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ASSESMENT OF INTERLAMINAR SHEAR STRENGTH OF HYBRID COMPOSITES SUBJECTED TO A FLUCTUATING HUMID ENVIRONMENT

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ABSTRACT

The present work aims to assess the interlaminar shear strength (ILSS) of interply woven fabric hybrid composites under the influence of a fluctuating humid environment. The ILSS values have been used for quantification of mechanical degradation. The effects of fluctuating environment on moisture sorption as well as the degradation kinetics have been assessed. It is seen that the ILSS shows a gradual degradation over a period of time. It is has been observed that the ILSS scales inversely with crosshead velocities. This is attributed to the presence of alternating strong and weak interfaces and the differences in their moisture sorption tendencies.

Key words: Fluctuating environment; ILSS; Degradation kinetics, Interfacial behaviour; Delamination

1. INTRODUCTION

Hybridization provides materials designers with an added degree of freedom in tailoring composites to achieve a better balance of stiffness, strength, increased failure strain, better damage tolerances, improved ability to absorb impact energy and possibly a significant reduction in cost [1]. Hence, the behavior of fiber reinforced plastic (FRP) hybrid composites under possible service conditions is a matter of significant practical interest. The mechanical behavior of FRP composites are dominated by the interfacial adhesion at the fiber-matrix interface. The presence of moisture at the interface can modify the interfacial adhesion thereby affecting the mechanical performance of the FRP composites. Moisture absorption in the composites introduces dilatational stresses. During moisture absorption, the outside ply of a composite laminate is in compression [2]. This results from the outer ply trying to swell, but being restrained by the dry inner plies. Similarly, on desorption, the outer plies try to shrink, but are restrained by the wet swollen inner plies. This results in tensile stresses in the outer plies. Consequently the mechanical properties and long term durability show a marked deterioration. Hence an environment comprising of high humidity fluctuations, where moisture absorption occurs in the high humidity regime and desorption occurs in the low humidity regime, can have highly deleterious effects on the mechanical behavior and long term durability of the composites.

The present study has been carried out to assess the effect of a fluctuating hygrothermal environment on the mechanical behavior of interply woven fabric glass-carbon fibers/epoxy hybrid composites. The rapid fluctuations, in essence, constitute a hygrothermal shock. A variety of FRP structural components may experience hygrothermal shock waves during their service life. The shocks induce non-uniform spatial distribution of hygroscopic stresses at glass/epoxy and carbon/epoxy interfaces which ultimately contributes to the failure of the material.

2. EXPERIMENTAL

Woven fabric carbon fibers (T-300, PAN based high strength carbon fiber) along with E-glass fiber woven roving having a density of 0.36 kg/m^2 were used as fiber reinforcement. Epoxy adhesive (Ciba-Geigy LY-556 araldite, HY-951 hardener) was used as the matrix material. The composite specimens were prepared using the hand lay-up method. Prior to the environmental conditioning the composites were dried in desiccators. The composite specimens were initially subjected to an environment characterized by 50% relative humidity (RH) and 50^{o}C temperature for a period of one hour. Then they were exposed to a second environment characterized by 90% RH and 50^{o}C temperature for another one hour interval. Thus nineteen humidity cycles were carried out with a time period of two hours for each cycle. The ILSS values were evaluated from the short beam shear test according to the following relation:

$$ILSS = \frac{0.75P_b}{bd}$$

where P_b = breaking load, b and d are width and thickness of the specimen respectively.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the variation of moisture absorption during the environmental conditioning. The data series reflects the moisture gain values at end-cycle points. The plots show a steady increase in the amount of moisture observed. It is reasonable to assume that when a composite is exposed to an environment comprising of fluctuating humidity, absorption and desorption of moisture occur according to the environmental change. When exposed to a high humidity environment (90% RH in the present studies), the moisture gets absorbed in the composite. The amount of moisture absorption by composites is a function of thermodynamic potentials of surroundings and the composite [3]. Consequently, upon subsequent exposure to dry environments (50% RH in the present studies), some amount of moisture diffuses out of the composite resulting in desorption. The first half of the cycle constitutes subjecting the composites to a low humidity environment. This is followed by exposure to a high humidity environment. This, in essence constitutes a “humidity shock”. The presence of such a shock ensures a significant difference in the partial pressures of moisture within the composites and the environment resulting in an accelerated moisture uptake as seen in the figure. As the composite is cyclically exposed to changing environments, absorption and desorption dominate the moisture diffusion behavior in an alternating manner. Figure 1, however, shows that the net moisture content in the composite increases over a period of time. This is indicative of the fact that the amount of moisture absorption outweighs desorption in a given conditioning cycle.

Figures 2 and 3 show the degradation kinetics due to the fluctuating environment. The ILSS is seen to deteriorate over a period of time with a significant measure of interim fluctuations. In the initial stages, the ILSS values are seen to plummet downwards. Amount of moisture absorbed by the epoxy matrix is significantly greater than fibers which absorb little or no moisture [4]. This results in significant mismatch in moisture induced volumetric expansion between matrix and fibers leading to evolution of localized stress and strain fields in the composite, at the interface leading to degradation of the interfacial bonds thereby resulting in deadhesion. Hence, possibly the moisture absorption in the initial cycles does not increase the partial pressure of moisture, so that significant desorption occurs when exposed to dry environments. With increased conditioning, the moisture content in the composite increases, and a greater probability of significant desorption exists. Desorption of moisture results in reduction of the stressed state of the material. It is interesting to note from figure 4 that the increase in ILSS corresponds to a noticeable fall in the moisture pickup rate, as evidenced from the slope of the moisture absorption curve. This could contribute to an intermediate increase in the ILSS values. With further absorption and desorption, stresses of opposite nature are introduced at the interface, which can be expected to prove detrimental. This can possibly explain the subsequent fall in the ILSS values.

Figure 4 shows a comparative study of the moisture uptake, degradation kinetics and the effect of varying the crosshead velocity. It is noted that the ILSS assessed at higher crosshead velocity have lower values as compared to those for lower crosshead velocity. This anomalous dependence of ILSS on the crosshead velocity may be attributed to the presence of two different types of interfaces. The epoxy matrix absorbs moisture amounting to 4% of its weight prior to saturation, whereas the glass-epoxy interfaces and carbon-epoxy interfaces can absorb 2% and 1% moisture respectively. As a compressive force is applied on the material, the moisture at the interfacial regions has a tendency to get rejected in the adjacent matrix. Since, the carbon-epoxy interfaces have lesser porous zones to accommodate the moisture, it is expected that this interface will reject a greater amount of moisture at a faster rate. The overall direction of moisture transport in such a situation would be towards the glass-epoxy interface.

The net effect, then, would be the accumulation of moisture in the matrix immediately adjacent to the glass-epoxy interface, even as the regions adjacent to carbon-epoxy interfaces remain relatively moisture free. At a higher crosshead velocity, the moisture transport has a greater impetus to move towards the glass-epoxy interface. Hence the probability of additional moisture trapping at the glass-epoxy interface would be greater. Moisture absorption results in significant mismatch in moisture induced volumetric expansion between matrix and fibers leading to evolution of localized stress and strain fields in the composite. Additionally moisture absorption leads to changes in thermophysical, mechanical and chemical characteristics of the epoxy matrix by plasticization and hydrolysis [5]. These changes decrease the glass transition temperature (T_g) and elastic modulus. At the same time, the moisture wicking along the fiber-matrix interface degrades their bond. Consequently, the interfacial adhesion degrades and the ILSS decreases even as the weak interface becomes weaker. This effect is more pronounced at higher crosshead velocities because of accelerated moisture movement through the resin. Consequently the ILSS values obtained at lower crosshead velocities are higher.

Initially, at lower conditioning times, there exists a marked difference between the ILSS values obtained at different crosshead velocities. Possibly, humidity shocks may cause additional interface cracking in a manner analogous to thermal shocks [6]. At higher conditioning times, the difference in the ILSS obtained from testing at different crosshead velocities narrows down gradually. Although in the present study, the conditioning has not been sufficiently prolonged so as to achieve statistical insignificance of crosshead velocities, it may be expected that prolonged exposure may result in that effect. This may be attributed to the fact that at higher levels of absorbed moisture, the degradation in the epoxy matrix and the interfaces are colossal. Such damage is likely to preclude the sensitivity to the crosshead velocities. Hence, the effect of crosshead velocities should become less significant over prolonged exposure periods [7].

4. CONCLUSIONS

In retrospection, one may conclude that the effect of fluctuating environment may have a reasonably deleterious effect on the mechanical behavior of hybrid composites. The humidity shock results in a sudden moisture uptake which results in a corresponding deterioration of mechanical properties. Following this, in absence of prolonged exposure, the interpenetrating network at the interface stalls the deterioration process. There is a chance that prolonged exposure could lead to a breakdown of this network, as a consequence of which the interface would become actively vulnerable to the hot and humid environments. The differences in percentage of elongation of the constituents in a hybrid composite at fracture could modify the nucleating stress required for delamination.

REFERENCES

1. Jang. B. Z., “Advanced Polymer Composites: Principles and Applications” (ASM International, Materials Park, OH 1994) p. 112.
2. Tompkins. S. S., Tenney. D. R., Unna. J., Composite Materials: Testing & Design (Fifth Conference), ASTM STP 674 (1979) p. 368.
3. George. S. C. and Thomas. S., Prog. Polym. Sci. 26 (2001) 985.
4. Ray. B. C., J. Mater. Sci. Lett. 22 (2003) 201.
5. Sala. G., Composites B 31 (2000) 357.
6. Ray. B. C., Mater. Lett. 58 (2004) 2175.
7. Ray. B. C., Mater. Sci. & Engg. A 379 (2004) 39.

FIGURES

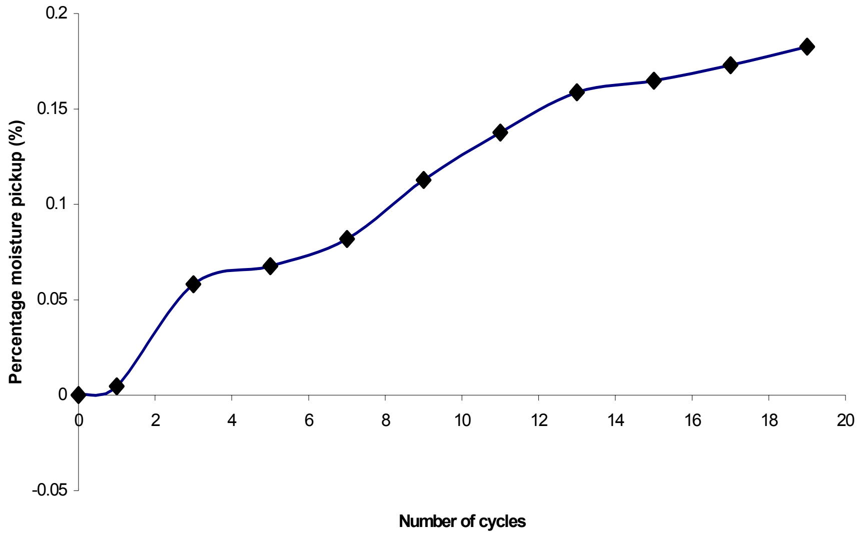

Figure 1 Moisture absorption plot over a number of cycles

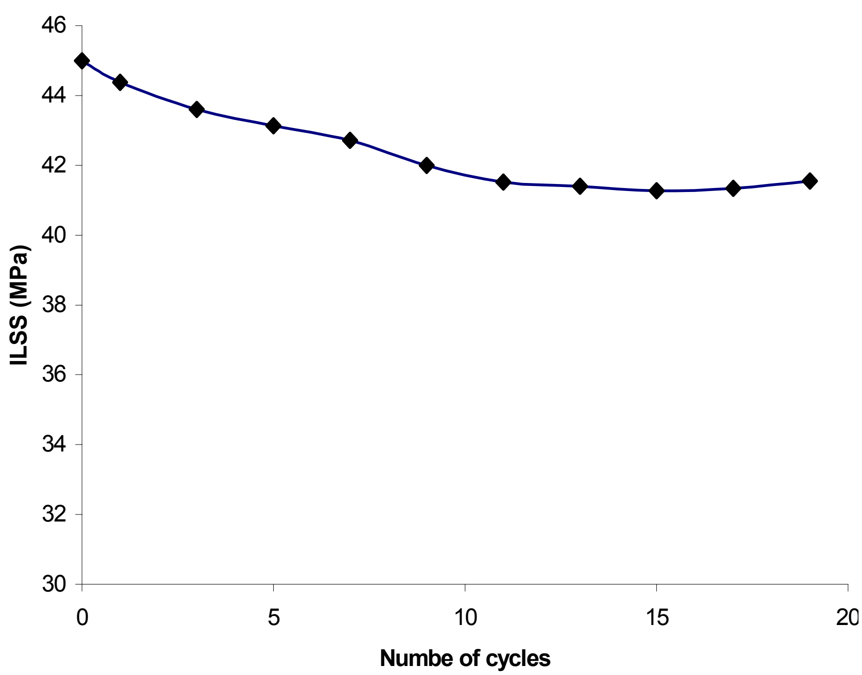

Figure 2 Degradation kinetics at a crosshead velocity of 2 mm/min

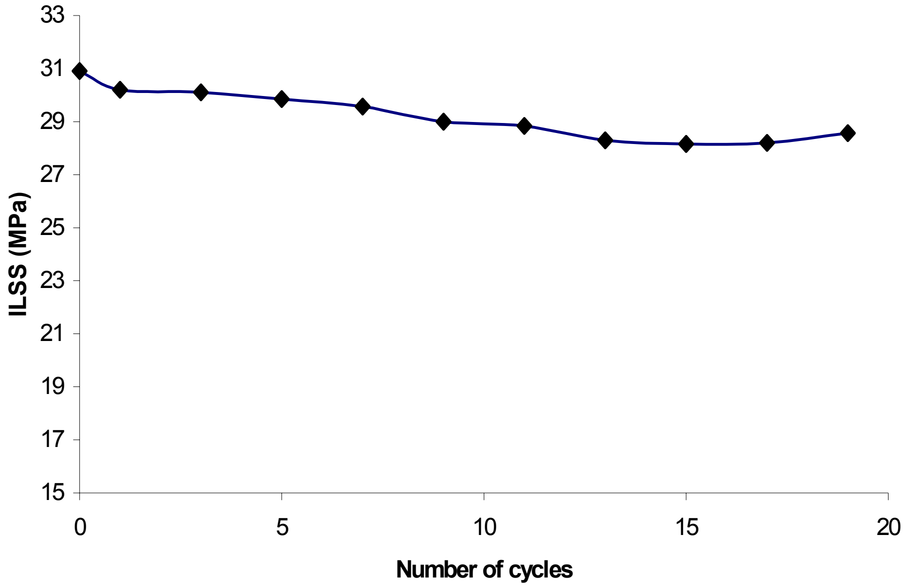

Figure 3 Degradation kinetics at a crosshead velocity of 50 mm/min

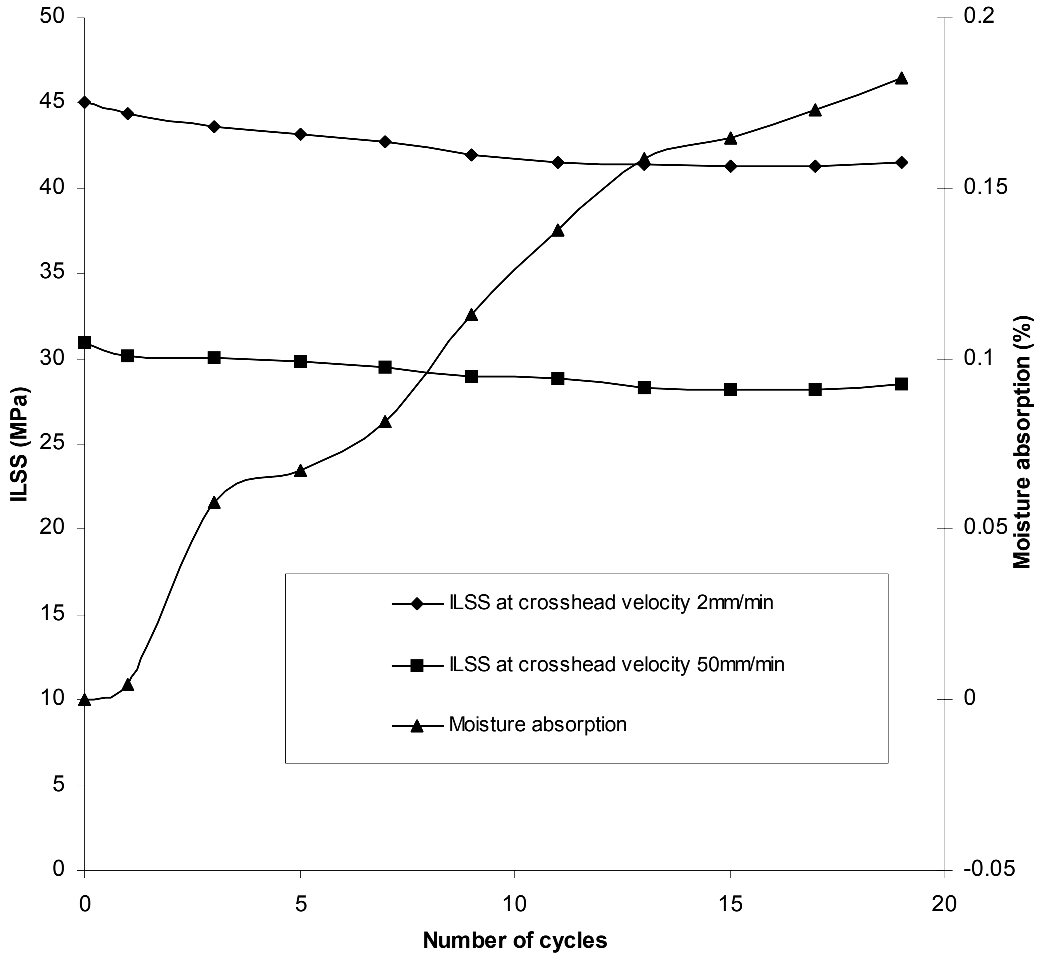

Figure 4 A comparative study of moisture pickup kinetics and degradation kinetics.