

Conference Paper

Impact of Environmental and Experimental Parameters on FRP Composites

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Impact of Environmental and Experimental Parameters on FRP Composites

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Abstract

The mechanical performance of a composite material is decisively controlled by the state of fiber-matrix interface or interphase. Its properties influence the integrity of composite behavior because of its role in transferring stress between the fiber and the matrix. The factors affecting the interface are too complex to be precisely concluded. Fibrous composites are increasingly being used in many casual as well as critical applications owing to various desirable properties including high specific strength, high specific stiffness and controlled anisotropy. But unfortunately polymeric composites are susceptible to heat and moisture when operating in changing environmental conditions. They absorb moisture in humid environments and undergo dilatational expansion. The presence of moisture and stresses associated with moisture-induced expansion may cause lowered damage tolerance and structural durability. The structural integrity and life time performance of fibrous polymeric composites are strongly dependent on the stability of the fiber/polymer interfacial region. The low molecular weight impurities may migrate from the bulk of the adhesive to form a weak boundary layer at or near the fiber surface. The active carbon fiber surface can strongly attract polar molecules of the polymer matrix. This may develop a boundary layer of high cross-link density. This micro-structural gradient at the interface may promote crack initiation and propagation through this layer. The environmental and experimental variations, such as moisture, temperature and variation of loading rate can limit the usefulness of polymer composites by deteriorating mechanical properties during service.

Introduction

Thermal shock and thermal fatigue are very common in many applications of FRP composites. Thermal loading is produced in structural components by the aerodynamic design of modern objects. The invincibility of composites has been their biggest myth. A reported premature failure of E-glass composite wraps applied to circular highway-supporting columns, under sustained stresses of approximately a third of the strength, is not an isolated incident.

The average bond strength of epoxy resin with an E-glass fiber (approximately 33 MPa) is lower than with a carbon fiber (approximately 57 MPa) [1]. But the anisotropy in carbon fibers limit their usage in various applications. However, particular structural requirements may need materials which have a higher modulus and a higher fatigue strength value than those which can be provided by the glass fiber. Epoxy resins are the most common matrices for high performance advanced polymer composites, but they are also inherently brittle because of their high degree of cross linking. The densely cross-linked structures are the basis of superior mechanical properties such as high modulus, high fracture strength, and solvent resistance. However, these materials are irreversibly damaged by high stresses due to the formation and propagation of cracks. These lead to dangerous loss in the load-carrying capacity of polymeric structural engineering materials. The growing number of uses for FRPs in many engineering critical applications has made the issue of interface (or more properly termed, interphase, a major focus of interest in the design and manufacture of composite. A classic definition of the *interface* in fiber reinforced polymers is a surface formed by a common boundary of reinforcing fiber and the matrix that is in contact with and maintains the bond in between for the transfer of loads. It has physical and mechanical properties that are unique from those of the fiber and the matrix. In contrast, the *interphase* is the geometrical surface of the fiber-matrix contact as well as the region of

finite volume extending there from, wherein the chemical, physical and mechanical properties vary either continuously or in a stepwise manner between those of the bulk fiber and matrix material. A need probably exists for an assessment of mechanical performance of such composites under the influence of harsh and hostile service conditions [2]. Thermal stresses caused by temperature gradient should be given special attention in many application areas. A better understanding of interfacial properties and characterization of interfacial adhesion strength can help in evaluating the mechanical behavior of fiber-reinforced composite materials. The mechanical properties of FRP composites are strongly influenced by the fibre/polymer matrix interface. Failure may occur in the interfacial region due to chemical reactions or to plasticisation when water penetrates the interfaces. Differences between the thermal coefficient of expansion of the reinforcement and that of the matrix phase, together with the cure shrinkage associated with thermosetting resins can often induce stress concentrations at the interface. The present review and research has been designed to study the effects of changing the seawater immersion temperature on the matrix-dominated short beam shear (SBS) strength of glass/epoxy and glass/polyester composites at different strain rates. The effect of volume fraction on delamination was also taken into account.

Materials and Methods

Glass fiber woven roving and epoxy adhesive (Ciba-Geigy, India; LY-556 Araldite, HY-951 hardener) were used to fabricate composite laminates. The layered structure after room temperature curing was cut into the required size for three-point bend (SBS) test by diamond cutter. Woven carbon fibers (T-300) of epoxy compatible sizing (PAN based high strength carbon fiber, M/S CARR Reinforcement Ltd., UK) were used with Araldite LY-556, an unmodified epoxy resin based on Bisphenol-A and hardener (Ciba-Geigy, India) HY-951, aliphatic primary amine to fabricate the laminated composites. They were cured for 48 h at room temperature and

were cut into tensile test and SBS test specimens. Then laminates were dried at a 50°C temperature in an oven for a sufficient time unless the variation of weight change was almost negligible.

An Instron 1195 tensile testing machine was used to perform tensile and SBS tests in accordance with ASTM D3039 and ASTM D2344-84 standards. Multiple samples were tested at each point of the experiment and the average value was reported.

Results and Discussion

The degree of environmental degradation that occurs in an FRP composite structure is linked directly with the amount of moisture that is absorbed. But the moisture absorption mechanism and kinetics of epoxy resins differ widely and also change with physical ageing [1]. Fibrous composites are increasingly being used in many applications owing to various desirable properties including high specific strength, high specific stiffness, and controlled anisotropy. But unfortunately, polymeric composites are susceptible to heat and moisture when operating in changing environmental conditions. They absorb moisture in humid environments and undergo dilatational expansion. The presence of moisture and the stresses associated with moisture-induced expansion may cause lowered damage tolerance and structural durability. The structural integrity and lifetime performance of fibrous polymeric composites are strongly dependent on the stability of the fiber/polymer interfacial areas.

Glass/epoxy system

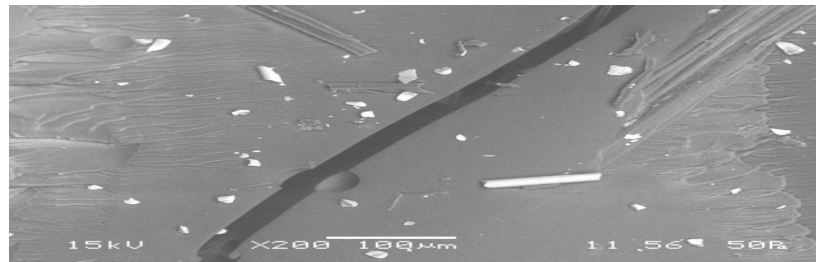


Figure 1(a).

The figure 1(a) shows the propagation of a delaminated crack front along the interface. This could be a result of the manufacturing defects, the

generated out of plane stresses and also because of the laminate geometry. There are as well a large number of striations being observed as smooth lines on the matrix. The damage may begin with the formation of striations/microscopic cracks (crazing) in the matrix or at the fibre/matrix interface. When these cracks develop to a certain density and size, they tend to coalesce to form macroscopic matrix cracks.

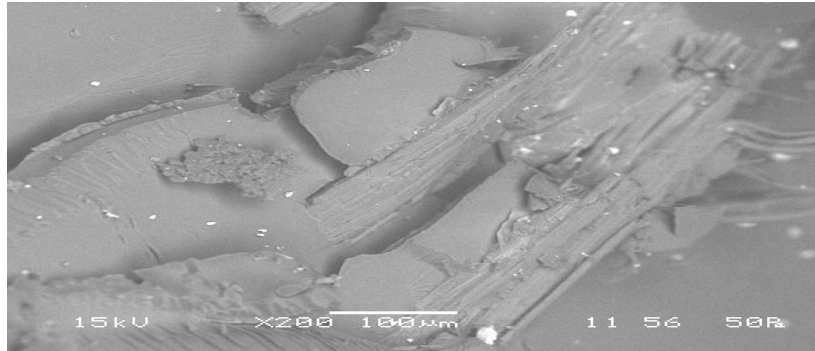


Figure 1(b).

The fig 1(b) shows the bursting of matrix due to the sudden collapse of any entrapped water molecule. The low molecular weight impurities formed by water absorption may migrate from the bulk of the adhesives to form a weak boundary layer at or near the interface. Matrix micro-cracking may also lead to such a burst.

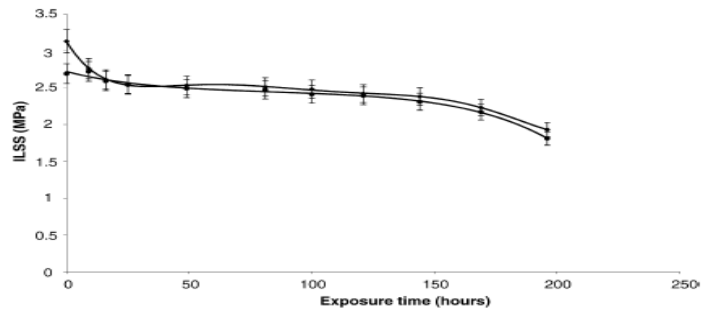


Figure 1(c). Variation of ILSS of conditioned glass/epoxy laminates with crosshead speed (Ref. 4)

Figure 1(c) shows the changes in mechanical properties with percentage of absorbed moisture at two different crosshead speeds. Multiple

crackings at the higher moisture content may additionally impart complicity to assess the strain rate sensitivity.

Jute/epoxy system

The figure 2 (a) shows the large number of striations through the matrix caused by the fatigue of the sample. These small cracks join under appreciable energy-favored kinetics to form larger cracks to lead to further failure of the matrix.

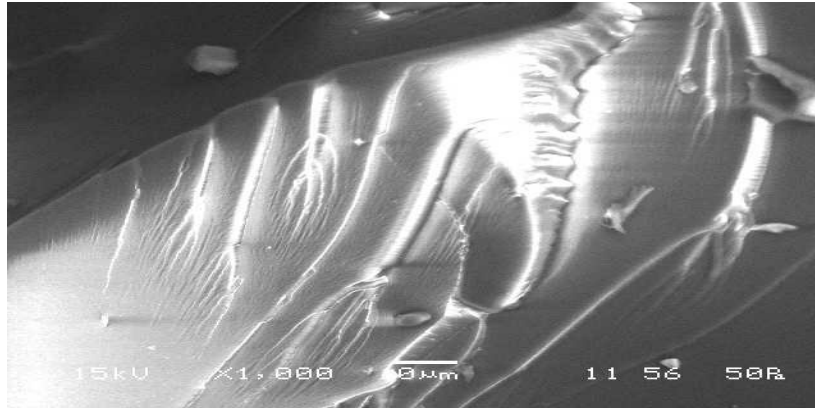


Figure 2(a).

Fracture behavior depends on factors, such as, resin relaxation, state of interfaces, post-curing phenomena, stresses relaxation and development, crazing and cracking in the matrix resin and also micro-void formation because of differential contraction/expansion among constituent phases. Recent reported AFM analysis is able to predict the swelling of the matrix as a result of the moisture uptake from the environment. The SEM analysis also gives information about mode of failure and specific response of composite to particular type of loading. By observing carefully the fracture surface of the composite, the factors affecting their respective failure and the type of environment they were subjected to could be determined.

The moisture absorption most often leads to changes in the thermophysical, mechanical, and chemical characteristics of the epoxy matrix by plasticization and hydrolysis [6]. Integrity of polymer composites

in terms of matrix cracking and/or fiber/matrix debonding/discontinuity by humid ageing may be reflected by moisture absorption kinetics and interlaminar shear strength studies.

Carbon/epoxy system

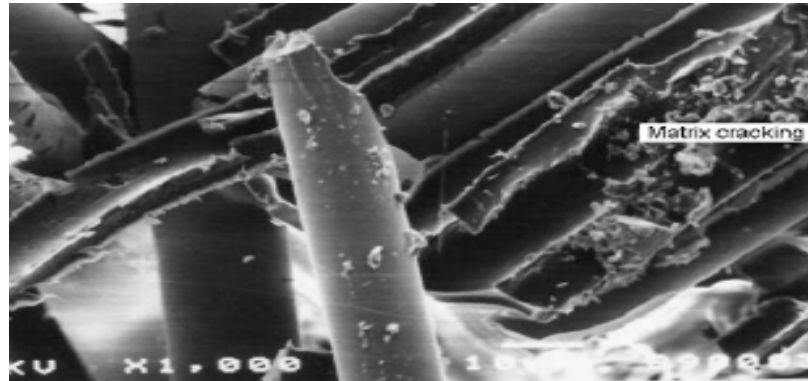


Figure 3(a). Ref. 8

Stress transfer at the fiber/matrix interphase requires a strong interfacial bond between the two components and an improvement of the coupling often causes a decrease in impact strength and fracture toughness since too strong adhesion can limit the energy absorption mechanisms, making the composite more brittle. A major problem in composite systems is that they show poor resistance to crack propagation and hence delamination. Improved resistance to delamination guarantees extended service life and improved mechanical durability.

The mechanisms of thermal aging are not clearly understood. Thermal degradation of plastics involves a chemical reaction and physical changes. Chemical reaction is represented by cross-linking and further reaction of unreacted monomers, while physical change is typical of viscoelastic behavior. It is demonstrated that, during thermal aging in air, organic matrix composites undergo a superficial oxidation leading to a “spontaneous” cracking without application of external load. At the macromolecular scale, chain scission, and crosslinking affect the polymer network and thus, alter the mechanical properties of the oxidized layer; at

the macroscopic level, the hindered shrinkage of the oxidized layer induces a stress gradient susceptible to initiate and propagate cracks

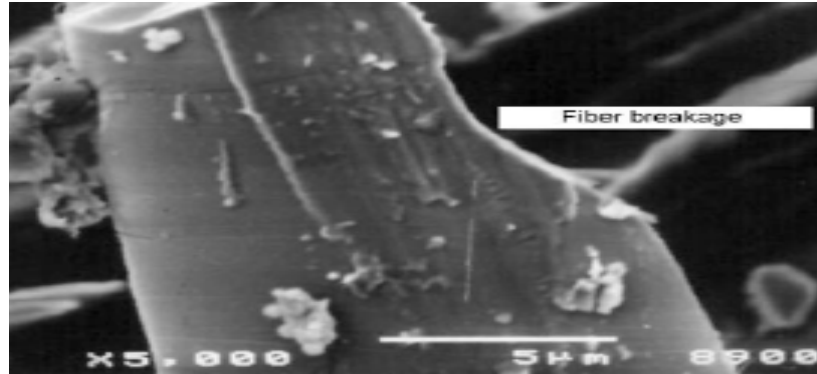


Figure 3(b). (Ref. 8)

The Scanning Electron Micrographs are highlighting the presence of polymer matrix adherence to the carbon fibers and epoxy matrix damage as well as fiber breakage (Figs 3(a) and (b)).

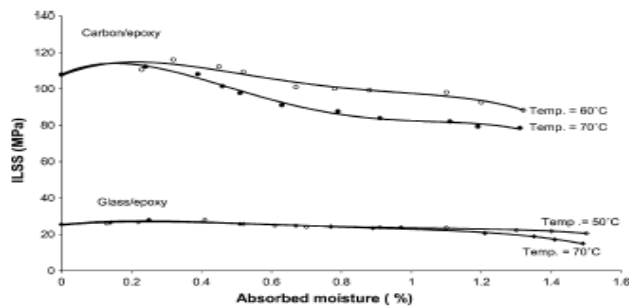


Figure 3(c). Variations of ILSS for Glass and Carbon epoxy systems (Ref.8)

The sensitivity of composite to strain rate is driven by the resin behavior. It was observed that the increasing strain rate leads to the increase of

failure strength. It may possibly be accompanied by a reduction in matrix ductility. Epoxy resins and glass fibers are known to be highly loading rate sensitive. A direct correlation between the loading rate dependency of composites and those of the constituent phases may be difficult or rather complicated. A laminate behaves like a rigid beam and thus less susceptible to bending at higher loading speed. Epoxy resin is more ductile at low strain rate but the failure strain of a matrix resin at high speed may become a limiting factor for the composite strength [3-5].

The diffusion process is complex in fibrous composites. It depends on the diffusivities of the individual constituents, their relative volume fractions, constituent arrangement and morphology. The rate of moisture diffusion is controlled by the diffusivity. It is a strong function of temperature and a weak function of relative humidity. Moisture can potentially cause debonding at the fiber/matrix interface not only through chemical attack and reaction, but also through mechanochemical effects such as osmotic pressure [6-8].

The observations from the SEM micrographs may be attributed to varying failure mechanisms with varying loading rate, fiber kinking coupled with the micro-buckling and fiber fracture at low strain rates and combination of global delamination, interfacial separation and spalling at higher strain rates [9].

Summary and Conclusion

The study leads to the conclusion that the higher temperature during hygrothermal ageing not only increases the moisture uptake rate, but it may also modify the local stress threshold required for delamination failure. The higher temperature acts like an activator of diffusion of the water molecules through the composites. The less value of ILSS for almost the same level of absorbed moisture at higher temperature could be attributed to the pronounced degradative effect of temperature. The room temperature test results further reflect the irreversible nature of

damage at the interface. It is reasonable to conclude that the interfacial adhesion in the carbon/epoxy and glass/epoxy composites is more affected by hygrothermal ageing at higher conditioning temperature and for more exposure time (i.e., more absorbed moisture). The reduction in ILSS values is significant here in both the systems for the same level of absorbed moisture at a higher conditioning temperature. It is not only the absorbed moisture, but also under what temperature it diffuses into the specimen that characterizes the interfacial degradation phenomena. An interfacial reaction may impart various morphological and structural modifications to the matrix microstructure in proximity to the fiber surface. The strain rate sensitivity is also evident.

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References

1. B.Z. Jang, *Advanced Polymer Composites: Principles and Applications*, P 50, ASM International, OH (1994)
2. B.C.Ray, *Mater. Lett.*, 58, 2175-77 (2004)
3. L.M. Weish, J. Harding, in: *Proceedings of the Fifth International Conference On Composite Materials (ICCM V)*, p 1517 TMS-AIME(1985)
4. B.C.Ray, *Mater. Sci. Engg* A379 39-44 (2004)
5. T.Z. Blazynski (Ed.), *Materials at High Strain Rates*, Elsevier Applied Science, Oxford, 1987
6. D. Hull, T.W. Clyne, *An Introduction to Composite Materials*, Cambridge Univ. Press, Cambridge, UK (1996).
7. C.L. Schutte, *Mater. Sci. Eng. Reports: Rev. J.* 13 265 311 (1994)
8. B.C.Ray, *J. Colloid & Interface Sci.*, 298 111-117(2006)
9. A.K.Srivastave, M.K.Behera and B.C.Ray, *J. Reinfor. Plast & Compos.*, 26 851-860 (2007)