TENSILE FRACTURE CHARACTERISTICS OF HYBRID FIBER COMPOSITE USING SINGLE FIBER FRAGMENTATION TEST

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ABSTRACT: The hybrid effect of carbon and glass monofiber hybrid composite systems with six kinds of hybrid ratios was demonstrated by the single fiber fragmentation test. The fiber fragment numbers show obvious differences between hybrid fiber and mono-one..

1 Introduction

The interface is a “bridge” between fiber and matrix in fiber reinforced composites, mainly playing a role of load transfer, and the properties of interface have significant impacts on the macro-mechanical performances of composite materials. To evaluate the interfacial adhesion in composites, micro-specimens embedding one or more fibers have been used for micro-mechanical tests[1-8]. From single fiber fragmentation test, the interfacial properties, such as interfacial shear strength and the aspect ratio of broken fiber can be obtained, so the method is widely used for polymer composites[9-10]. Hybrid fiber composite is reinforced by two or more kinds of fibers. The mechanical property of hybrid composite has close relationship with the fiber / matrix interfaces and the stress transfer among different fibers[11]. In this study, a model hybrid fiber composite has been constructed by assembling carbon fibers and glass fibers in an epoxy resin matrix. This model composite was analyzed using single fiber fragmentation test. The tensile fracture characteristics of the hybrid fiber composite were studied with different hybrid ratios. In addition, the numbers of fiber breakpoint of hybrid composites were compared with the cases of non-hybrid composites. This work would provide important information for exploring hybrid mechanical mechanism and designing hybrid structures.

2 Experimental

S-2 glass fiber with diameter of 12 μm was used, which was the standard high-strength glass fiber. T300 carbon fiber with diameter of 7μm was supplied by Toray Co. The elastic moduli of carbon fiber and glass fiber were 230GPa and 80GP. The hybrid fiber composites were prepared with epoxy resin (YD-128), which was provided by Dasen Chemical Co. in Tianjin. Epoxy resin is based on diglycidylether of bisphenol-A (DEGBA). CA-H36 based on polyoxypropylenediamine was used as curing agent and also purchased from Dasen Chemical Co.

In order to study the interaction among the fibers in multi-fiber system (using one kind of fiber) and hybrid fiber system (using two kinds of fibers), three-dimensional arrangement was adopted[7]. Firstly, two fibers with 19 cm length were simultaneously dipped in the epoxy resin and then were hung on a frame. After two-fiber system was cured, the third fiber was fixed on it under magnifying lens. The position of the third fiber was adjusted to ensure the cross sections of the three fibers to form a triangle, as shown in Fig. 1. Then, the three-fiber composite specimen was prepared according to the specimen of single fiber fragmentation test. The resin was cured at 70℃ for 6 hours in the atmosphere. After the specimen was taken out from the mold, it was polished to obtain the smooth surface and uniform thickness.

During the fragmentation test, the interfacial failure occurring on the individual fiber was observed via an optical microscope with a specially-designed tensile machine. In the system of the triple fiber/matrix system, the fragments occurred on each fiber, and the number of the fragments was recorded

with the tensile strain. The micro-failure modes were observed via the polarized-light microscope. The interaction of different kinds of fibers was evaluated by the number of fragments under the increasing strain and the positions of the fragments on the individual fiber.

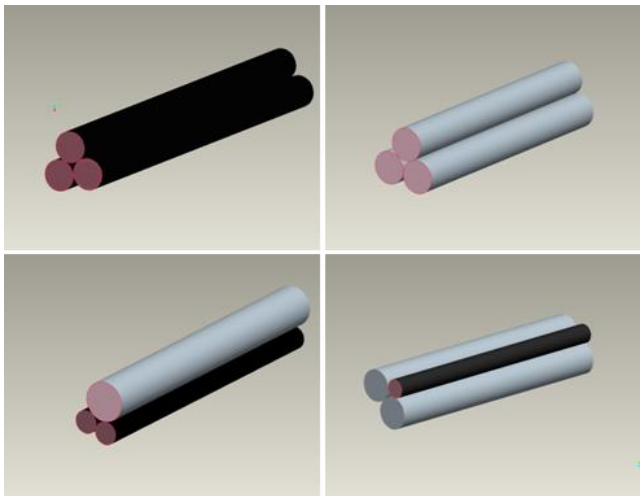


Fig.1. Schematic of three-fiber hybrid system, where the black fibers denote the carbon fibers and the blue fibers indicate the glass fibers

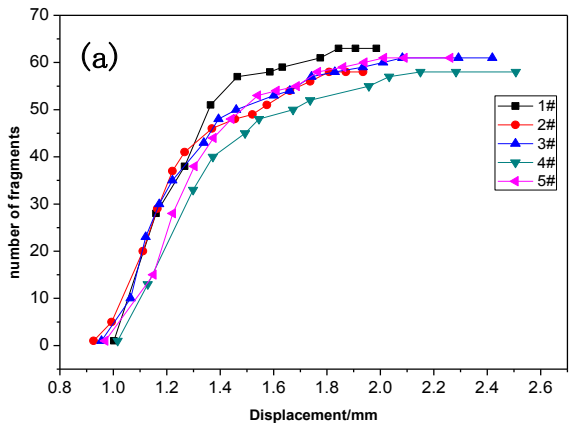
3 Results and discussion

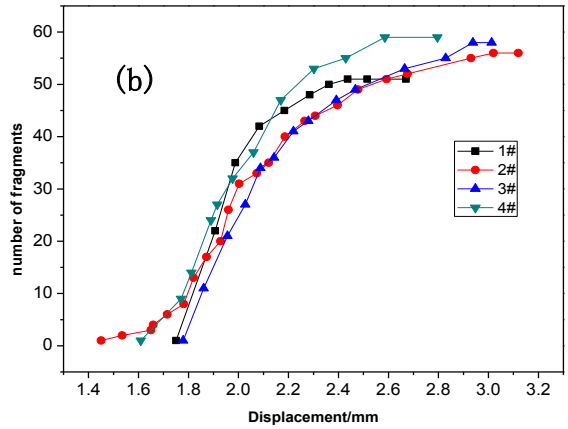
Fig.2 shows the number of fragments vs. tensile displacement curves of the single fiber, multi-fiber and hybrid fiber/epoxy systems, respectively. All the number of breakpoints increases with the tensile strain. And for each kind of fiber, the tensile fracture numbers on multi-fiber systems(see Fig. 2c and 2d) are much less than those of monofiber ones(see Fig. 2a and 2b). In the hybrid systems, since the carbon fiber has smaller fracture elongation ratio, breakpoint can be observed earlier than the glass fiber counterpart as the axial tensile load increases. In addition, the breakpoints number of the carbon fiber is more than that of glass fiber owing to higher interfacial strength and fiber strength of the carbon fiber system (as shown in Fig. 2e and 2f). Moreover, there are obvious differences between hybrid fiber and mono-one in the fiber fragment numbers. As listed in Table 1, the saturation breakpoints of hybrid fiber composites are less than that of the single fiber system and more than that of the triple-fiber system. Therefore, in the hybrid systems, the interaction between the two kinds of fibers leads to the changes of tensile fracture behaviour of the fibers.

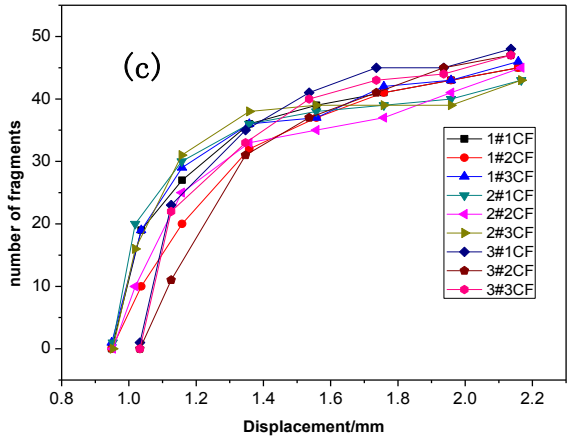
Furthermore, the position of the breakpoints between the same kind of fiber in multi-fiber specimen is consistent(as shown in Fig. 2c and 2d), indicating that the breakpoints cause stress concentration in the adjacent fibers in most cases[5], so other fibers are prone to further break. Therefore, the stress concentration near the breakpoints is the primary factor to determine the fracture mode of the multi-fiber systems.

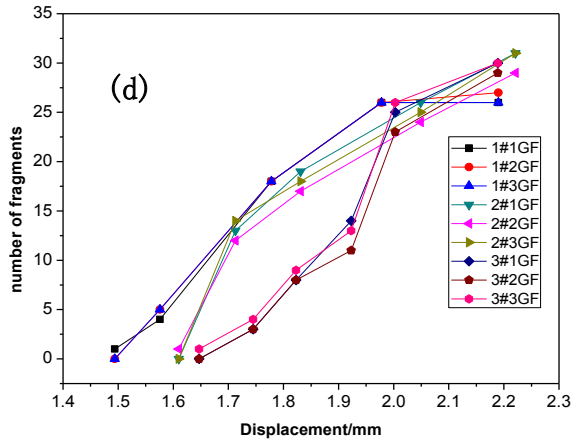
Table.1. The number of saturation fragmentation of monofilament composite systems with different hybrid ratio.

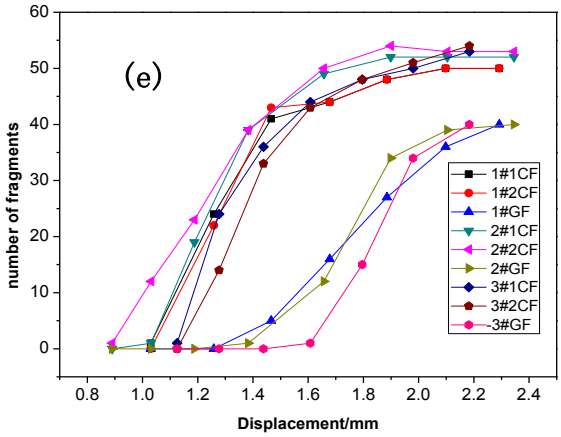
Hybrid ratio of carbon fiber/glass fiber	Fracture number of carbon fiber	Fracture number of glass fiber
1/0	60	—
0/1	—	56
3/0	45	—
0/3	—	29
2/1	52	40
1/2	59	33











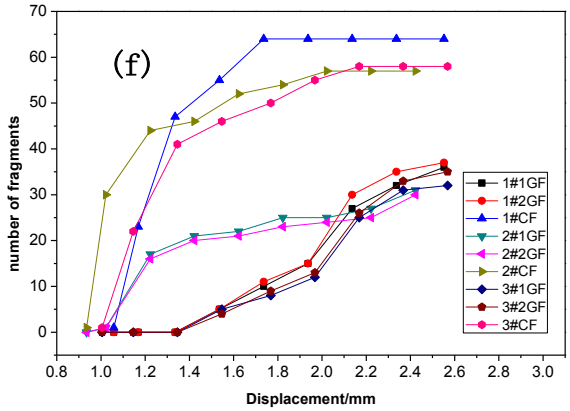


Fig.2. The number of fiber breakpoints vs. tensile displacement curves for the single fiber/matrix system, the multi-fiber/matrix system and hybrid fiber/matrix system: (a) single carbon fiber; (b) single glass fiber; (c) three carbon fibers; (d) three glass fibers; (e) hybrid fibers with two carbon fibers and one glass fiber; (f) hybrid fibers with two glass fibers and one carbon fiber

Obvious fiber fracture modes are exhibited in Fig.3, and all fibers break successively in a series around neighboring fibers. It is considered that the fracture energy caused by a fiber break strongly affects the adjacent fibers[12]. This breaking process can be observed throughout the tests. In addition, the experimental results indicate that the major damage near fiber breaks is matrix cracking, and the growth of interfacial debonding from a fiber break is hardly observed at the breaking strains in Fig.3.

Fig.3a reveals the polarizing micrographs of multi-T300/A0 system at strain of 2.43%. Under axial tensile load, when the strain reaches a certain value, the fiber firstly fractures because the fracture elongation ratio of carbon fiber is much smaller than that of epoxy matrix. As the strain increases, the

number of breakpoints increases. After reaching saturation, the size of breakpoints enlarges with the increasing strain, and interfacial debonding appears in some areas. Since the interfacial strength is high enough, the breakage would extend to the matrix, forming a matrix crack. When the crack reaches a certain extent, the crack begins to expand quickly, eventually leading to destruction of the entire specimen.

The polarizing micrograph of multi-S-2/A0 system [13]and its corresponding strain are demonstrated in Fig. 3b. Due to the weak interfacial property, when the first breakpoint appears, the interfacial debonding emerges. As the strain increases, the breakpoints increase more quickly. Eventually, the strain reaches a certain value, and the entire specimen fractures.

Fig.3c shows the polarizing micrograph of hybrid system with two carbon fibers and one glass fiber at its corresponding strain. Because of the fact that the fracture elongation ratio of glass fiber is higher than that of carbon fiber, under the axial tensile load, the carbon fiber firstly emerges breakpoint. When the strain reaches a certain extent, the glass fiber begins to fracture near the break position of carbon fiber under the influence of stress concentration. For the hybrid system, the interfacial debonding phenomenon is more severe. In addition, the cracks begin to extend from the breakpoints, and the destruction of the specimen occurs. Therefore, the number of fragments is smaller than that of the single fiber systems.

As shown in Fig. 3d, in the hybrid system with two glass fibers and one carbon fiber, the carbon fiber fragments initially with increasing strain. When the strain reaches to a certain level, the adjacent glass fiber begins to fracture, and the positions in the glass fibers are determined by the positions of carbon fiber breakpoints. With the increase of the breakpoints, interfacial debonding becomes severe, eventually leading to the destruction of the entire specimen.

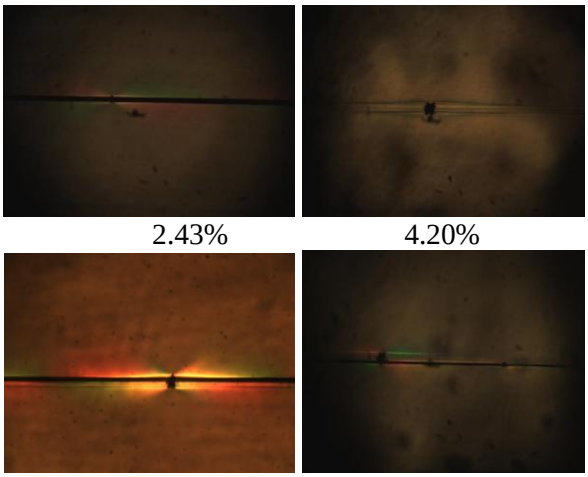


Fig.3. Polarizing micrographs of single fiber fragmentation test: (a) three carbon fibers; (b) three glass fibers; (c) hybrid fibers with two carbon fibers and one glass fiber; (d) hybrid fibers with two glass fibers and one carbon fiber, the numbers on the micrographs indicating the tensile strain

4 Conclusions

In summary, the triple-fiber fragmentation test approach was implemented to investigate the tensile fracture behavior and stress distribution around the breakpoints for hybrid fiber composites. Axial tensile test shows that carbon monofiber breakpoints are more than those of glass fiber counterpart. And for each kind of fiber, the tensile fracture numbers on monofiber systems are much larger than that of multi-fiber one. There are obvious differences between hybrid fiber and mono-one in the fiber fragment number. The saturation breakpoints of hybrid fiber composites are less than that of the single fiber system and more than that of the triple-fiber system. Furthermore, these differences can be attributed to the different stress distribution due to the interaction among fibers.

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