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Surface Treatment of Carbon Fibers - A Review

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Abstract

Carbon Fibers (CFs) are widely used as reinforcement material in polymer composites. However, they are having inert surface and do not allow matrix material to make bonding with it. Surface treatment of fibers is one of the suggested methods to improve adhesion between the two. Present paper concentrates on various methods used to surface treat the CF and gives details on physical, chemical and morphological changes occur in fiber properties. These changes due to treatment lead to improved composite properties due to improved surface area on fiber surface, chemical bonding and adhesion between fiber and matrix. Mainly used surface treatment methods are acid oxidation, plasma treatment, rare earth treatment, gamma irradiation etc. comparative study of these methods help in selection of appropriate treatment method as per requirement.

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Keywords: Carbon fibers; surface treatment; composites

1. Introduction

CFs are mainly used as reinforcements in composite materials such as CF reinforced plastics, carbon-carbon composite, CF reinforced materials, and CF reinforced cement. CF offer the highest specific modulus and highest specific strength of all reinforcing fibers. CF composites are suited to applications where strength, stiffness, lower weight, and outstanding fatigue characteristics are critical requirements. They are also finding applications where high temperature, chemical inertness and high damping are important criteria. CFs also have good electrical conductivity, thermal conductivity and low linear coefficient of thermal expansion [1, 2].

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The two main sectors of CFs applications are aerospace and nuclear engineering, and the general engineering and transportation sector, which includes engineering components such as bearings, gears, cams, fan blades, etc., and automobile bodies.
CFs when used without surface treatment produce composites with low interlaminar shear strength (ILSS). This has been attributed to weak adhesion and poor bonding between the fiber and matrix [3]. Treatments increase the surface area and surface acidic functional groups and thus improve bonding between the fiber and the resin matrix [4, 5]. This tends to increase the wettability of the CFs and enhances the ILSS. Surface treatments may be classified into oxidative and non-oxidative treatments. Oxidation treatments involve gas-phase oxidation, liquid-phase oxidation carried out chemically [6] or electrochemically [7] and catalytic oxidation. The non-oxidative treatments involve deposition of more active forms of carbon, such as the highly effective whiskerization, the deposition of pyrolytic carbon [8]. CFs can also be plasma treated to improve bonding between the fiber and matrix. Liquid phase oxidation treatments are milder, very effective and are preferred [2].

2. Effect of surface treatment of CFs

CFs, though very expensive are most favoured for tailoring high performance composites and tribo-composites. Their surface, however, is chemically inert and leading to the most potential problem of inadequate adhesion and hence weaker composite than the expected one. It is essential to treat them with proper treatment so as to explore their full potential in composites. Several types of reported surface treatments of CFs are classified in two categories. First, improves the adhesion by physical means thereby enhancing the roughness resulting in more surface area and a large number of contact points, micro-pores or surface pits on already porous CFs surface. The second on the other hand, involves chemical reactions leading to inclusion of reactive functional groups that promote good chemical bonding with the polymer matrix. Most of the methods bring both the changes simultaneously. Interestingly any surface treatment method especially which etches fiber's surface also leads to affect the strength of the fiber adversely. First effect called as positive effect leads to the enhancement in fiber-matrix adhesion and hence improvement in the strength of composite since matrix supports the fibers more firmly. Simultaneously, other effect which is in negative direction reduces the strength of fibers due to etching contributing to deteriorate the strength of composite. The final strength of the composite depends on the net contribution of these two opposing effects. It is hence imperative to optimize the extent of treatment to get the maximum possible enhancement in the performance properties of composite.
Various surface treatment methods viz. electrochemical, chemical, thermal, discharge plasma etc. have been practiced to improve the adhesion between fiber and matrix which can be improved by the following means [9]:

- By increasing the wettability of the fiber surface by the matrix resin.
- By removing the weak boundary layer, e.g., contaminant species or gas molecules physically adsorbed on the fiber surface. This would provide a more intimate contact between the fiber and the polymer to ensure a significant level of van der Waals force which being a short-range force would otherwise be relatively weak.
- By allowing the matrix molecules physically to entangle with, or diffuse into, the molecular network of polymer coating applied on the fibers.
- By promoting mechanical interlocking between the fiber and the matrix. This can be achieved by creating surface porosity, into which resin molecules can penetrate.
- By increasing the number of active sites on the fiber surface for subsequent chemical bonding with the unreacted species in the matrix resin.
- By applying a thin layer of 'coupling agent' that will chemically bond to both; fiber and matrix.

3. Surface treatment methods

Various treatment methods used for CF are classified in two categories i.e. oxidative and non-oxidative methods. In these categories, mainly used methods are; acid (**HNO_3**) treatment, plasma treatment, rare earth treatment and gamma irradiation of CF. Major types of surface treatments for CFs are discussed in brief as follows.