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Influence of marine environment on mechanical properties of glass fiber reinforced composites

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Abstract. In the present study effect of artificial sea water environment on mechanical properties of glass/polyester composites was investigated. The laminates fabricated by using vacuum bagging method, were characterized for moisture absorption in artificial sea water for an immersion period of 60 days. Degradation of mechanical properties of aged composites were examined through tensile, flexural, hardness and impact test. The results revealed that long term absorption of sea water reduces the mechanical property of the glass/polyester composite. Rate of degradation of mechanical properties of laminates shown higher trend during earlier days of immersion in sea water and the rate slows down as the immersion period increases.

1.Introduction

Polyester and glass fibers are materials commonly used in marine applications. These composites have good mechanical, thermal and chemical properties. The main disadvantage of polyester matrix system were sensitivity to water absorption because of substantial number of OH groups in the chemical structure. The effect of moisture reduces mechanical properties of the composites due to plasticization, swelling of the system and decrement in glass transition temperature (T_g) [1]. Continuous exposure of FRP to moisture creates a new phase between fiber and matrix region and creates change in glass transition temperature at elevated conditions. Most of composites show ductile properties below its glass transition temperature; because of restriction to mobility of the polymer chains. Above transition temperature, resin system exhibits visco-elastic properties. This presents severe and unique challenges in using glass/polyester composites in naval structures because of their prolonged exposure time to moisture.

Glass fiber composites either with orthophathalic polyester or with epoxy are generally used in marine applications because of their high corrosion resistance and low moisture absorption properties. Polyester composites will absorb water up to 1-3% [2]. The absorbed water will penetrate in to matrix material and will be stored in the micro cracks of the material. This may lead to swelling of composites and reduce the bonding between matrix and reinforcement interface. Major reasons for the degradation of composites in marine environment are voids and micro cracks of the composites. Immersion of polyester based composites in water for one year reported reduction of mechanical properties by 20%. Accelerated hydrothermal ageing in seawater environment also leads to loss of mechanical properties by 30 to 40%. Investigation of effect of marine environment on composite structures is limited to accelerated laboratory testing methods in artificial sea water. In the past research work distilled water is used as an ageing medium to understand the significant effect of moisture on composite structure. The comparison study of distilled water and sea water ageing showed significant difference in the results, specifically in terms of weight gain [3]. Based on these, recent studies are focused on ageing of composite structures in artificial sea water. Gracia et al. [4] performed experiments on marine civil engineering structures made of GFRP to determine its corrosion resistance by immersing in seawater for a period of 65, 210 and 810 days.

The results showed degradation of flexural properties of epoxy and vinyl ester based glass fiber composites. Chakravarty et al. [5] performed experiments on glass fiber polymer composites material to understand the effect of marine environment on glass transition temperature and weight of the composites. The results showed degradation of T_g and increment in the weight of the composite specimens. Summerscales et al. [6] found the durability of epoxy and vinyl ester resins as a function of immersion time and temperature. The rate of degradation increased as the immersion period and temperature increased. Epoxy shown more chemical stability as compared to vinyl ester. Bankim et al. [7] immersed specimens in sea water for a period of 626 hours to understand the effect of moisture on interfacial strength. Kootsookos et al. [8] compared the water absorption properties of vinyl ester and polyester matrix system and concluded that polyester matrix less stable than vinyl ester in marine environment. Visco et al. [9] studied the water diffusion properties of vinyl ester and polyester and results showed that vinyl ester had lower water diffusivity and higher chemical stability as compared to polyester.

The main aim of this research work is to understand the mechanical behavior of glass/polyester composites in artificial sea water. To quantify the degradation of mechanical properties tensile test, flexural test, impact and hardness tests are conducted on unaged and aged specimens as per ASTM standards.

2. Methodology

2.1 Materials and method

Glass/polyester laminates were used to understand the mechanical behaviour under the influence of artificial sea water. E-glass woven type-twill weave of 360 gsm was supplied by S and S polymers Bangalore. Orthophathalic polyester resin, Cobalt and Methyl ethyl ketone peroxide (MEKP) supplied by Sri Mokambika Polymers Udupi, Karnataka. Hand lay-up followed with vacuum bagging technique as shown in figure 1 was used to fabricate the specimens with the fiber to matrix ratio in the range of 40 wt.% - 60 wt.%. Specimens cured in ambient temperature for a period of 24 hours.

2.2 Accelerated ageing

To simulate marine environment artificial sea water was prepared as per ASTM-1141 by dissolving NaCl (24.53g/l), $MgCl_2$ (5.2 g/l), Na_2SO_4 (4.09 g/l), KCl (0.695 g/l), $CaCl_2$ (1.16 g/l), $NaHCO_3$ (0.201 g/l) in 1 litre of water [10]. Specimens were immersed in artificial sea water for a period of 60 days as shown in figure 2. The specimen weights were measured periodically to study the moisture absorption behaviour by weight difference method as per Eq.1 as per ASTM D 5229.

$$\boldsymbol{M}\% = \frac{W_{final} - W_{initial}}{W_{initial}} \times \mathbf{100} \tag{1}$$

Where M is the moisture absorption in percentage, $W_{initial}$ is the weight of the specimen before immersion and W_{final} is the weight of the specimens after immersion.

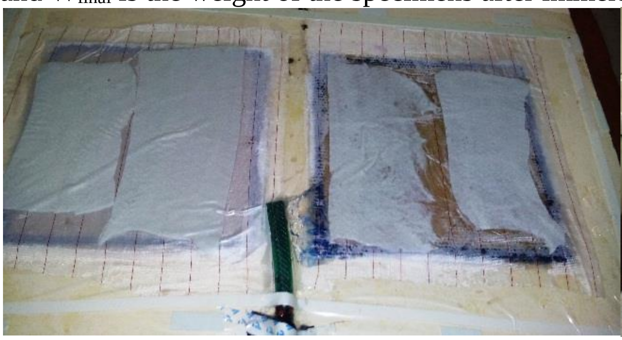

Fig. 1 Fabrication of laminates

Fig. 2 Ageing of composite specimens

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2.3 Mechanical Tests

Tensile properties of aged and dry specimens were tested as per ASTM D3039 [11]. A servo hydraulic controlled universal testing machine (BiSS Bangalore, India) equipped with 50 kN load cell was used to conduct the tensile test as shown in figure 3. The dimensions of the samples were 250mm×25mm×3mm and loading rate of 2 kN/min was used.

Fig. 3 Tensile test setup

To investigate the effect of artificial sea water environment on flexural properties of the laminates three-point bending test (FIE Pune, India) were employed as shown in figure 4. The test was conducted as per ASTM D790-10[10]. The specimen dimensions of the coupons were 127mm×12.7mm×3mm; and crosshead rate of 4mm/min were maintained during testing. Load and deflection measured for five specimens to obtain average maximum flexural strength.

Fig. 4 Flexural test setup

The hardness measurement test was conducted using MATSUZAWA MMT-X micro Vickers hardness tester. Diamond indenter of cone angle 136° was used to create indentations over a dwell time of 15 second on the material surface. Five measurements were made on dry and 60 days aged samples and average values computed. Impact strength degradation of specimens measured by using FIE make Charpy impact test machine as per ASTM D6110 [12]. The striking energy of testing pendulum was maintained at 300 N-m. Five samples were used to measure the impact strength of aged and dry specimens.

3. Results and discussion

Figure 5 shows the measured tensile strength and strain at specimen failure for 20, 40 and 60 days aged and dry specimen. Dry specimen showed a maximum tensile strength of 220 MPa and strain of 2.7 % as compared to aged specimens. Stress value was reduced in case of aged specimens but strain remained constant for all specimens. Stress-strain curve indicates brittle kind of failure of glass/polyester composites.

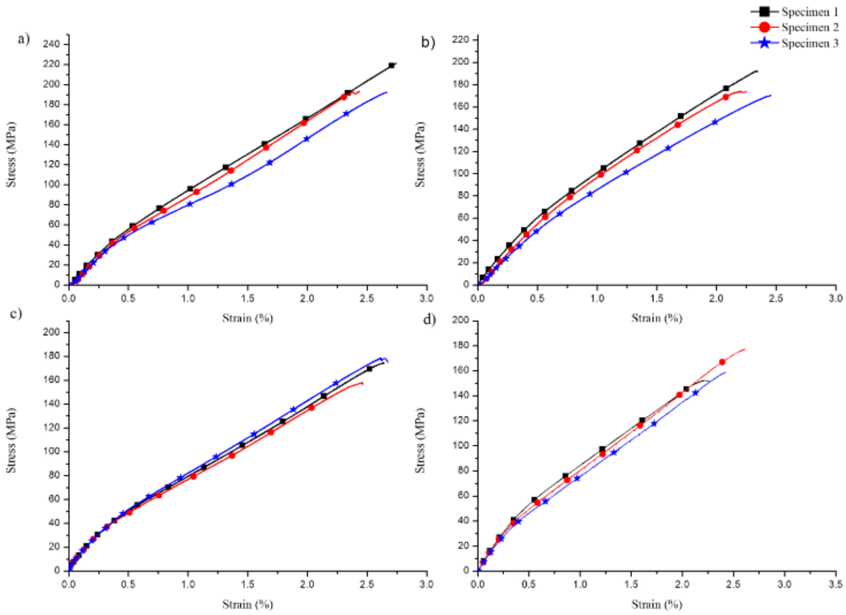

Fig. 5 Stress-Strain curve of a) Dry specimen, b) 20 days aged, c) 40 days aged, d) 60 days aged specimen

Flexural strength measure using three-point bending test. Figure 6 shows the variation of flexural strength of dry and aged specimens. It was revealed that rate of change of flexural properties greatly influenced by the moisture intake. Higher water absorption rate and swelling of composites in the initial 20 days of immersion period reduced flexural properties by 50%.

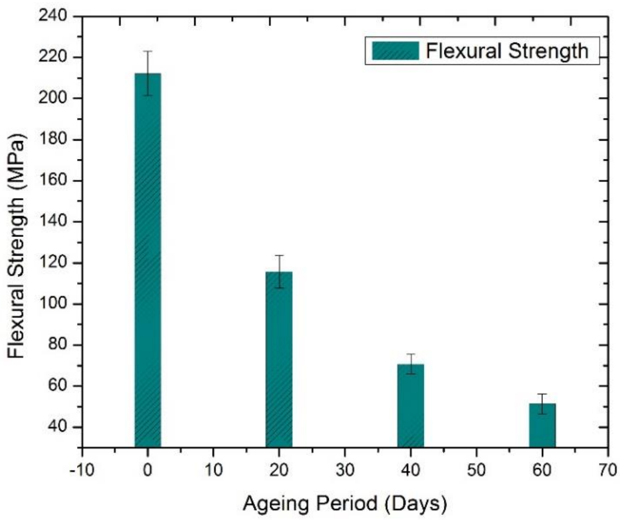

Fig. 6 Comparison of flexural properties of aged specimen with dry specimen

Impact strength measured for dry and aged specimens by using Charpy impact test machine. Variation of impact strength of specimens shown in table 1. Dry specimen shown maximum energy absorbing capacity compared to aged specimens. Debonding and plasticization and swelling of matrix material is the major reason for the degradation of impact strength of specimens.

Table 1. Average impact strength

Ageing period in days	Impact strength in kJ/mm^2
0	6.3
20	4.5
40	3.9
60	3.72

Micro Vickers hardness measurement gives a clear indication of stability of aged specimens. 60 days of exposure of composites to marine environment reduced hardness value by 9%. Table 2 shows the hardness values of aged and dry specimens.

Table 2. Average micro Vickers hardness value

Ageing period in days	Micro Vickers hardness
0	18.84
60	17.36

Moisture absorption behaviour in artificial sea water of glass/polyester composites is shown in figure 7. Weight gain of composite versus immersion period were plotted; and showed deviation from Kicks law of diffusion. From plot, in the initial immersion period weight gain takes place rapidly and reaches to a maximum in the initial 30 days. After this period weight gain of the specimen reduces. In the final days of immersion glass/polyester composites showed increment in weight of the specimens. The total moisture absorption behaviour of specimen known as absorption-desorption-reabsorption nature.

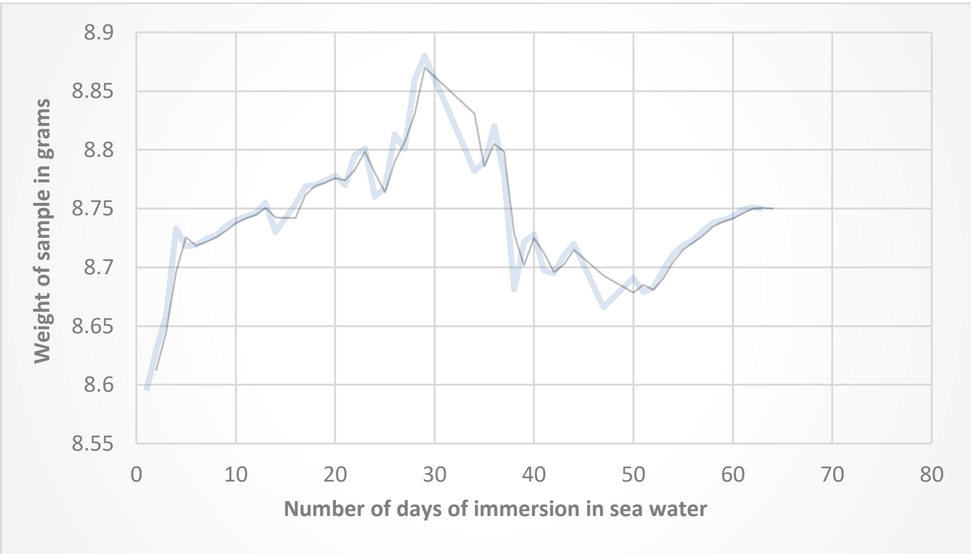

Fig. 7 Moisture absorption behaviour of glass/polyester composites

4. Conclusion

In this research work, we studied the behaviour of glass/polyester composites under the influence of artificial sea water. Laminates fabricated using E-glass and polyester with a weight content of 40% wt. and 60% wt. by vacuum bagging method. Accelerated ageing test carried out on laminates for a maximum duration of 60 days.

Based on experimental results, it is possible to conclude that the mechanical properties of glass/polyester composites depended upon the working environment. Tensile test results showed degradation of maximum strength value by 10%, 15% and 23% in the case of 20, 40 and 60 days aged specimen as compared to dry specimen. Flexural strength reduced by 40%, 65% and 72% in the case of 20, 40 and 60 days aged specimen as compared to dry specimen.

Immersion of laminates in artificial sea water for a period of 60 days reduced impact strength and hardness value. Impact strength reduced by 41% and hardness value by 8% as compared to dry specimen. Water absorption rate of laminates was higher in the early days of immersion and the weight gain reached to a saturation point. After reaching saturation point, the laminates shown desorption property in the successive period of immersion. In the final stage of immersion, specimen showed reabsorption kind of phenomenon.

5. Acknowledgments

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6. References

[1] K. Berketis D Tzetzis, Journal of Material Science, Vol 44, 2009, no. 9, pp. 3578–3588.
[2] Sang Bake Lee, Rockette, and L. Hoffman, Polymer, Vol 33, 1992, no. 17, pp. 3691-3697
[3] E. Faguaga, C.J. Pérez, N. Villarreal, E.S. Rodriguez, and V. Alvarez, Materials and Design, Vol 36, 2012, no. 10, pp. 609–616.
[4] J.D. Garcia-Espinel, D. Castro-Fresno, P. Parbole Gayo, and F. Ballester-Munoz, Materials and Design, Vol 66, 2015, pp. 46–50.
[5] A P Chakraverty, U K Mohanty, S C Mishra and A Satapathy, IOP Conf. Series: Materials Science and Engineering, Vol 75, 2015, pp. 782–788.
[6] John Summerscales, Solid Mechanics and Its Applications, Vol 208, 2013, no. 3, pp. 1–13.
[7] Bankim Chandra Ray and Dinesh Rathore, Polymer Composites, Vol 36, 2014, pp. 410–423.
[8] Mouritz AP, Kootsookos A and Mathys G, Journal of Material Science, Vol 39, 2004, pp. 6073.
[9] A.M. Visco, N. Campo and P. Cianciafara, Composites Part A, Vol 42, 2011, no. 9, pp.123–130.
[10] Ratna Pal, H. N. Narasimha Murthy, M. Sreejith, K. R. Vishnu Mahesh, M. Krishna, and S. C. Sharma, Material Science, Vol 6, 2012, no. 3, pp.225–235.
[11] N H Padmaraj, MV Kini, BR Pai and BS Shenoy, Procedia Engineering, Vol 64, 2013, no. 3, pp.966–972.
[12] A Pai, N H Padmaraj, K N Chethan and S Vibhor, Materials Research Innovations, Vol 21, 2017, no. 2, pp.115–121.