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Influence of microbond test parameters on interfacial shear strength of fiber reinforced polymer-matrix composites

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ABSTRACT

The microbond test commonly used to determine the interfacial shear strength (IFSS) of fiber-reinforced composites involves a number of experiment parameters that are not standardized in practice. This investigation is aimed to quantify and explain the influences of these parameters on the test results. We first validated the force-displacement curves and IFSS results of finite element simulated model pull-out tests with that from experiments conducted at equivalent conditions. The von Mises and contact friction stress distributions from the simulation models were used to explain the influences of experimental parameters on IFSS from microbond test. The study shows that fiber diameter has the largest effect on IFSS. Bead size and blade position also have significant influences on the IFSS results from microbond tests. These testing parameters should be kept as close to constants as possible when conducting comparative microbond tests.

1. Introduction

Fiber reinforced polymers (FRP) are used in a large variety of applications because of their excellent mechanical properties. As a 2-phase material, the mechanical properties of FRPs strongly depend on the effectiveness of load transfer between fiber and matrix through the interphase [1]. The interfacial bond property between fiber and matrix plays a critically important role in the mechanical properties of FRPs.

Three micromechanical techniques are commonly used to measure the interfacial shear strength (IFSS) between fiber and matrix, that is, single fiber pullout test, single fiber fragmentation test and microbond test [2]. The traditional single fiber pullout and fragmentation tests involve difficult specimen preparation procedures. The microbond test developed by Miller et al. [3] in 1987 has now become the most widely used single fiber-matrix interfacial bond test method [4]. In a microbond test, a pullout test is carried out on a composite specimen containing a single fiber embedded in a bead (droplet) of resin. The IFSS is then calculated using the following equation

$$\mathrm{IFSS} = fracF_{\max} \pi d l_e \quad (1)$$

where F_{max} is the maximum load recorded when deboning occurs, d is the diameter of fiber, and l_e is the embedded length of fiber in the droplet.

The microbond test technique has been used to study different fiber-matrix interface systems, including glass fiber-epoxy [5], glass fiber-polyamide [6], glass fiber-polypropylene [7], carbon fiber-epoxy [8], carbon nanotube fiber-epoxy [9], flax fiber-polyester [10] and etc. The dimension of microbond test sample is of micron-scale (sometimes submillimeter-scale), and slight variations in test parameters can have a significant effect on the test result. Researchers [11–13] have reported large data variabilities from microbond tests and have attributed the variabilities to several parameters involved in the microbond test, including bead size, blade position, fiber diameter and testing environment.

In recent years, numerical analysis has been used to investigate microbond test. Kang et al., used finite element simulation to explain the mechanics of microbond testing [8]. They used a 2D axisymmetric finite element model to study the stress distribution of carbon fiber-epoxy composites and reported a good agreement between the stress values obtained from their finite element analysis and the average stress from experiments. Ash, et al., [14] studied the effects of blade vice angle on the interfacial stress distribution for microbond test using a 2D axisymmetric finite element model. They found that a higher load was required to debond the fiber from the bead when the vice angle was increased. Pandey

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et al. [15] simulated both 2D axisymmetric and 3D finite element models of a carbon fiber-epoxy composite system using a general purpose finite element software ABAQUS. The stress distributions predicted by their models were greatly affected by the blade separation distance. Increasing the separation distance of the blade from the fiber decreases the peak stress but with little effect on the average stress. Schüller et al. [16] simulated the debonding of microbond samples using an axisymmetric finite element model using the general purpose finite element software ANSYS. They noticed a strong positive correlation between the friction coefficient and the maximum load occurring in the test. The above predominantly 2D axisymmetric finite element models have explain some aspects of the droplet fracture mechanics involved in the microbond test. However, they do not simulate the pullout load-deformation relationship, the 3D stress distributions in the fiber and the resin bead, and the interfacial shear stress during the microbond test. The 3D models of microbond test employed so far have not addressed systematically the testing parameters that strongly affect the interfacial bond properties of FRPs, including bead length (fiber embedded length) and fiber diameter.

Contact analysis based on finite element method is widely used in civil engineering to simulate the interface bonding conditions of rebar and concrete [17,18]. The technique has not been widely used to simulate the interface bonding conditions of FRPs. In this paper, we aim to explain the influences of FRP microbond test parameters. A finite element contact analysis model based on ANSYS is established to simulate the stress distributions on the fiber and the droplet in microbond test, from which the characteristic pullout load-displacement relationship is computed. For each test parameter, we first confirm the agreement between the IFSS results from experiments and results from the finite element simulation, and then use the contact friction stress distribution generated from the simulation to explain the influence of the microbond test parameter on IFSS results. The microbond test parameters investigated include fiber diameter, blade position and fiber embedded length.

2. Experimental methods

2.1. Materials

Ambient temperature curing epoxy resin system consisting of bisphenol-A based epoxy resin (105-A) and modified amine aliphatic polyamine hardener (206-A) (West System®) was used as the matrix material in the microbond test. The polyester fibers (supplied by Wuyang Textile Machinery Co., Ltd, China) used in this research have diameters of 0.012 mm, 0.16 mm, 0.2 mm and 0.3 mm. The reason for choosing polyester fibers instead of the more popular carbon and glass fibers in this investigation was the availability of such a wide range of fiber diameter. We conducted tensile tests on the polyester fibers and found that the elasticity modulus and tensile strength of polyester fiber were 3387 MPa and 184 MPa, respectively.

2.2. Specimen preparation

The resin and the hardener were mixed in a beaker at the mass ratio 5:1 as recommended by the manufacturer. The slurry was used to form a droplet on a chosen polyester fiber using the tip of a fiber with a diameter of 75 μm. The specimens were then cured at 26 °C for 24 h according to the manufacturer's instruction. Fig. 1 shows a typical microbond test specimen used in this study.

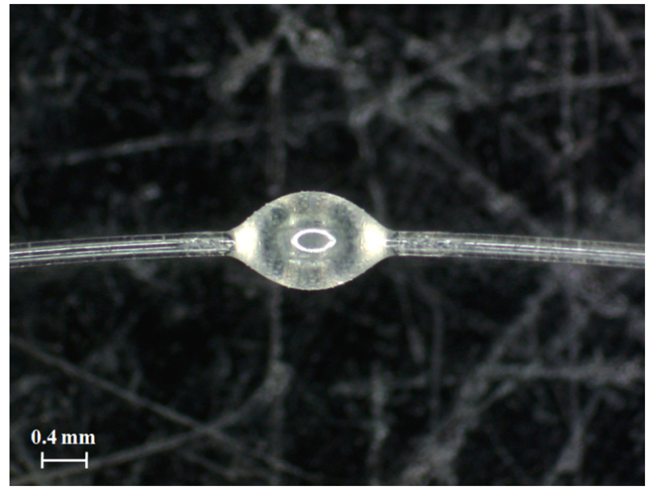

Fig. 1. A microbond test specimen (0.2 mm fiber diameter). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Microbond test

The microbond test was carried out on an Instron 5567 universal material testing machine using a pair of tailor-made adjustable blades as shown in Fig. 2. The blades were fixed on the bottom jaw of the Instron testing system and the fiber is pulled by the upper jaw using a cross-head speed 1 mm/min. At least 50 specimens were used for each IFSS evaluation and their average value and standard deviation were reported.

3. Finite element simulation

Finite element software ANSYS (ver. 15.0) is used to simulate the interface combination status of the FRPs. In this investigation,

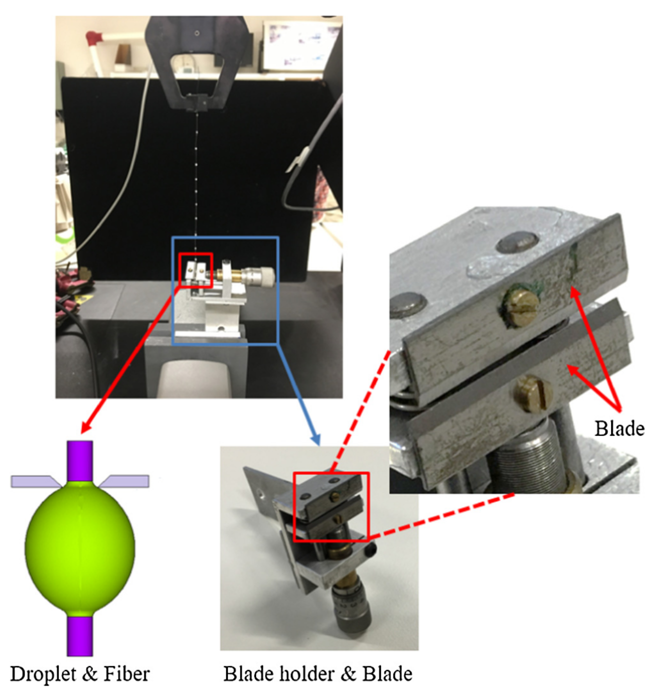

Fig. 2. Experimental setup for microbond testing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)