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Historical perspective

Environmental effects on fibre reinforced polymeric composites: Evolving reasons and remarks on interfacial strength and stability

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ABSTRACT

The interface between fibre and matrix of fibrous polymeric composites is most critical and decisive in maintaining sustainability, durability and also reliability of this potential material, but unfortunately a comprehensive conclusion is yet to meet the label of confidence for the engineering viability. Fiber reinforced polymer (FRP) composites are being accepted and also utilized as better and reliable alternative materials for repairing and/or replacing conventional materials, starting from tiny objects to mega structure in various engineering applications. The promise and potential of these materials are sometimes threatened in speedy replacement of conventional materials because of their inhomogeneities and inherent susceptibility to degradation due to moist and thermal environments. Environmental conditioning is traditionally believed to be a physical phenomenon but present literature has revealed that the interdiffusion between fiber and polymer matrix resin comprises of physical, chemical, mechanical, physico-chemical and mechano-chemical phenomena. The failure and fracture behavior at ambient conditions itself is a complex phenomenon till at present. The service conditions which are mostly hygrothermal in nature, along with a variation of applied loads make the mechanical behavior nearly unpredictable, far off from conclusions in evaluating the short term as well as long term durability and reliability of FRPs. It is essential to accurately simulate the initial and subsequent evolution process of this kind of damage phenomena, in order to explore the full potential of the mechanical properties of composite laminates. The present review has emphasized the need of complying scattered as well as limited literature on this front, and has focused on creating the urgency to highlight the importance of judicious uses of these materials with minimum safety factors with an aim to achieving lighter weight in enhancing specific properties.

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1. Introduction

Fibre reinforced polymer (FRP) composites are the most promising and elegant materials of the present century. Their durability and integrity in various service environments can be altered by the response of its constituents i.e., fibre, polymer matrix, and the existing interface/interphase between the fibre and polymer matrix, in that particular environment. Their susceptibilities to degradation are dependent on the nature of environment and the different and unique responses of each of the constituents. All these structures and components are exposed to some environment during their service life. The environmental conditions can be high and low temperatures, high humidity, UV light exposure, alkaline environment and may be more severe if there is a cyclic variation of temperature, hygrothermal environment and low earth orbit space environment [1]. A widespread application spectrum of FRPs covers almost every type of advanced engineering structures. Their usage includes various components in aircraft, helicopters, spacecraft, boats, ships, offshore platforms and also in automobiles, chemical processing equipment, sports goods, and civil infrastructure such as buildings and bridges [2]. The behavior and performance of advanced structural FRP composites cannot be explained only in terms of specific properties of its constituent fibre and matrix but the existing interface/interphase between fibre and matrix has a great significance as well [3,4]. The presence of moisture at the interface can modify interfacial adhesion thereby affecting the mechanical performance of the FRP composites. The energy associated with UV radiation is capable of dissociating the molecule bonds in the polymer matrix and may lead to the degradation of the materials. The border surface between the fibre and the matrix is a result of the linking of constituents; it has its own morphology and chemistry and represents the critical area in fibre-reinforced composites [3]. Fig. 1 represents the schematic view of fibre/matrix interface/interphase of polymer matrix composite material.

A great deal of research has been focused on attempting to assess the relationships between interfacial structure and properties of fibre-matrix composites. The presence of an interphase with a molecular gradient (an extended region, where two adjacent components are mixed) can promote adhesion and compatibility at the composite interface [4]. At the interfacial area, stress concentration develops because of the differences in the thermal expansion coefficients between the reinforcement and the matrix phase. A significant mismatch in the environmentally induced degradation of matrix and fibre leads to the evolution of localized stress and strain fields in the FRP composite [5].

Advanced composites, initially developed for the military aerospace, offer performances superior to those of conventional structural metals and now find applications in satellites, aircraft, sporting goods and in the energy sector in oil and gas exploration and wind turbine construction. According to Luedtke, aircraft doors, fairings and interior panels are perfect for the FRP technology [6].

Weather and radiation factors that contribute to degradation in plastics include temperature variations, moisture ingression, sunlight exposure, oxidation, microbiologic attack, and other environmental elements. Cyclic exposure is an important factor when considering the service environment of a composite material. Environmental conditions can promote brittle fracture in normally ductile plastics at levels of stress or strain well below those that could usually cause failure. Exposure to lowered temperatures may cause a plastic to become brittle, which may cause cracking and propensity to fracture can occur whereas exposure to elevated temperature can result in degradation of mechanical properties, cracking, chalking and flaking of polymers [5,7].

Moisture damage begins near the surface of the material and spreads inward over time, with cracks tending to grow parallel to the free surface. This damage is often localized, resulting in a small number of large cracks [8,9]. Crack growth is dominated by different effects at different levels of loading. At lower load levels, cracking is most influenced by chemical reactions. However, at moderate load levels, cracking is most influenced by diffusion whereas at higher load levels, stress-assisted corrosion controls crack growth [10]. The rate of degradation of FRPs has been observed to be directly correlated with the rate of moisture sorption [11]. Moisture is attracted to areas of air entrainment such as voids and delamination.

Moisture may penetrate into polymeric composite materials by diffusive and/or capillary processes. The interactions between the fiber and the matrix resin are important complex phenomena. Both reversible and irreversible changes in mechanical properties of thermosetting polymers are known to occur as a result of water absorptions [15].

Delamination is a critical failure mode in composite structures. The interfacial separation caused by the delamination may lead to premature buckling of laminates, excessive intrusion of moisture and stiffness degradation, whereas in some cases a delamination may provide stress relief and actually enhance the performance of a composite component [5,12]. In short-term treatment of the specimen, damage growth and premature failure occurs due to delamination. However, for long-term, this may lead to load-bearing layers for different environmental factors [13]. Delamination of a laminate occurs when the resultant transverse shear force exceeds a threshold value [14]. Low interfacial shear strength may be the reason of initiation and propagation of delamination.

The absorbed water molecules in polymer composites are known to have significant effects on the final performance of the composite structures, especially in their long-term utilization. The resulting hygrothermal forces and residual stresses combined with each other may be sufficiently large enough to influence the failure of laminated composite and thus should not be neglected in modern design analysis and lifetime estimation [15,16]. Cracks and voids, even microscopic ones, allow easier penetration of water into the composite system via capillary action and diffusion [17]. Regardless of the application, once cracks have formed within polymeric materials, the integrity of structure is significantly compromised. Microcracking induced by environment is a long-standing problem in polymer composites which leads to mechanical degradation of fibre reinforced polymer composites.

Polymer composites are a rapidly developing field that seeks to understand, control and exploit new physical, mechanical and chemical properties that arise from systems at length scales between atoms and bulk materials. It is well known that properties of fibre reinforced composite materials largely depend on the nature and intensity of adhesive interaction between the matrix and fibre surfaces. To tailor composites to have desirable properties, it is necessary to know the mechanisms of the polymer-fibre adhesive contact formation and their behavior under