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Test method

Interfacial shear strength of carbon fiber reinforced polyphenylene sulfide measured by the microbond test

Baoying Liu [a], Zhao Liu [a], Xiaojun Wang [b,**], Gang Zhang [b], Shengru Long [b], Jie Yang [b,c,*]

[a] College of Polymer Science and Engineering, Sichuan University, Chengdu 610065, China
[b] Institute of Materials Science and Technology, Sichuan University, Chengdu 610064, China
[c] State Key Laboratory of Polymer Materials Engineering, Sichuan University, Chengdu 610065, China

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ABSTRACT

Interfacial micromechanical performance of carbon fiber (CF) reinforced polyphenylene sulfide (PPS) composite was studied by the microbond test. A novel homemade apparatus which is operated simply was employed and a different microsample preparation method was introduced. Comparative tests at various loading speeds were made to investigate the influence of testing rate on the interfacial shear strength of CF/PPS micro-composite. It was found that the interfacial shear strength increased with increasing fiber embedded length at speeds below 0.02 mm/s and above 0.04 mm/s, but it was constant between 0.02 and 0.04 mm/s. It is recommended to perform the microbond test in the test rate range of 0.02–0.04 mm/s, where the interfacial shear strength does not change with the embedded length and no significant deviations are observed, thus could better reflect the true interface strength of the composite.

1. Introduction

The ever-increasing usage of composite materials based on carbon fiber reinforced polymer composites is largely due to their high strength-to-weight ratio and good mechanical behavior, which makes them widely used in several fields, such as aerospace engineering, transportation manufacture, civil constructions and sports equipment [1,2]. Since the macroscopic mechanical performance and durability of these materials are closely related to the interfacial properties of fiber and matrix, which is responsible for transferring the stress from matrix to the reinforced fiber [3,4], therefore, it is of great importance to have quantitative and reliable methods to characterize the adhesion between a fiber and the surrounding polymer matrix. So far, quite a large number of micromechanical test methods have been developed to determine parameters of interfacial interaction between fibers and matrices, such as the microbond test [5–8], push-out test [9–11] and pull-out test [8,12–14], as well as single-fiber fragmentation tests [15–17]. Among these techniques, the microbond test, as the most effective and extensively used technique due to the direct measure of interfacial shear strength of the fibers and matrices, is what we are most interested in.

In recent years, most studies using the microbond technique are devoted to carbon fiber/epoxy composites. However, there are few discussions on carbon fiber with thermoplastic materials. This is probably due to the difficulties in preparing the thermoplastic-microsphere specimens. A limitation to this approach is that, if the length of fiber embedded in the matrix is longer than a critical length, fiber failure will occur before debonding. It is

* Corresponding author. State Key Laboratory of Polymer Materials Engineering, Sichuan University, Chengdu 610065, China. Tel.: +86 028 85412866.
** Corresponding author. Tel.: +86 028 85412866.
E-mail addresses: wangxj@scu.edu.cn (X. Wang), ppsf@scu.edu.cn (J. Yang).

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difficult to manufacture samples with sufficiently short embedded length. Usually, the procedure [5,18] used in thermoset composites involves the deposition of a small amount of resin onto the surface of a single fiber in the form of one or more discrete microdroplets. It is necessary to prepare resin solution with a particular formulation in this method, but this is difficult for thermoplastic resin dissolved in an appropriate solvent. Moreover, the shape and size of the microdroplets made by this method cannot be well controlled. To overcome this problem, Gaur et al. [4,19] reported a different method to form microdrops for various fiber/thermoplastic systems. A small, thin piece of film was used in this procedure, which was cut to form two strips. They were then joined together like a pair of trousers and suspended on a single fiber followed by quickly heating the films up to melting temperature to melt the resin, when a nearly uniform sized droplet was obtained. A slightly different method has been reported by Yang and Thomason [20]. A small piece of thermoplastic resin fiber instead of resin film was used to prepare microdroplets. However, both the polymer fibers and films were loosely hung on the reinforced fibers, and could be shaken off easily, so great care is necessary during the preparation of these micro-samples. In addition, Liu with co-workers [21], N. Choi [22] and B. Morlin [23] proposed disc shaped microbond specimens, a film or plate with a hole was used to form the micro-samples with uniform geometry. However, the procedure of preparing the test samples in these methods is complicated. In order to overcome these problems, a new method with simple operation has been developed in this work.

The strength of the interface between the reinforcing fiber and the matrix in a composite, for viscoelastic matrices, is not only dependent on the surface chemistry and topography of the fiber, and the chemistry of the matrix, but also on the rate of loading [3,4,24]. To the best of our knowledge, the loading rate dependency of the interfacial shear strength has been rarely studied, although there are several studies related to the effect of strain rate in fiber/polymer composites [23–25].

In this work, we used a microbond test with a novel, simple and efficient microdroplet preparation procedure to investigate the effect of stretching rate on the scatter of experimental data and the interfacial shear strength of carbon fiber (CF) reinforced polyphenylene sulfide (PPS) composite.

2. Experimental

Hereinafter, the test results obtained by the standard droplet-based microbond test are summarized and the sensitivity of the microbond test to change in pull-out speed is investigated.

2.1. Materials

Commercial carbon fibers (T700SC-12000, Toray Co., ltd, diameter of 7 μm) were used because they are relatively strain rate insensitive over a wide range of loading rates [26], and they have been widely utilized as a reinforcing component in composite structures.

Poly (phenylene sulfide) resin, injection grade, with melting temperature 280 °C (Deyang Chemical Co., Ltd, Sichuan, China) was employed in this study. PPS is a versatile semi-crystalline engineering thermoplastic with an unusual combination of properties, such as high chemical resistance, excellent thermal stability and good mechanical properties, which has been mainly used as matrix material for high-performance fiber-reinforced composites in recent years, and hence was a natural choice for this work.

2.2. Sample preparation

There is no standard way of using thermoplastic polymers to make samples for the microbond test and each laboratory has developed their own methods with substantially the same idea but different procedures. The method employed in manufacturing microbond test samples in this work is different from those have been adopted in other works [4,19,20]. As illustrated in Fig. 1, at first, PPS resin was melted and pulled into fibers, then the resin fiber was knotted slightly around a carbon fiber monofilament that was glued in advance onto a card tab, and the extra part was carefully cut away. Next, the sample was put onto a microscope melting point apparatus at a temperature of 300 °C, which is well above the melting temperature of PPS, to ensure complete melting and to remove any thermal history. After this, the specimen was removed from the hot plate after being retained on the melting instrument for about one minute to fully form a testable droplet, and finally cooled down to ambient temperature. The prepared samples were placed in a petri dish and subsequently transferred together into a vacuum oven, where they were annealed at 120 °C for 12 h. Each of the samples was eventually screened under an optical microscope, only well-shaped, symmetrical droplets were selected for the experiments. In comparison with other well known procedures of micro-specimen preparation, this method is simple and most of the geometry of the samples is well defined and flawless.

2.3. Experimental apparatus and procedure

It is essential to study the micro-samples with an instrument that is comparatively simple to operate and has a high degree of sensitivity. To perform the microbond test, a novel laboratory-developed device (as seen in Fig. 2) was manufactured, with two knife-edges secured at the bottom of two vertical steel pillars. One of pillars is mounted rigidly on the main body of the equipment and the other is free to

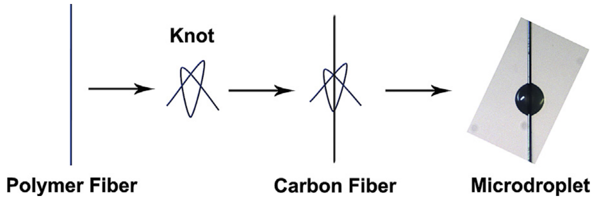

Fig. 1. Forming procedure of thermoplastic resin droplets on a single carbon fiber and an optical microscope photograph of microdroplet.