Conference Paper

Impact of Environmental and Experimental Parameters on FRP Composites

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Environmental Durability of Fibrous Polymeric Composites

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Abstract

Durability of fiber reinforced polymer composites (FRP) are controlled by the durability of their constituents: reinforcement fibers, resin matrices, and the status of interfaces. It is at the interfacial area where stress concentration develops because of differences in the thermal expansion coefficients between the reinforcement and matrix phase. A significant mismatch in the environmentally induced degradation of matrix and fiber leads to the evolution of localized stress and strain fields in the FRP composite. The bond strength of composites, deteriorate during service periods depending on the environmental conditions. Both short-term and long-term properties of a composite depend decisively on the microstructure, and the properties of the interface or inter-phase between the fiber and the matrix. A strong interface displays an exemplary strength and stiffness, but is very brittle in nature with easy crack propagation through the interface. A weaker interface reduces the stress transmissibility and consequently decreases the strength and stiffness. Here a crack is more likely to deviate and grow at the weak interface resulting in de-bonding and/or fiber pull-out and contributes to improved fracture toughness. Most polymers lose their ductile properties below their glass transition temperature. The factors affecting the mechanical response of composites are fiber–matrix interfacial properties, volume ratios, load transfer mechanisms, and fabrication techniques. As the volume fraction of reinforced fiber in composites increases, more fiber–matrix interfacial area is created and more energy may be absorbed by the interface.

Introduction

Nowadays polymer composite materials are in good demand for applications in the field of aerospace vehicles, automobile parts, satellites, sports goods, robots and also in biomedicine for body compatible implants [1, 2]. These materials exhibit exceptionally good optimum properties such as low density, high specific strength, good anticorrosion properties, fatigue resistance and low manufacturing costs. These materials have received increased attention for applications in cryogenic environment also [3].The cryogenic properties of polymers are recently drawing attention with new development in space and electronic technologies. Although mechanical strength of most polymers increases or remains same as temperature is decreased, the elongation to failure decreases to extremely low values at cryogenic temperatures. This behavior restricts the use of most polymeric materials at low temperatures. Now Polymer composites are contenders for use in reusable launch vehicle components. Mostly such components are cryogenic fuel tanks, cryogenic fuel delivery lines, and parts of the cryogenic side of turbo-pumps [4]. Fiber-reinforced composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone.

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) [2]. But the anisotropy in carbon fibers limits 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 irreversively 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 change in temperature, or when the component comes from the cold condition to the normal ambient condition, it may affect the residual stresses leading to either deterioration or enhancement of mechanical properties. It is generally accepted that the bond strength variation at the interface greatly affects the integrity of composite materials. The bond strength depends on quality of interfacial chemistry adhesion. The non-zero state of residual thermal stresses at low temperatures is the underlying cause of micro-cracking in composites and these micro-cracks propagate results in transverse cracks. When the transverse crack develops further, the crack deflects through the interface between layers and early de-lamination initiates. The de-laminations connect the micro-cracks in adjacent layers and provide leakage paths. The combined cryogenic and elevated temperature thermal cycle produces substantially greater amounts of damage in polymer composites [5, 6]. Epoxy resin and E-glass fiber are reported to be loading rate sensitive also [7]. This sensitivity is controlled by the area of the interfaces and the percentage of polymer matrix phase present in composites [8].The ductility of a matrix resin may become a limiting factor at high strain rate for composite strength [9]. Epoxy resin is more ductile than it's composite at low strain rate. So to increase the reliability of polymer composites it is necessary to understand the mechanical behavior of these composites at low temperature.

A better fiber/matrix interfacial adhesion/bond will impart better properties such as interlaminar shear strength, delamination resistance, fatigue and corrosion resistance to a polymeric composite. The interface sensitive properties are weaker in polyaramid reinforced composites than in their

glass or graphite counterparts. Aramid fiber is a generic term for aromatic polyamide fibers, which have high specific strength, great cohesiveness and a tendency to form fibrils. They absorb much more energy than brittle fibers and are widely used in aircraft, aerospace and ballistic applications. The interfacial adhesion between the aramid fiber surface and the polymer matrix is of major influence on the response of the composite to stress. The fiber/matrix interfacial behavior is based on mechanical principles with the assumptions made at either the level of fiber/matrix adhesion or using the surface chemistry approach [10]. It is reasonable to assume that the interfacial shear strength is the net result of a number of contribution to the fiber/polymer adhesion. These possibly include chemical bonding, secondary forces of attraction, residual thermal compression forces due to differential shrinkage and also mechanical interlocking between the fiber and matrix [11]. The unique chemistry and morphology of Kevlar aramid fiber is also manifested in its composite behavior. The high radial expansion coefficient of the Kevlar fiber also causes an unfavorable tensile stress state at the interface.

Materials and Methods

Glass fiber woven roving and epoxy adhesive (Ciba-Geigy, India; LY-556 Araldite,HY-951hardener)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.

Kevlar aramid 49 fibers of woven cloth (Scott Bader, UK), epoxy (Gougeon West System, UK, 105 resin and 205 hardener) and polyester (Scott Bader, Crystic 471 PALV and Catalyst Butanox M-50) were used for the experiment.

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. The JEOL JSM 6480LV Seanning Electron Microscope has been used to analysis fractures surfaces of FRP composites.

Results and Discussion

There has been a pressing need to quantify the degree of environmental degradation on the alteration of mechanical properties of fiber/polymer composites. Impact of environmental factors such as temperature (above- and subambient-temperatures) and humidity on composite materials behavior is of significant concern for the aircraft industry since storage and operating conditions vary considerably. The microstructural gradient between the weak boundary layer at the fiber/polymer interface and the bulk of matrix may promote the initiation of interlaminar failure and/or propagation of crack through this layer. Differential coefficients of thermal expansion between fiber and polymer further develop residual stresses at the interface. These different natures of stresses may weaken the brittle thermoset epoxy resin and/or the interfacial region of the laminate. The mechanisms of interfacial degradation due to hygrothermal ageing range from the reduction in bond strength, to creation of osmotic cracks, to the lowering of the glass transition temperature of the epoxy resin. Failure in many cases occurs in the interface region due to chemical reaction and/or plasticization when impurities (commonly water) penetrate the interface. The stress transfer efficiency from the matrix to the fibers, the stress build-up in broken fibers and the redistribution of the stresses in the neighboring intact fibers are all controlled by the interfacial strength and

integrity. Fiber reinforced composite structures are expected to experience a range of hygrothermal environmental conditions during service life. Since absorbed moisture can alter the stress state and degrade the interface, understanding of hygrothermal behavior is critical for predicting structural performance.

Glass/epoxy system

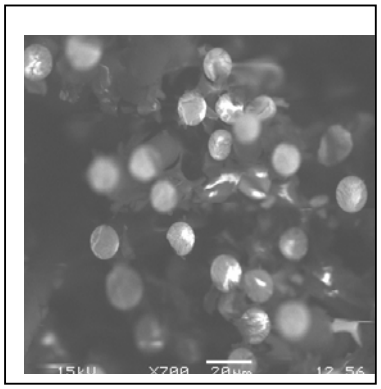

Figure 1(a)

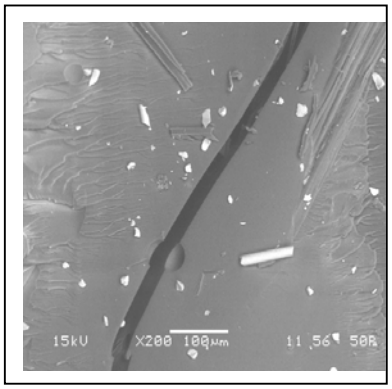

Figure 1(c)

Figure 1(b)

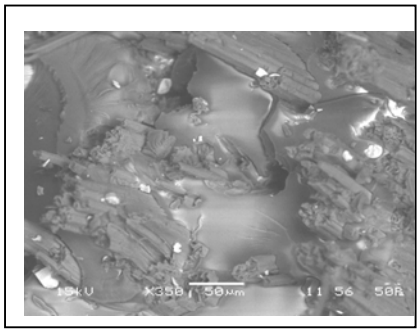

Figure 1(d)

The figure 1(a) shows fibre fracture transverse to the direction of application of load, without any fibre pull-out. But in figure 1(b) fibre

fracture can be seen along with the fibre pull out, which might have happened due to the poor adhesion characteristics between the glass fibres and the resin matrix. The figure 1(c) shows matrix cracking which might be due to the residual curing stresses, but there is not much of matrix damages as in case of figure 1(d).

A change in temperature can alter the relative rates of the diffusion and relaxation processes in the polymer matrix. Furthermore, moisture absorption at elevated temperatures may induce irreversible changes to polymer composites, such as cracking, blistering, chemical degradation and debonding, hydrolysis, oxidation and the leaching of small molecules. Increasing the volume fraction of fibres in a composite means more fibre/matrix interfacial area for the same fibre diameter. Thus more energy can be dissipated by the interface.

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.

Carbon/epoxy system

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. Figures 2(a) and (b) are showing liquid nitrogen temperature-induced different possible failure modes and also matrix damages in carbon fibre- based composites.

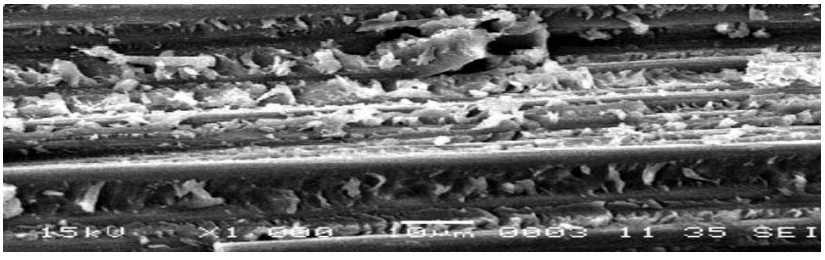

Figure 2(a) Ref. 12

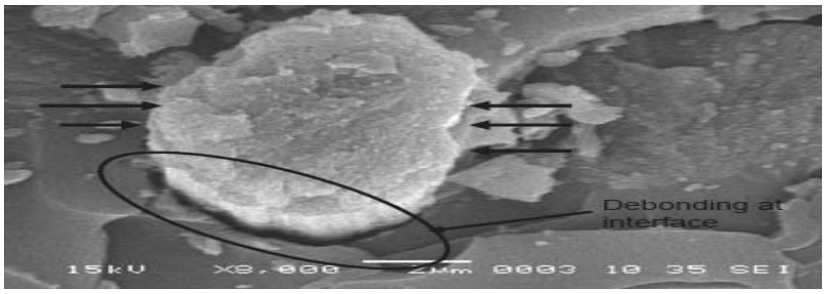

Figure 2(b) Ref. 12

A need probably exists for an assessment of mechanical performance of such potentially promising materials under the influence of changing environment and loading speed. A strong interface displays an exemplary strength and stiffness, but is very brittle in nature with easy crack propagation through the interface. A weaker interface reduces the stress transmissibility and consequently decreases the strength and stiffness. Here a crack is more likely to deviate and grow at the weak interface resulting in de-bonding and/or fiber pull-out and contributes to improved fracture toughness.

Kevlar/Epoxy Syatem

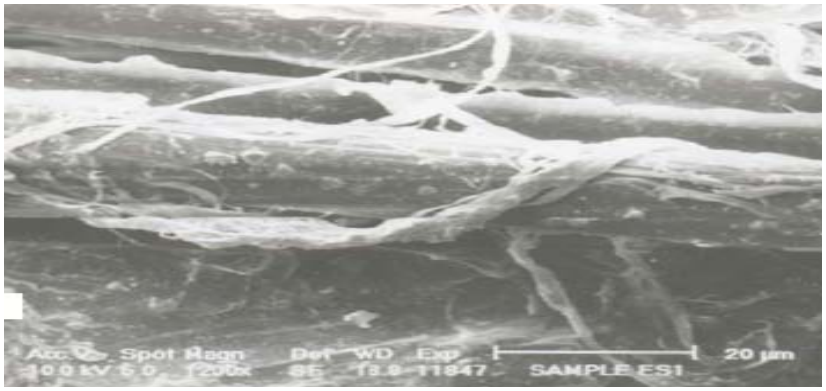

Figure 3(a) Ref. 13

The weal interfacial adhesion between Kevlar fibre and polymer matrix is of major influence on the response of a composite to stress after environmental exposure. The weak interfacial adhesion of Kevlar/epoxy composites makes them more susceptible to environmental degradation. A weal interface may alos promote extensive debonding. This can result in a significant increase in impact strength.

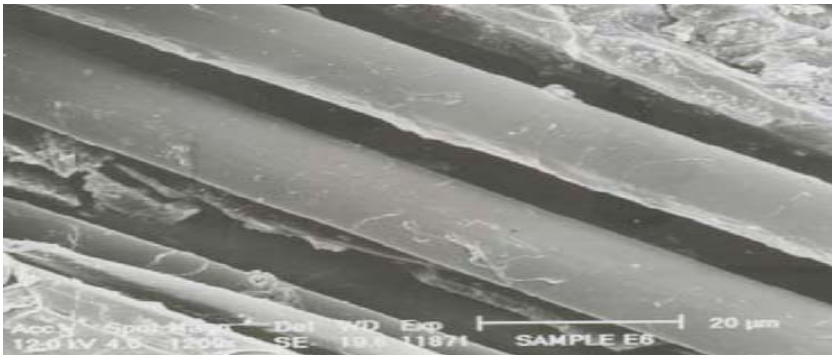

Figure 3(b) Ref. 13

The SEM micrographs above (Figures 3(a) and (b)) are showing extensive damages in the matrix resins as a result of environmental exposures. Environmental exposure results in reduced interfacial stress transmissibility because of matrix polymer plasticization, chemical degradation, and mechanical damage. Matrix plasticization reduces matrix modulus. Chemical degradation is the result of weakening of the bonds at the fiber/matrix interface.

Summary and Conclusion

Envoronmental sensitivity seems to be controlled by the area of interfaces and the percentage of polymer matrix phase present in composites. Its nature of variation appears to be dependent on temperature. Reasonably high loss of integrity at some points of experiment in ultralow temperature could be a possible cause of inconsistent variation of mechanical strength. The observations from the SEM micrographs may be attributed

to varying failure mechanisms with varying environmental and 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. Contradictory and inconsistent variation of shear strength with loading speed at higher condition times for all experimental ultralow temperatures.

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