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Review

Interfacial characterization, control and modification of carbon fiber reinforced polymer composites

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ABSTRACT

Fibrous carbon materials have been attracted many researchers' attentions. Carbon fibers have been developed as one of the most important industrial materials for modern science and technology since 1960s [1]. Due to the superior mechanical properties including high-specific strength and modulus, low density and thermal expansion, heat resistance, and chemical stability, carbon fibers as reinforcement materials have provided the impetus for researchers in developing high-performance composite materials. Nowadays, carbon fiber reinforced plastics (CFRP) are widely applied in the industries of aeronautic, aerospace, sporting goods, as well as new energy.

The region between the fibers and matrix, contains unique micromechanical properties, is characteristically called the interphase and influence the bulk composite properties. Interface between fibers (reinforcements) and matrix is an important component for CFRP which may govern the CFRP performances [2]. For example, the interphase determines the off-axis strength and impact toughness of CFRP, environmental stability of CFRP and functional performance of CFRP. The effect of interface on composite can be achieved by regulating the composition, structure and distribution of the interface [3]. It has been proved that there has an optical interface for polymer based composite through the match of composite interface, reinforcement and polymer matrix. However, in terms of the smooth surface and chemical inertness of carbon fiber, the interface between carbon fiber and resin matrix is unsatisfactory. The interface should be modified and carefully controlled, which can be through by increasing the surface polarity of carbon fiber, improving the wettability between carbon fiber and resin, as well as promoting the chemical reaction. Obey these principles, the interfacial modification methods have been well developed.

The universality of carbon fiber and polymer matrix, and the variability of the composite material forming process result in the complexity of polymer-based composites interface problems. Meanwhile the scale of the interface region is very small, it has great difficulty in characterizing the chemical structure, physical properties and mechanical characteristics. Recently, a series of effective characterization methods have been developed and initial interface characterization system is always being improved. With interface characterization techniques, the interfacial composition, structure morphology and micro-mechanical characteristics of interface can be researched easily, which can provide the basis for studying the interface physical and chemical properties. Hence interface characterization techniques not only are theory researches, but also have important practical significance for solving practical application problems of carbon fiber composites. Interface characterization techniques have become an important research direction of interface engineering research.

In this paper, the researches in this field of carbon fiber interface were described, such as carbon fiber composite material characterization methods, interface control, and interfacial modification methods. With reference to the research achievements of a large number of scholars at present, so their current development trend were systemic concluded.

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Contents

1. Interfacial characterization of FRP

Interfacial characterizations are used to acknowledge the function of interface and the influence of the interfacial structure on material overall performances. It mainly includes characterization of interfacial chemical and physical structure, thickness and morphology, adhesion strength and residual stress. Based on these characterized results, the relationship between interface performance and the composite material performance can be clarified. Nowadays, the scientific development provides a powerful mean to characterize the interface of composite materials, and some of the advanced technologies have been applied in the composite interface analysis, which contributes to revealing the nature of the interface and enriching the theoretical research of the interface. However, due to the micro area and the complicated structure of the interface, the studies on characterization methods of composite material interface, which are comprehensive and accurate, have been the difficulties and hot spots in the field of composite material interface research.

1.1. Characterization on interfacial adhesion of FRP

Characterization of interfacial bonding strength has always been a very active research field for composite materials. Compared to the overall composite materials, the proportion of interface is relatively small and complex, which results in a great difficulty in measuring the performance of a separate interface. The methods used to measure the interfacial strength of composites can be mainly divided into three categories: macroscopic test methods, mesoscopic interface test methods and micro-composite experimental methods, as shown in Table 1. The macroscopic test methods are focus on the macroscopic composite, such as 3D fabric carbon fiber reinforced resin composites, 2D carbon fiber composite board, etc. Macroscopic test methods mainly include 90° tensile, Off-axis tensile, Notched impact, Noel ring (NOL), Interfacial shear strength (IFSS), Scanning electron microscope (SEM), etc. Mesoscopic interface test methods can be used for the carbon fiber bundle composite and single fiber composite. Mesoscopic interface test methods include IFSS, SEM, atomic force microscope (AFM), X-ray photoelectron spectra (XPS) and Wetting characterization, etc. Micro characterization methods focus on the micro fiber surface performance characterization which include SEM, AFM and XPS, etc.

Macroscopic test methods are used to evaluate the macro interfacial adhesion between fibers and polymer matrix. Some testing methods are put forward by Prosen and Chiao [4], such as short beam shear, off-axis tension and guide groove shear method. All of these methods are sensitive to the interfacial strength. The obtained results depend on the volume contents, distribution and nature of fibers and matrix. Pores and defects' content and distribution in composites also affect the results. Specially, these experiments damage the interface, matrix, even fibers. These methods have significance for composite material applications in engineering, i.e. the effect of interface modification can be quickly evaluated. However, they can be only used for qualitative comparison of the interfacial adhesion properties, not for the independent quantitative evaluation of the interfacial strength.

Characterization of microscopic composite material interface includes testing of micro-composites and in-situ characterization. Micro-composite material testing method is to measure the interfacial adhesion of micro-composite materials composed of resin and embedded monofilament fiber in matrix. Some methods, such as single-fiber pull-out, fragmentation, micro-debonding, proposed by Broutman and Cox [5], could directly measure the interfacial strength quantificationally or semi-quantificationally. Some experimental data have been used in composite materials design and life estimation, but the complexity of the sample preparation, experimental technology, and model simplification make the measured values of interfacial strength quite different via various methods.

Micro-debonding testing is an in-situ characterization method of interfacial adhesion, which can be directly carried out on the actual composites. The basic principle is to add an axial pressure on a selected individual fiber of composites by a diamond probe with the help of an optical microscope and precise positioning mechanism. When interfacial debonding occurs between the fiber and surrounding matrix, the axial pressure is obtained, and the resulting interfacial shear strength is calculated through finite element method based on the micro model. The samples used in this method can be directly cut from the actual composites, without special preparation. The measured results can not only be used to evaluate the performance of composite material products, but also