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Hydrothermal Shock Cycles on Shear Strength of Glass Fiber-Polyester Composites

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ABSTRACT

Degradation of glass-fiber-reinforced polyester composite by hydrothermal shock cycles was studied experimentally. The interface-interphase in glass fiber composites is assumed to be a polymer film, thus, it may be susceptible to perish by environmental shock. Glass fibers of 55, 60 and 65% weight percentages were used to fabricate polyester matrix polymer composites. The test specimens were first treated at 50°C temperature water bath for 30 minutes and then they immediately were immersed in another water bath at 100°C temperature for the same time. The treatment was repeated for different cycles. The short beam shear (SBS) test was performed at room temperature on the conditioned samples for two different crosshead speeds (2 mm/min. and 50 mm/min.). The objective of the experiment is to assess the deterioration effect of hydrothermal shock on interfacial bonding of varied weight fraction constituents in the composite. The fiber-matrix interfacial damage is reflected in the 3-point SBS test. The fall in shear values were observed to be 19-27%, depending of volume fraction of constituents. The variation in loading speeds was taken into consideration for the assessment of interlaminar shear strength (ILSS).

KEY WORDS: hydrothermal shock, glass fiber, polymer, crosshead speed, cracks, mechanical behavior

INTRODUCTION

One of the major drawbacks of thermoset resins is their tendency to absorb significant amounts of water when they are exposed to hydrothermal environments. Temperature is likely to influence moisture pick-up kinetics in polymer composites in a complex manner [1]. The equilibrium moisture content in fiber-reinforced polymer (FRP) composites was observed to be either independent of temperature [2] or dependent on temperature [3]. Absorbed water is rarely distributed uniformly and thus a distribution of internal stress associated with water uptake. Polyester resins unlike others undergo net shrinkage after long exposure to water [4]. Three processes (hydrolysis, hydrophilisation, formation and migration of low-molecular weight electrolytes) predominate at different stages of water sorption behavior in fiber/polyester composites [5]. Delamination is the most prevailing life-limiting crack growth modes in laminate composites. It may be introduced by cyclic fatigue of any nature. It was reported [6] that polyester matrix is more susceptible to damage/debonding by thermal fatigue compared to epoxy matrix composite. The moisture-induced volumetric change between the matrix and fiber is of significantly different order. Thus, the mismatch often leads to the development of localized stress and strain fields in the composite. Moisture absorption along the fiber-matrix interface degrades the interfacial bond, consequently results in a loss of micro-structural integrity. Thus the deterioration of matrix-dominated properties such as interlaminar shear strength, fatigue resistance and impact tolerance is evident in such materials [7–11]. The one of the objectives of the present study was laid on the assessment of interfacial damage in harsh and changing environmental conditions. The mechanical properties of most polymer tend to be sensitive to temperature changes and exposure in aqueous environments with different temperature will have a synergistic effect [12]. Thus, at any given time, the properties may be affected by complex and changing nature of residual stress-strain states due to hydrothermal shock. The transition region between fiber and matrix is known to play as essential role in the performance especially the durability of composite components. The utilization of polymer composite in engineering structures necessitates their characterization between energy absorption and loading speed. Unfortunately, a little information is available on the strain rate dependence of mechanical properties of FRP composites, especially after environmentally treated conditions. Furthermore, unsaturated polyester matrix composites generally perish in hydrothermal ageing by blistering/cracking due to an osmotic process [13]. Hydrothermal shock waves which are expected in many applications may accelerate the process of degradation of such materials. The degradative effect of hydrothermal shock cycles has been investigated here on polyester reinforced by varied weight fraction of woven glass fiber composites. The characterization was extended to a over range of crosshead speeds during 3-point bend test of the conditioned specimens. The high curing shrinkage and the mismatch of the thermal expansion coefficient between glass fiber and polyester matrix are the probable reasons for high residual stresses. The fiber generally has a lower coefficient of thermal expansion then the polymer matrix. The resulting thermal residual stresses are of compressive nature in fiber and tensile in matrix of FRP composites. There may be slight influence of the fiber volume fraction on the initial matrix failure and in the interfacial failure behavior [14]. The thermal micro-stresses in the fiber decrease when fiber-matrix adhesion is poor. An increase in adhesion strength may lead to significant deformations of composite subjected to temperature changes [15].

EXPERIMENTAL

An unsaturated polyester resin (Saint-Gobain Vetrotex) was used with woven roving E-glass fibers to fabricate the laminates. Three fiber weight percentages, 55, 60 and 65% were targeted in the laminate fabrication. They were cured for 48 hours at room temperature. The composites laminates were cut into SBS test specimens. The SBS tests were conducted to assess the interlaminar shear strength of composites. The test specimens were first immersed in a water bath at 50^0C temperature for 30 minutes. Then they were immediately plunged in another water bath at 100^0C temperature for again 30 minutes. It was treated as one hydrothermal shock cycle. The conditioning was carried out for different cycles. The 3-point SBS bend test was performed on the hydrothermally shocked specimens at room temperature for different cycles. The tests were performed on the conditioned specimens with equal time of holding after conditionings to eliminate/minimize the variable of any reversible recovery process of polymer matrix. The ILSS value was calculated as follows:

$$\text{ILSS} = 0.75p/bt$$

where p is the maximum load, b is the width of specimen, and t is the thickness of the specimen.

RESULTS AND DISCUSSION

Figure 1 shows the effect of number of hydrothermal shock cycles on ILSS value of glass-polyester composites (for fiber 0.55 weight fraction) at 2 mm/min. and 50 mm/min. crosshead speeds. Figure 2 shows the same effect for 60% weight percentage glass fiber reinforced polyester composites for the two loading speeds. Similarly, the effect of conditioning cycles on ILSS value is shown in Figure 3 for the 65% weight percentage glass fiber in polymer matrix composites again for the two speeds. All figures indicate the fall in shear strength with more conditioning cycles for both the crosshead speeds. But order of degradation is different for the different weight fraction constituents in composite. The figures are drawn separately as this failure stress is a function of the volume fraction, which is not account for in calculation of the SBS strength. It is the polyester resin that is more susceptible to hydrothermal shocking. This may change the locus of failure from the interface and can produce cohesive failure in the polyester matrix. The reduction in ILSS value due to the hydrothermal shock is not only attributed to moisture content only but also because of the debonding effect of thermal shock involved in the changing environments. Thermal expansion coefficients in polymers are considerably high and so failure of the bond between fiber and resin may occur under thermal shock leading to ingress of moisture [16]. It is reasonable to assume that the interfacial shear strength is the resultant of a number of mechanisms to fiber-resin adhesion. These possibly include chemical bonding, inter-diffusion, electrostatic attraction, adsorption and wetting and also the mechanical locking adhesion. These main mechanisms either in isolation or in combination may yield the interphase in the polymer matrix composite. The interphase in some glass fiber composites is due to the film former, which is also a polymer [17]. It may be addressed here in the light of the present state of literature, that the understanding of the interphase in glass fiber composite has neither been explained theoretically nor solved conclusively.

Thermal shock may often result in intense thermal stresses in the structure during service periods around cracks and other kinds of common manufacturing defects of FRP composite. This may modify the local stress threshold required for interfacial debonding. It quite possibly leads to the premature nucleation of delamination failure. The failure in a fiber composite initiate from small defects such as matrix pores and debonded interfaces. The propagation of cracks can cause fiber-matrix interfacial debonding and interlaminar cracking. Matrix micro-cracking may also occur near the tip region [18]. Figure 4 reveals the matrix cracking and interfacial debonding in the scanning electron micrograph (SEM) of the treated sample. The multiple matrix cracking by the treatment may become a macroscopic form of damage accumulation that eventually may dictate the initiation of delamination failure. The residual stress distribution, differences in Poison's ratios and differential coefficient of thermal expansion can influence the crack multiplication stage of failure process.

Figures 1 to 3 show that the mean shear strengths at all points of hydrothermal shock cycles are higher at higher loading speed. A laminate behave like a rigid beam or plate when it is subjected to higher loading speed. Then it is less susceptible to bending. It is important to state that a variation in loading rate may result in change of failure modes. Epoxy resins are known to be highly loading rate sensitive. A direct correlation between the rate dependency of the composite and those of the constituent phases need to be explored. The experimental results show the rate-dependent constitutive relations are required for critical and reliable durability study of polymer matrix composites [19, 20].

CONCLUSIONS

Effects of hydrothermal shock cycles on mechanical behavior of glass-polyester composite for the varied volume fraction constituents are shown here in slow and moderate loading rates. The adverse effect of the changing environments is noticed. The loading rate sensitivity is found to be evident after the shock cycle treatments. The degradative phenomena are comparatively less sensitive to the interfacial area of the composite. The interfaces increase with more volume fraction of fibers. But the nature of the curves and the degree of fall in ILSS value are comparable for the different volume fraction of the constituents. Matrix as well as interface damages are possibly contributing to the weakening phenomena of glass/polyester composite by the hydrothermal shock cycles. It is also observed that the damaging effect is sensitive to the loading speed. It is noticed that the ILSS value is higher at higher loading rate.

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FIGURE CAPTIONS

Figure 1 **Hydrothermal shock cycles on ILSS value of glass-polyester composites (for 55% fiber weight) at 2 mm/min (●) and 50 mm/min (♦) crosshead speeds.**

Figure 2 **Hydrothermal shock cycles on ILSS value of glass-polyester composites (for 60% fiber weight) at 2 mm/min (●) and 50 mm/min (♦) crosshead speeds.**

Figure 3 **Hydrothermal shock cycles on ILSS value of glass-polyester composites (for 65% fiber weight) at 2 mm/min (●) and 50 mm/min (♦) crosshead speeds.**

Figure 4 **Scanning electron micrograph shows matrix and interfacial crackings in glass/polyester composites at a 1000 magnification.**

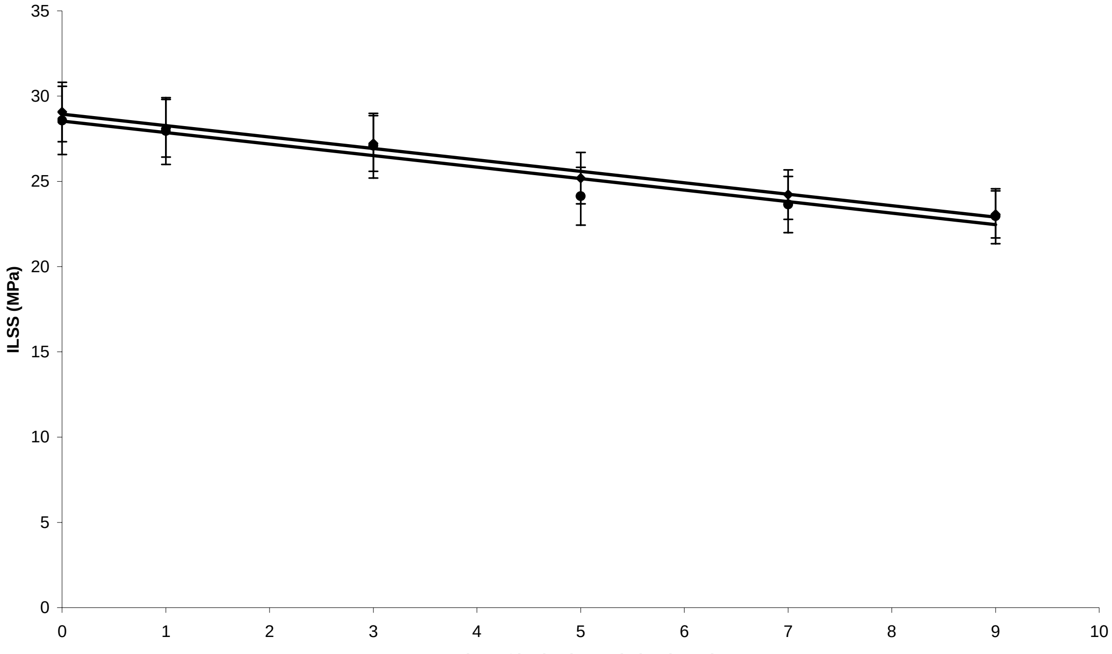
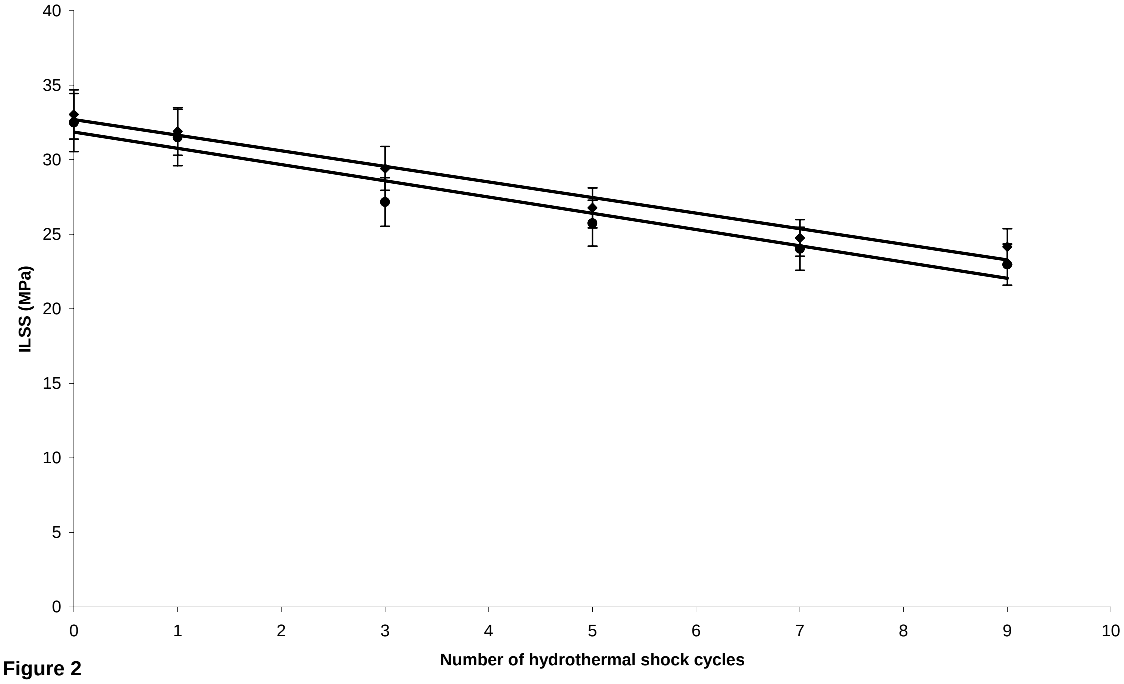

ILSS (MPa)
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
Number of hydrothermal shock cycles

Figure 1



40
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ILSS (MPa)
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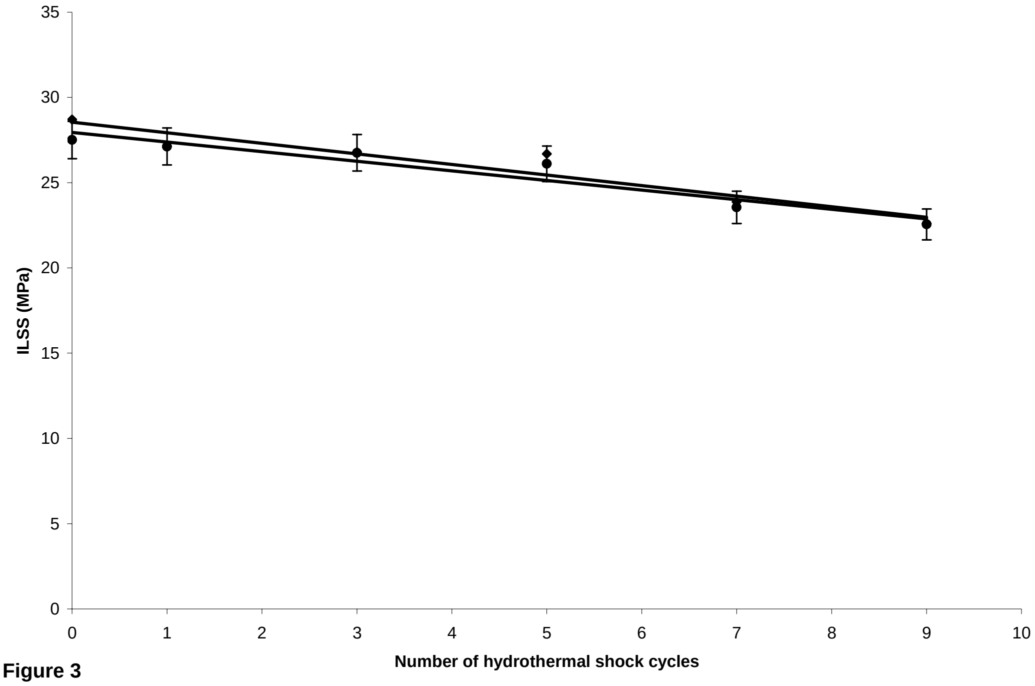
Number of hydrothermal shock cycles

Figure 2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ILSS (MPa)
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Number of hydrothermal shock cycles

Figure 3

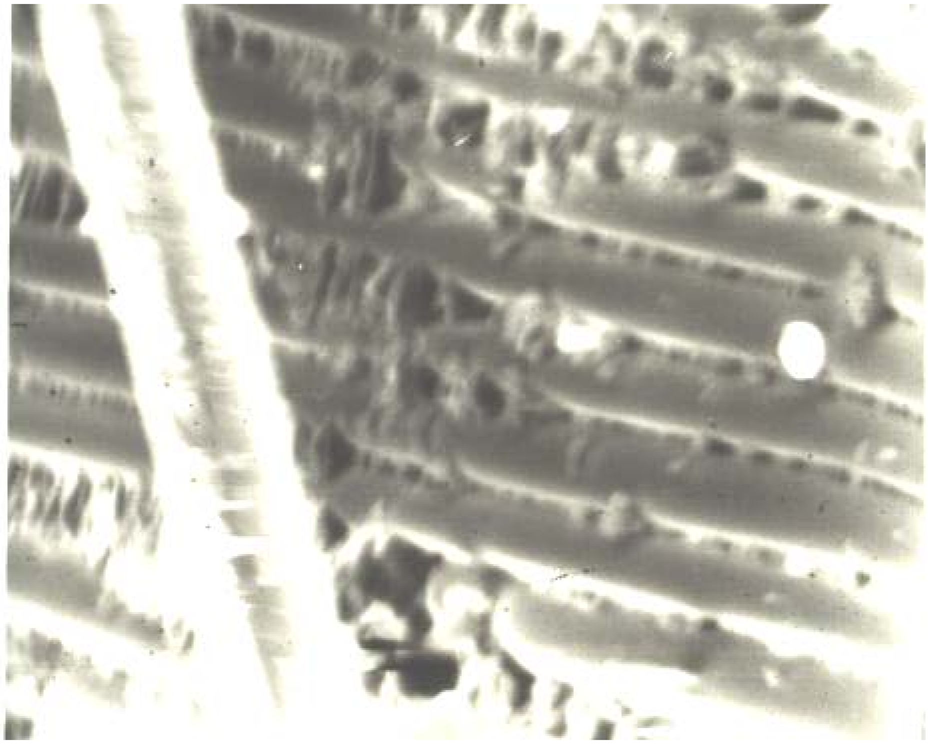

Figure 4