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Methods for Evaluating the Properties of Composite Materials

Korneeva NV[1]*, Kudinov VV[2], Krylov IK[2], Mamonov VI[2]

[1]*Laboratory of Fiber Reinforced Plastics, Semyonov's Institute ofChemical Physics, Russian Academy of Sciences, Russia*

[2]*Laboratory of Physicochemistry and Technology of Coatings, A.A. Baikov's Institute of Metallurgy and Materials Science, Russian Academy of Sciences, Russia*

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***Corresponding author:** Natalia Korneeva, Laboratory of Fiber Reinforced Plastics, Department of Polymers and Composite Materials, Semyonov's Institute of Chemical Physics, Russian Academy of Sciences,4, Kosygin St., Moscow, 119991 Russia, Tel: +7(499)135-86-61,Fax: +7(499)135-86-80, E-mail: natakorneeva@mail.ru; korneeva@imet.ac.ru

Abstract

The article presents a review previously published experimental material deal with of using plasma-activated UHMWPE-fibers in manufacturing CM. To obtain new types of FRP with good properties, it is necessary to activate the reinforcing fibers, which allows one to raise the joint strength at the fiber/matrix interface. Wet-Pull-Out (W-P-O), Full-Pull-Out (F-P-O), and Impact Break (IB) methods have been developed due to this aim.

Keywords: UHMWPE-fibers; CM, FRP, CFRP, HCM, Non-equilibrium low-temperature (NLT) plasma; Wet-Pull-Out (W-P-O) method; Full-Pull-Out (F-P-O) method; Impact break(IB) method; Specific absorbed-in-fracture energy

Abbreviations: UHMWPE-fibers: Ultra-High-Molecular-Weight Polyethylene Fibers; CM: Composite Materials, FRP: Fiber-reinforced plastics; CFRP: Carbon fiber reinforced plastics; HCM: Hybrid composite materials; NLT plasma: Non-equilibrium low-temperature plasma; RF: Radio-Frequency; W-P-O: Wet-Pull-Out; F-P-O: Full-Pull-Out method; IB: Impact Break

Introduction

The historical growth of the world market of Ultra-High-Molecular-Weight Polyethylene Fibers (UHMWPE-fibers) and the products made of them is for better than 25-30% per year. Production of fibrous polymer Composite Materials (CM) made of UHMWPE-fibers, woven and non-woven fabrics will lead to a considerable increase in the market. Higher specific characteristics of such CM give the opportunity to reduce products weight and decrease the ecological pressure on the environment by lowering atmospheric emissions and reducing energy demands and fuel consumption.

Polyethylene molecule has covalent fully saturated chemical bonds and is noted for a low surface energy (≈33mJ/m2), which is the cause of UHMWPE-fibers inertness in interaction with different polymer matrices. Without the fibers activation their bonding with the matrix in CM is weak. It is necessary to increase surface energy of fibers. Fibers may be activated by means of Non-equilibrium Low-Temperature (NLT) plasma treatment of Radio-Frequency (RF) capacitive discharge at low-pressure. Plasma treatment increases surface energy and thereby activates the fiber [1].

To research effect of NLT plasma on the properties of multifilament UHMWPE-fiber and physical and chemical interaction between the fiber and the matrix, a set of experimental methods has been developed:

a. The technique of studying the wettability and impregnation of fiber with liquid polymer matrix [2];

b. The technique of determination of their joint strength and fiber critical length [2-4];

c. The technique of researching the effect of wettability and fiber impregnation with the matrix on their joint strength (Wet-Pull-Out method or laconic W-P-O) [5-8];

d. Technique of researching the mutual effect of reinforcing fibers and their properties on CM strength, strain and failure mode (Full-Pull-Out method or laconic F-P-O) [9]. All methods allow us to estimate the quality of UHMWPE-fibers treatment with plasma.

The velocity of loading strongly affects the mechanical properties of anisotropic fiber-reinforced composite materials (fiber-reinforced plastics FRP). To estimate dynamic properties of isotropic materials the pendulum-type testing machine is applied. The pendulum machine allows one to increase the velocity of impact by a factor of 10000. However, using the pendulums that look like the ones present in the tests by Charpy and Izod, have not provided suitable data upon impact for some FRP due to the materials anisotropy. Now the importance of materials anisotropy is recognised and failure theories suggested by Puck (1965) and Tsai (1984) are well known. At the same time the heterogeneous character of anisotropic CM is often neglected.

A method for study of the impact properties of anisotropic FRP by pendulum machine under low-velocity loading conditions has been developed. The method is called "Impact Break" (IB) and described in [10-12].

Discussion

To improve the deformation and strength properties of CFRP and to eliminate the brittle-fragmentation nature of their destruction, it is advisable to include in their composition flexible organic fibers [10]. Effect of the components on the character of destruction and the properties of Hybrid Composite Materials (HCM) on the base of flexible and rigid matrices under a shock loading was investigated by the IB method [13].

HCM contain two or more fibers of various types. The more fibers are included in the composite, the more important is their interaction with the matrix at the fiber/matrix interface. To improve the adhesion of reinforcing fibers to the matrices and, correspondingly, shear strength at the interface, their NLT plasma treatment in RF capacitive discharge at a reduced pressure was used.

Changing the ratio of carbon fibers and plasma-activated UHMWPE-fibers into hybrid fiber, it is possible to control the properties of HCM. Introduction of 20% of UHMWPE-fibers into the hybrid fiber is increased the strength and specific absorbed-in-fracture energy of CFRP based on a flexible matrix by a factor of 1.3. HCM strength and specific absorbed-in-fracture energy are increased by the factors of ~1.4 and ~2.1 respectively at 50% of UHMWPE-fibers.

Conclusion

Main challenges of the technology of FRP production from multifilament fiber are the following: the complete impregnation of the fiber with the matrix and creation of the strong joint between the matrix and the fiber. For improving the properties of CM, reinforced with UHMWPE- fibers, one should use three following methods: First, it is the impregnation of initial fibers in vacuum and the production of CM in vacuum; Second, it is plasma treatment of the fibers and the production of CM by the impregnation of plasma-activated fibers in air; Third, it is plasma treatment of the fibers and the production of CM by the impregnation of plasma-activated fibers in vacuum.

A W-P-O method for investigation of interaction of strengthening multifilament fibers with matrix in CM has been developed. The W-P-O method allows one to determine the basic parameters of CM production, loading and failure. By means of F-P-O method specially developed, it has been found out experimentally, that the strength of the joint of reinforcing UHMWPE-fibers with the matrix of CM was depended on the properties of adjacent fibers.

IBmethod for investigating the CM properties upon impactallows one to determine thespecific absorbed-in-fracture energy of FRP, ultimate tensile strength, the shear strength of the fiber to the matrix, the relative deformation and other characteristics of the CM under static and dynamic loading conditions.

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