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Water absorption behavior and residual strength assessment of glass/epoxy and glass-carbon/epoxy hybrid composite

Water absorption behavior and residual strength assessment of glass/epoxy and glass-carbon/epoxy hybrid composite

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Abstract. Present investigation is aimed to study the water absorption behaviour and evaluation of residual strength of glass fibre/epoxy (GE) and alternate plies of glass-carbon/epoxy (GCE) hybrid composite. Both the composite systems were exposed to water at 70°C. Specimens were weighed after certain time periods to study the water uptake kinetic. Flexural tests were conducted after 4, 100 and 450 hours of ageing to evaluate the effect of hot water ageing on the mechanical properties of these potential materials. The water uptake kinetic was found to follow Fickian diffusion kinetic for GE as well as GCE hybrid composite but the rate of diffusion was higher for GE composite over GCE composite. The water content was also higher in GE composite over GCE composite after 450 hours of ageing. Significant decrement in flexural strength was observed with the increase in ageing time. Presence of water in the composite also imparted significant embrittlement to the matrix as reflected in the decrease in strain at peak for both the composite systems.

1. Introduction

Fibre reinforced polymer (FRP) composites are promising materials in the marine and offshore applications due to their relatively lighter weight and higher corrosion resistance over their metallic counterparts. Further their low maintenance cost and larger life span also makes them potential candidate for this application area. During their service life these materials are exposed to different environments which may include moisture, different low and high temperatures and may be more complex under changing humid conditions. Environmental degradation and damages are quite advanced issues in FRP composites[1]. Polymeric materials are susceptible to degradation when interact with water during their service life. The water absorption kinetic and the mechanism of degradation for fibrous polymeric materials under the exposure to humid ageing or hot water are still far away from conclusion. Presence of moisture in the composite leads to swelling, hydrolysis and plasticization of the polymer matrix[2]. The durability and integrity of fibrous polymeric composites is primarily governed by the interface/interphase which is most stressed and non-uniform region[3]. This interface also becomes susceptible upon the interaction with the environmental moisture. The concept of fiber hybridization is s recent advancement in the field of composite materials, where two or more types of reinforcements are used to take advantages of both reinforcements[4]. Out of the synthetic fibres, glass and carbon are the most commonly used materials. Glass fibers are fairly cheap and exhibit moderate strength and strain to failure, but lack in stiffness when compared with carbon fibers. Carbon fibers exhibit very good strength and stiffness, but at the same time they are quite brittle and very costly. Hence the motivation behind using both carbon and glass fiber in a single polymer matrix composite is to derive the advantages of both material, hence optimizing the properties of the resulted composite[5], [6]. In addition to these mechanical properties, carbon/polymer and glass/polymer composites show different moisture absorption tendency.

Present investigation is focused on the water uptake kinetic study of glass/epoxy (GE) composite and glass/carbon/epoxy (GCE) hybrid composite and its subsequent effect on the flexural performance of these materials.

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2. Materials and Experimental methods

The materials used in the present investigation were woven fabric E-glass fibre supplied by Owens Corning and the epoxy was Diglycidyl Ether of Bisphenol A (DGEBA) from Atul Industries Ltd under the trade name Lapox l-12 and K-6 hardener which is triethylenetetramine (TETA). The carbon fibres were also 3K plain weave supplied by Soller composites. Some specifications of the used materials are given in table-1. The resin to hardener ratio were taken as 10:1 as per the manufacture's specification. Both the composite laminates (GE and GCE hybrid) were prepared by hand lay-up method with total 7 layers of fibers. Alternate layers of glass fibre and carbon fibre (4 glass and 3 carbon layers) were used in the fabrication of GCE hybrid laminate. The laminates were consolidated in the hot press at 5MPa pressure and 60°C temperature for 20 minutes. The final thickness of the laminates was 1.8±0.1 mm.The specimens for mechanical testing were cut from the laminate by diamond tipped cutter. The dimension of the specimens for flexural testing was taken as per ASTM standard D790-10. All the specimens after cutting were post cured in an oven at 140°C temperature for 6 hours[7]. After post curing 5 specimens of each GE and GCE composite were tested for having the reference flexural properties without any hot water ageing at 1 mm/min loading rate. Remaining samples were then marked and their dry weight has been recorded. All these samples were then immersed in hot water at 70°C temperature. After a regular interval of time the weight of these immersed samples has been taken to study the moisture uptake kinetics. Flexural testing of samples was then carried out after 4, 100 and 450 hours of hot water ageing.
Mechanical properties of E-glass, carbon fibers and epoxy are shown in table 1.

Material	Tensile strength (MPa)	Young's Modulus (GPa)	Density (g/cm^3)
E-glass	2000	80	2.58
Carbon	2900	525	1.85
Epoxy	85	3.5	1.2

Table 1. Mechanical Properties of E-glass, carbon fibers and epoxy.

3. Results and Discussions

3.1 Water uptake kinetic study

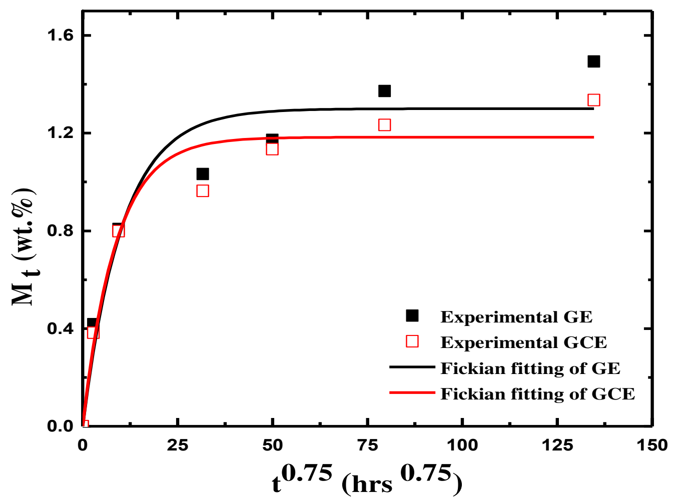

Figure 1: Water uptake kinetic analysis of GE and GCE composites

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To study the water absorption rate in the composite specimens the water content in the samples were measured and then plotted against the ageing time as shown in figure 1. It has been seen that for both the composites the rate of water uptake was quite high at the initial time and there is no significant difference in the water content for GE and GCE composite. As the outer layers of both the composites are of glass plies, the water intake behaviour remains similar in the initial time.

The water molecules then start diffusing into the bulk material. In case of GCE composite the presence of carbon plies next to the outer glass plies retards its further water diffusivity inside the material and this has been replicated in the graphs where the rate of water uptake in both the composite starts deviating from each other. In both the composite systems a linear trend has been noticed till an absorption time of 100 hours after which a remarkable deviation from linearity was observed. Fick's diffusion kinetic has been fit (eq. 1) for both the composite and it was observed that the water uptake kinetic in this linear portion resembles with Fick's law of diffusion.

$$\frac{M_t}{M_\infty} = 1 - \exp\left[-7.3\left(\frac{Dt}{h^2}\right)^{0.75}\right] \quad \ldots (1)$$

Where, M_t is the water content in the composite at time t, M_∞ is the saturation water content. D represents the diffusivity of the material at the testing conditions and h is the thickness of the sample.

3.2 Flexural Behaviour

Flexural properties of all GE and GCE samples are presented in fig.2 with hot water ageing time. Fig.2 (a) represents the stress-strain behaviour of the samples with 450hours of ageing and without ageing. It is evident from figure that there is significant change in the stress-strain response of both the composites after 450 hours of ageing. Although the stress-strain pattern of aged and unaged samples resembles.

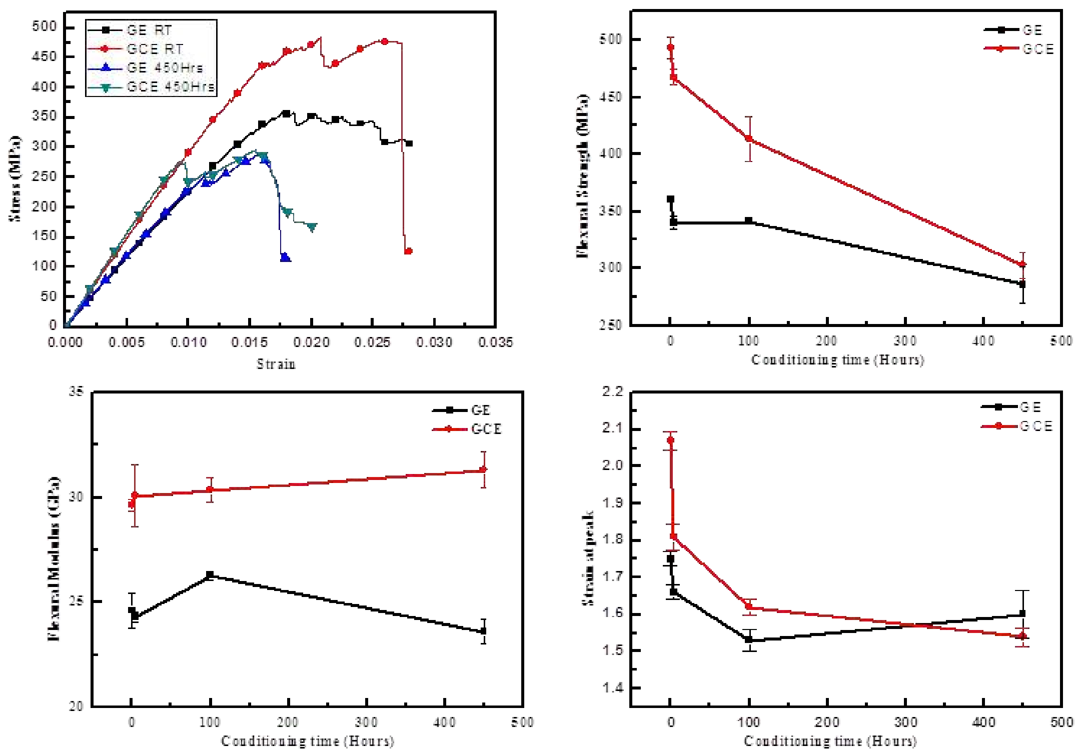

Figure 2: Variation of flexural properties of GE and GCE hybrid composites with hot water ageing time.

From these stress-strain plots other flexural properties have been derived and plotted in fig.2 (b), (c) and (d).A decrease of about 5% in the flexural strength was observed for both the composites only after four hours of hot water ageing. This decrease was remains same upto 100 hours of ageing for GE composite whereas there was further decrement in strength of about 16% for GCE composite. After 450 hours of exposure to hot water the strength of GE composite reduced by 20% whereas GCE hybrid experienced 38% reduction in its flexural strength. The variation of flexural modulus with hot water ageing upto 450 hours was not significant. For GE composite 4% decrease was observed whereas for GCE hybrid composite there was an increment of about 5% in its modulus. The variation of strain at peak can provide an indication about the relative ductile or brittle nature of the composites under consideration. Under the exposure to hot water there was a noticeable change in the strain at peak for both the composite systems indicating that the presence of moisture has modified the deformation behaviour of the composites. On the initial exposure to hot water for a short period of time (100 hours) there was nearly 5% and 12% decrease was observed for GE and GCE composite respectively. Further ageing of nearly 450 hours to GE composite did not significantly altered the strain at peak but the GCE hybrid composite experienced dramatic decrease of nearly 25%. The rate of decrease in strain at peak was higher of GCE composite over GE composite which depicts that the rate of embrittlement due to presence of moisture is higher in this composite.

4. Conclusion

It can be concluded that at the initial period, the water uptake behaviour is similar for both the composite system as the outer layers of both composites comprise of glass plies. Again in both materials, the initial water uptake follows Fick's law. Remarkable difference in the water content appears after certain time period and the hybrid composite seems to be more water resistive due to presence of carbon plies. With increase in water content, the flexural modulus for both the composite materials remains mostly unaffected; whereas a significant reduction in the flexural strength was observed as the water uptake time increases. The rate of strength degradation was found to be more in case of hybrid composite than GE composite.

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