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Fiber reinforced polymers use limitations and remedies - Quick review

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Abstract

Fiber reinforced polymers (FRPs) are increasingly being used and implemented in many industrial fields such as transportation, automotive, aerospace aviation and civil engineering due to their low cost, light weight and high mechanical properties. Yet the use of such complex materials could sometimes be limited by their surface poor adhesion properties and low resistance to severe environmental conditions such as moisture and temperature. The aim of this research is to highlight organic composite use barriers and so far founded solutions.

Keywords: Fiber reinforced polymers, Adhesion properties, Surface treatment, Structural bonding, Durability, Aging, Fire, Temperature, Moisture.

1 Introduction

Composite is the assembly of two or more immiscible materials. In general, there is a discontinuous phase distributed in a continuous phase. Discontinuous phase plays the role of inclusions. This phase usually has mechanical properties superior to the continuous phase that plays the role of the matrix. The matrix maintains inclusions' geometrical disposition and enables applied stress distribution. Composite materials are very heterogeneous and strongly anisotropic. Their properties depend on components properties, inclusions geometrical distribution and inclusion/matrix interface nature.

The most communally used composites are polymers reinforced with synthetic fibers such as glass, aramid and carbon fibers [1]. Bio-composites, mainly polymers reinforced with natural fibers like hemp and flax fibers are gradually being included in the industry. Fiber reinforced polymers (FRPs) are characterized by a brittle and a linearly elastic behavior up to failure and a high tensile strength in fiber direction [2, 3]. Composites could be custom tailored in order to increase

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their strength by modifying the fiber content or their geometrical distribution [4, 5, 6].

Due to their lightweight, good corrosion resistance, non-conductivity and failure elongated strain, FRPs have been used as alternative reinforcements for steel in civil engineering structural application [7, 8]. Glass fiber reinforced polymers (GFRPs) are one of the more cost effective FRP products commercially available with significant cost advantage over stainless steel. The combination of GFRP and steel bars as column reinforcements was also proven to be effective [8]. Yet the use of composite materials in this field could sometimes be limited by their low compressive stress and low resistance to fire and temperature [9, 10, 11, 12, 13].

Joining processes are unavoidable in manufacturing fiber reinforced polymers especially those with complex geometries. Structural bonding is the most used and profitable composite assembling technology. Nevertheless, composites' poor adhesion properties at their raw state limited the use of this technique in hybrid structures. Surface treatment before bonding is essential in order to enhance composites' surface quality. Another problematic issue for composites' industrial implementation is their low resistance to severe environmental conditions such as moisture and high temperature [2, 14, 15]. Aging is a complicated problem for composite materials that usually leads to their mechanical properties degradation thus reducing their service life by inducing premature and catastrophic failure modes.

Fiber reinforced polymers use limitations and their so far founded solutions are discussed in this paper.

2 Moisture effect on fiber reinforced polymers (FRPs)

Moisture is one of the most damaging factors to organic composites. It affects all of its components starting from the matrix and the fibers to the fiber-matrix interface. Matrix is the primary victim of water absorption due to the hydrophilic nature of many widely used resins [15]. A research carried out by Chilali et al. [16] revealed that thermostat composites absorb more water than thermoplastic composites. Resin water absorption usually results in its plasticization, swelling, hydrolysis, and fiber debonding. Plasticization and hydrolysis are irreversible phenomena that can change both the stiffness and the strength of the polymer. Many studies [2, 14] have reported the decrease of FRPs maximum load, fracture toughness and Young's modulus due to water absorption. Synthetic fibers, such as glass and carbon fibers, are hardly affected by humidity. Hence, aging resistance of polymers reinforced with synthetic fibers depends mainly on the resin permeability and cracking resistance. Composites' weakness to moisture is located at the matrix-fiber interface. Due to fiber water non-absorption and some resin hydrophilic nature, a differential swelling could occur causing residual stress. Fiber reinforced polymers aging resistance could be enhanced by increas-

ing fiber-matrix adhesion strength using fiber surface chemical treatments such as silane [17, 18], epoxy [19] and poly methacrylic acid [20]. Synthetic fiber based composites have higher water aging resistance compared to bio-composites [21]. This is mainly due to the hydrophilic nature of natural fibers. Natural fibers based composites hybridization with GFRP, CFRP or BFRP was proven to be a good solution for this problem [22, 23, 24, 25]. Carbon fibers have a higher resistance to moisture than aramid and glass fibers [2]. Water absorption usually increases with the increase of temperature and the presence of external stress. Interlayer delamination is the most critical deterioration mode for organic composites. The rupture can occur in the matrix, between plies, and at the fiber-matrix interface level.

3 Fiber reinforced polymers behavior under high temperature and fire

Synthetic fibers can maintain their strength at relatively high temperature. Yet, most polymers are vulnerable at much lower temperature due to their low glass transition temperature T_g . Hajiloo et al. [11] studied GFRP reinforced bars mechanical behavior under severe conditions. All bars lost their strength and stiffness at elevated temperature. Another study [15] revealed that high temperature could enhance GFRPs' strength when it is under the material's T_g . Exposed to heat, GFRP components can ignite and sustain flaming combustion during a short time period [10]. The flames spread depends on several factors essentially the resin type and flammability and the fiber content. The decomposition of the composite polymeric matrix releases fine soot particles and non-combustible fiber micro-fragments that may induce dense smoke. Hawileh et al [12] carried out a numerical study in order to investigate the behavior of continuous concrete decks doubly reinforced with top and bottom GFRP bars subjected to top surface fire. The study revealed that the top concrete cover thickness is the most important parameter that influences the fire resistance of GFRP reinforced concrete slabs when exposed to top fire loading.

4 Composite surface treatment before bonding

At their raw state, composite materials have poor surface adhesion properties [26]. Hence surface treatment before bonding is necessary in order to improve the surface quality. Mechanical surface treatment such as sanding [27, 28], sandblasting [28], peel ply [29, 30, 28] and milling [31] improve mechanical anchoring between joined materials by roughening the surface, creating more areas for bonding and enhancing the surface free energy. Chemical surface treatment such as plasma and corona discharge [32] reinforce high energy chemical interactions between the composite and the adhesive. Peel ply is a no-complicated low cost surface treatment. The effect of this treatment depends on the peel ply fabric nature, its grammage and fiber size. Polyamide tear-off fabrics were

proven to provide more adhesion strength to composite bonded structures than polyester tear-off fabrics [29, 30]. Peel ply generates homogeneous surface with regular and controlled roughness. Materials with regular surface topography were reported to have high adhesion properties [33]. Peel ply fiber remainings could cause surface defects and weaken the bonded substrates adhesion [28]. Hence, cleaning the surface after treatment is highly recommended. Abrasion treatments such as sanding and sandblasting were also proven to highly improve the adhesion properties of composite materials. The effect of these treatments depends on the abrasive grains grit size [27, 34]. Sanding and sandblasting were reported to cause fiber exposure at the treated surface level and in some cases fiber damage and sand residues. Milling could also be used as a surface treatment for composite materials [31]. Similar to sandblasting, the effect of this treatment depends on machining parameters.

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