at two phases. In the first phase FRP pultruded bars were exposed to different diffusion aging conditions to determine their structural credibility. The second phase involved in conduction of mechanical tests (tensile, compression & flexural) using Universal Testing Machine. The tensile test on bare and aged samples shows reduced physical strength. Maximum tensile strengths of unaged FRP bars of 12mm diameter found to be 463.6 MPa, as that of 60 days aged specimen found to be 412.6 MPa. The compression tests were conducted and a maximum compressive strength of bare specimens was found to be 408 MPa, as the specimens subjected to aging for 60 days in salt water, the strength of the specimen found to be decreasing by 19.64%. The reduced tendency of strength found in flexural mode, and found that 8.3% of decreased flexural strength. All the mechanical test results show the reduced physical strength when compared between aged and unaged specimens.

Keywords : GFRP bars, epoxy resin,Rebars.

1 INTRODUCTION

Historically, steel reinforcing bars (rebars, from here onwards referred to as bars) have been effectively used as concrete reinforcement. Steel bars perform well under chloride-free environment. When reinforcing bars undergo oxidation due to chloride attack, oxidation products of steel with considerably larger volume are produced. This oxidation product volume increase in turn generates additional radial tensile stresses around the bar, in matrix. With the advent of fiber reinforced polymers (FRP) consisting of high-strength fibers in a polymer matrix, an alternative has been found for reinforcing concrete structures to address corrosion problems. The fibers in FRP composites are the main load-carrying elements. The polymer matrix (cured resin) protects the fibers from damage, ensures good alignment of fibers, and allows load distribution among individual fibers. Fibers are selected based on the strength, stiffness, and durability requirement for specific applications. Resins are selected based on the function and manufacture of the FRP bar. Fiber types that are typically used in the construction industry are carbon and glass, with thermoset epoxy, vinyl ester, polyester, and urethane resins, even though aramid has been used occasionally.

Advantages of FRP bars:

Non-corrosiveness, high strength to weight ratio, non-conductivity, good thermal insulation, magnetic transparency, good impact resistance, and light weight. FRP bars are made up of continuous glass fibers, which are bound together with a resin and are manufactured using pultrusion process. GFRP bars have high strength to weight ratio and are good corrosion resistant. So it is necessary to know the rate of degradation of FRP bars and the mechanism driving the degradation. So to predict the strength retention properties of these bars under working conditions, the bars are subjected to aggressive accelerated (short term) ageing conditions for shorter time periods. This study deals with the strength degradation of FRP bars when exposed to salt solution and high temperature and also the moisture absorption property of the bars.

2 LITERATURE REVIEW

A major hindrance in using FRP reinforcing bars in engineering applications is the susceptibility of their behavior to weathering conditions. The research done has shown that FRP is prone to degradation when exposed to different environmental conditions. The scope of this literature review encompasses a brief overview of fibers and matrices used in FRP reinforcing bars and the various environmental conditions that causes the degradation.

2.1 Environmental Factors Affecting FRP Products

The environmental factors which are causes the degradation of GFRP reinforcing bars and sheets are, temperature, moisture, alkalinity, freeze-thaw, ultraviolet rays and others. Considering the environmental effect on the degradation of FRP, ACI 440 has recommended environmental reduction factors for different fibers depending on their exposure condition. The environmental factors for FRP are 0.7-0.8 as per their exposure conditions. Hartman et al. (1994) observed that E-Glass fibers lose more strength than S-2 Glass fibers when exposed at 96°C to acidic environment (H_2SO_4 and HCl), alkali environment (Na_2SO_4) and water for a period of 24hrs and 168 hrs [1]. According to Fuji et al. (1993) there was a reduction of tensile strength to about 28% when E-Glass fibers were exposed to 5% HNO_3 after 100 hrs [2]. Chin et al. (1997) observed that when vinyl ester and polyester were exposed to water, salt water and cement pore water at temperatures 23°C, 60°C and 90°C there was not much change in the glass transition temperature (Tg) but there was considerable change in their tensile strengths. The change in tensile strength of polyester resin was so much that they could not be tested after 10 weeks at 90°C as they were degraded [3]. Bakis et al. (1998) studied E-Glass fiber reinforced plastic composite reinforcement rods made with different proportions of resins-100% vinyl ester, 50% vinyl ester and 50% iso-polyester, 20% vinyl ester and 80% iso-polyester following accelerated ageing. They observed that rods made up of 100%vinyl ester had the smallest reduction in modulus of elasticity and the least degradation in tensile strength as compared to the rods made with the other proportions[4].

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2.2 Moisture and Temperature

Malvar, L. J. et al. (1995) observed that high moisture absorption leads to swelling of the bars resulting in internal cracking and progressive loss of bond between concrete and aramid bars. This behavior is similar to the undesirable cracking and swelling of concrete in conventional steel reinforced concrete due to corrosion and related expansion of steel and consequent cracking of concrete [5]. According to ACI 440-3.1.3, the use of FRP reinforcement is not recommended for use in structures that are exposed to high temperature, as the modulus is reduced after being exposed to temperature in excess of the glass transition temperature (Tg). In general the value of glass transition temperature ranges from 200 to 300°F. As fibers provide the strength and stiffness in FRP reinforcement, a structural collapse can occur only after the temperature reached is in excess of that the fibers can handle, which for glass is 1800°F. Tannous et al. (1999) examined strength loss on 10mm (3.15/8 in.) and 19.5mm (3.07/4 in.) diameter GFRP bars in water at room temperature. Their goal was to determine changes in the moisture content and mechanical properties of GFRP bars when fully submerged in chemical solution that resembles the conditions in the field. They observed that there was more loss in strength for bars having polyester as resin than vinyl ester [6]. Pantuso et al. (1998) conducted a study on FRP bars where polyester was used as resin. The bars used in the study were of three different diameters 12, 16 & 20mm. The bars were exposed to water cyclically, one full day of immersion and the other day air dried at a temperature of 23.2°C. After 2 months of this type of exposure, they observed that there was small reduction in tensile strength and modulus of elasticity in the order of 1 to7% and 1 to 10% respectively[7]. Phifer et al. (2001) studied the moisture absorption and strength reduction curves of pultruded E-glass/ vinyl ester laminates as a function of water immersion temperature ranging from room temperature to 80°C and time. The authors showed that the moisture diffusion process and strength reduction with respect to time require a double exponential solution, thus indicating that there are two mechanisms driving the degradation. The mechanisms may be fiber degradation and resin or fiber interface degradation. And also an Arrhenius model gives a good representation of diffusion and strength reduction with respect to temperature[8]. Faza, S. S (1991) was also observed that the activation energies associated with strength loss for various vinyl ester and polyester systems were in the range of 8 to 16kcal/mol [9].

3 MATERIALS AND METHODOLOGY

3.1 MATERIALS

The specimens used for this study is Pultruded bars of 12, 16 & 20mm, diameters (FRP). The reinforcement materials are E-glass fiber and Epoxy resin. The volume ratio is 70:30 (70% E-glass content and 30% Epoxy matrix).

3.2 METHODOLOGY

3.2.1 Pultrusion process for preparation of bar

Pultrusion is a continuous molding process using fiber reinforcement in polyester or other thermosetting resin matrices. Pre-selected reinforcement materials such as fiberglass roving, mat or cloth, are drawn through a resin bath in which all material is thoroughly impregnated with a liquid thermosetting resin. The wet-out fiber is formed to the desired geometric shape and pulled into a heated steel die. Once inside the die, the resin cure is initiated by controlling precise elevated temperatures. The laminate solidifies in the exact cavity shape of the die, as it is continuously pulled by the pultrusion machine. The pultrusion process is as shown in Fig 1.

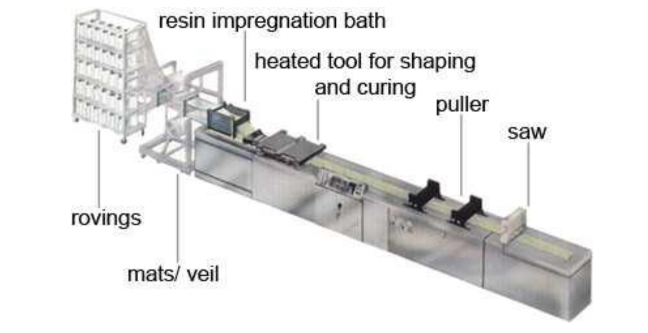

Fig.1. *Pultrusion Process*

4 Experimental results and discussion

GFRP bars (aged & unaged) were used for the tensile, compression, flexure & absorption tests. Aged specimens are the bars, were heated in an oven at different temperature conditions & immersed in salt solution and fresh water at room temperature. Unaged (bare) specimens are the bars under room temperature without exposure to any solutions. Salt water solution was prepared according to ASTM D 1141 standard for aging studies of the specimens. The salt solution was prepared in a beaker and after the preparation of the salt solution the specimens were immersed in it.

4.1 MOISTURE ABSORPTION TEST

Specimens used for the weight gain measurements were 12, 16 & 20mm in diameter and 320mm in length. At the specified ages the specimens were removed from the beaker, surface dried and weighed. The various plots of absorption (%) versus time (days) are shown in Fig.2 for salt water and fresh water aging respectively. The mechanism of diffusion was found rapid in the case of salt water rather than fresh water. This can be justified as change in molar concentration between fresh &salt water, will entertain the diffusion mechanism.

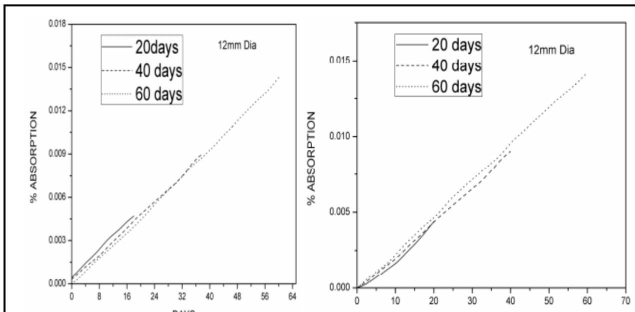

Fig.2. *The various plots for salt water & fresh water respectively.*

The diffusion behavior of E-glass/Epoxy pultruded bars being analyzed. It is observed that glass fibers acts as an inert media in the water absorption process of Epoxy matrix cause the loss of interfacial adhesion between matrix and the reinforcement.

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4.2 TENSILE TEST

A test specimen of length 320mm was adopted with a grip length of 80mm on each side. A preferable grip length of 10mm is suggested for FRP bars.Fig. 3 & Fig. 4 shows the tensile testing of specimens, before and after the failure. For tensile test we have taken 3 bare bars (GFRP) of each dia 12, 16 & 20mm, which all are unaged. A similarly set of bars (GFRP) which all are immersed in salt water for 20 days, 40days & 60days, and also heated to 100ºC for 2 hour (3bars), heated to 150ºC for 1.5 hour (3bars), heated to 200ºC for 1 hour (3bars).

Fig 3. *Before* Failure.

Fig.4. *After Failure.*

The following table 1, 2 & 3 highlights the outcome of tensile test results, for 12, 16 & 20mm dia bars

TABLE 1

Tensile test on GFRP bar (φ 12mm).

Specimens	Stress (MPa)
Bare	463.6783
Immersed in salt water for 20 days	436.7962
Immersed in salt water for 40 days	425.3051
Immersed in salt water for 60 days	412.6478
Heated to 100ºC for 12 hour	461.4837
Heated to 150ºC for 1 and ½ hour	457.5084
Heated to 200ºC for 1 hour	440.6649

TABLE 2

Tensile test on GFRP bar (φ 16mm).

Specimens	Stress (MPa)
Bare	312.2649
Immersed in salt water for 20 days	306.5044
Immersed in salt water for 40 days	294.3459
Immersed in salt water for 60 days	291.3276
Heated to 100ºC for 12 hour	309.4856
Heated to 150ºC for 1 and ½ hour	304.7924
Heated to 200ºC for 1 hour	297.4298

TABLE 3

Tensile test on GFRP bar (φ 20mm).

Specimens	Stress (MPa)
Bare	221.5762
Immersed in salt water for 20 days	208.4331
Immersed in salt water for 40 days	200.1553
Immersed in salt water for 60 days	192.4571
Heated to 100ºC for 12 hour	217.2732
Heated to 150ºC for 1 and ½ hour	214.7389

Failure in all the specimens was observed at the mid span length. It was initiated with some sand particles popping followed by splitting of fibers in the outer layer as observed during the test. At the end of test, the fibers failed at the center forming a conical mesh pattern.

4.3 COMPRESSION TEST

The specimen length of the pultruded bar specimens are done as per ASTM standard. The specimen (coin) lengths were 10mm while the diameters were 12, 16 & 20mm respectively.

Fig.5. *Compression test specimens before & after the test.*

The test results were given in the table 4, 5 & 6 respectively for 12, 16 & 20mm dia bars (GFRP).

TABLE 4

Compression test on GFRP bar (φ 12mm).

Specimens		Stress (MPa)
Bare		408.1406
Immersed in salt water	For 20 days	386.4123
	For 40 days	379.0273
	For 60 days	361.5231
Heated to 100°C for 2 hour		364.1287
Heated to 150°C for 1 and ½ hour		353.0219
Heated to 200°C for 1 hour		341.2689

TABL E 5

Compression test on GFRP bar (φ 16mm).

Specimens		Stress (MPa)
Bare		298.3611
Immersed in salt water	For 20 days	279.0959
	For 40 days	264.8985
	For 60 days	254.6734
Heated to 100°C for 2 hour		272.1367
Heated to 150°C for 1 and ½ hour		267.5499
Heated to 200°C for 1 hour		259.1673

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TABL E 6

Compression test on GFRP bar (φ 20mm).

Specimens		**Stress (MPa)**
Bare		243.6912
Immersed in salt water	For 20 days	227.3597
	For 40 days	207.4402
	For 60 days	192.3491
Heated to 100°C for 2 hour		240.4669
Heated to 150°C for 1 and ½ hour		213.324
Heated to 200°C for 1 hour		196.9485

The compressive behavior of furnace treated specimens found to be more than the bare. The ability of taking load starts in steep form and the specimens subjected to salt bath show gradual manner, but the furnace treated specimens show lower yielding, but later takes on load until the disintegration of edges.

4.4 FLEXURAL TEST

The test procedure is done in accordance to ASTM D4476-97. The overhang section adopted was a minimum of 10% of the test section on each side of the specimen. The length of the test specimen was 235 mm. The Fig.6 shows the specimen under flexural test and Fig.7 shows the specimen before & after the test.

Fig. 6. *flexural testing.*

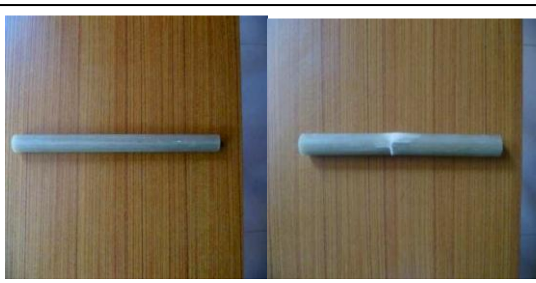

Fig.7. *Flexural tested specimens before & after the test.*

The results were given in table 7, 8 & 9 for 12, 16, 20mm dia bars respectively.

TABLE 7

Flexural test on GFRP bar (φ 12mm).

Specimens		Breaking Load (N)	Moment of Flexure Mb (MPa)	Flexural stress σ b (MPa)	Coefficient of elasticity E (MPa)
Bare		2948.7	142502.4	722.1	30867.89
Immersed in salt water	For 20 days	2743	136113.75	701.36	29478.56
	For 40 days	2650.6	117965.25	685.38	29526.12
	For 60 days	2304.4	109897.43	667.28	28428.75
Heated to 100°C		2850.6	137965.25	709.38	28867.78
Heated to 150°C		2799.8	127039.5	691.87	28963.89
Heated to 200°C		2556.3	104353.875	675.14	27561.22

TABLE 8

Flexural test on GFRP bar (φ 16mm)

Specimens (20mm diameter)		Breaking Load (N)	Moment of Flexure Mb (MPa)	Flexural stress σ b (MPa)	Coefficient of elasticity E (MPa)
Bare		10080.5	453712.5	577.6	26152.464
Immersed in salt	For 20 days	9989.52	452432.23	546.12	23687.461
	For 40 days	9945.2	451678.56	520.456	21063.98
	For 60 days	9910.4	450342.23	490.45	19678.23
Heated to 100°C		9975.2	452678.12	550.6	24567.23
Heated to 150°C		9952.7	451654.47	516.2	23082.94
Heated to 200°C		9926.5	450345.25	490.56	20155.73

TABLE 9

Flexural test on GFRP bar (φ 20mm)

Specimens (16mm diameter)		Breaking Load (N)	Moment of Flexure Mb (MPa)	Flexural stress σ b (MPa)	Coefficient of elasticity E (MPa)
Bare		7063.2	326673	786.1	29704.42
Immersed in salt Water	For 20 days	6876.5	304913.12	768.47	27963.722
	For 40 days	6493.6	294079	742.10	26842.343
	For 60 days	6287.4	251947.8	725.3	25123.276
Heated to 100°C		6972.7	313987.3	772.3	29324.123
Heated to 150°C		6584.1	276764.6	756.7	26423.678
Heated to 200°C		6376.5	264913.1	730.4	23784.521

It was observed that in general, bars with larger diameters show lower flexural stresses. The loading rate for all the flexure tests ranged between 1000 per minute, such that the failure of the specimen was reached between 3 to 5 minutes. Loading rates were lower for larger diameter bars and higher for smaller diameter. Suggested loading rate helps in minimizing stress concentration effects due to quick loading and creep effects due to slow loading.

5 CONCLUSION

The pultruded bars with 20 days of aging, from the figure it is clearly shows that the matrix degradation has initiated. The degradation in the FRP bars is due to the migration of water molecules into the matrix phase. As the specimens aged beyond 20 days, the fibers also tends to lose its shape, the rea-

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son for this phenomenon is swelling of fabrix, hence fiber also tend to degrade. The FRP bars with 60 days of aging are heavily destructed due to diffusion mechanism. Of the three types of bars tested, 12 mm diameter bars gave a maximum average tensile stress of 463.67 MPa, and 16 mm bar yielded 312.264 MPa, and 20 mm dia bar found to be least among all as 221.57 MPa, followed by glass bars showing an average stress range of 308.23 MPa. This stress variation results in reduction of average tensile stress in the bar. The stress variation increases with the increase in bar diameter, resulting in reduced average stresses in higher diameter bars.On comparing all variety of bars it is found that stiffness is contributed by matrix. As it is seen that 20 mm dia bar has got maximum share of matrix yields most stiff. The failure mode suggested that the stress distribution across the cross-section of the bar was not uniform. The compression tests were conducted and a maximum compressive strength of bare specimens was found to be 408 MPa, as the specimens subjected to aging for 60 days in salt water, the strength of the specimen found to be decreasing by 19.64%. The reduced tendency of strength found in flexural mode, and found that 8.3% of decreased flexural strength.

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