Study of interface influence on bending performance of CFRP with embedded optical fibers

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ABSTRACT

Studies showed that the bending strength of composite would be affected by embedded optical fibers. Interface strength between the embedded optical fiber and the matrix was studied in this paper. Based on the single fiber pull out tests, the interfacial shear strength between the coating and the clad is the weakest. The shear strength of the optical fiber used in this study is near to 0.8MPa. In order to study the interfacial effect on bending property of generic smart structure, a quasi-isotropic composite laminates were produced from Toray T300C/ epoxy prepreg. Optical fibers were embedded within different orientation plies of the plates, with the optical fibers embedded in the same direction. Accordingly, five different types of plates were produced. Impact tests were carried out on the 5 different plate types. It is shown that when the fiber was embedded at the upper layer, the bending strength drops mostly. The bending normal stress on material arrives at the maximum. So does the normal stress applied on the optical fiber at the surface. Therefore, destructions could originate at the interface between the coating and the clad foremost. The ultimate strength of the smart structure will be affected furthest.

Keywords: smart structure, optical fiber, interface, performance

1. INTRODUCTION

Optical fiber sensors are being used more and more in structures [1], for example, in aerospace industries [2]. The sensors have the advantages of their small physical size, insensitivity to electromagnetic interference, and capability of sensing at high temperature and in environmentally unfavorable conditions. Individual fibers or fiber networks are often embedded in the composites, as smart sensors, for real time structural health monitoring [3, 4]. Since the birth of sensors with optical fiber, much attention has been paid on the mechanical performance effect of the embedded fiber [5,6,7]. M.Surgeon [8] found that when embedding the fiber at the middle layer, the performance didn't change so much. However, the bending strength reduced nearly 50% as the fibers embedded at the outer layer. He pointed out that the formed interface around the embedded optical fibers unfavorably changed the bending characteristic of the final structures.

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The interface between materials plays an import role in determining the performance of the resulting composite structures [9-10]. Therefore, the interface shear stress was studied experimentally. The effect of the interface on the bending performance of a quasi-isotropic composite laminates was discussed.

2. THEORETICAL ANALYSIS

In his study [8], Surgeon carried out three-point and four-point bending tests on similar quasi-isotropic laminates. Fig.1 shows the three-point bending result. It is obvious that the bending strength drops mostly for material type B. The type with optical fiber embedded in the middle layer decreased the least.

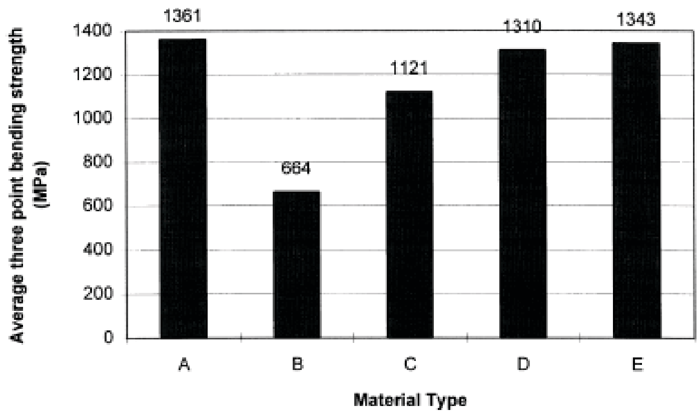
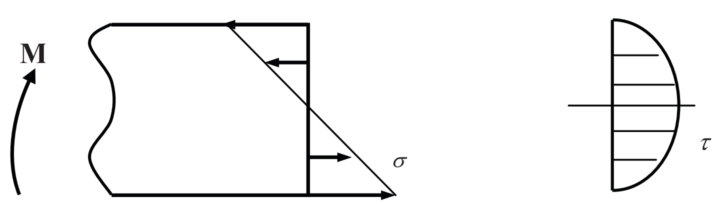


Fig. 1Surgeon's experimental results

When a laminate is subject to bent, the normal stress distributes linear along the height on the section. Fig.2 (a) shows the normal stress distribution. The material in the neutral layer is free of normal stress. The material is subjected to tensile at one side of layer, pressure at the other side. Fig. 2(b) shows the shear stress distribution. It can be seen from Fig. 2 that the fiber at the upper surface bears to pure tensile. However the fiber at the middle layer sustains pure shear. The maximum tensile stress is at the upper.



2(a) Normal stress along the height 2(b) Shear stress value along height

Fig.2 Bending normal stress distribution

The normal stress can be calculated by the below equation.

$$\sigma = \frac{My}{I_z} \tag{1}$$

For type B, the optical fiber was embedded at the layer between the first two. Consequently, the optical fiber stands the maximum tensile stress. What happens to the optical fiber when it endures maximum normal stress and the effect of the fiber on structural strength are interested. Thus the interface between the embedded fiber and the matrix is a study issue.
Interface cracks or debonding at the interface between the embedded fiber and the matrix can cause the final damage and also dissipate energy [11]. Microscopic interface tests, such as single fiber pull-out test, fiber push-out test and the single fiber fragmentation test, are often applied in studying the interface shear stress.
Single fiber pull-out test was applied here to study the interface shear stress. The theory is introduced simply below.

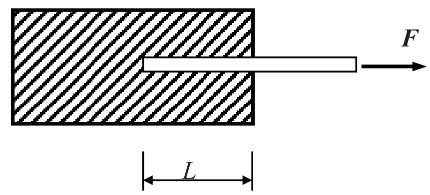


Fig.3 Schematic of single fiber pull-out test

Single fiber is embedded into matrix at the length of L (Fig.3). The force loads at one end of the fiber to pull it out. According to equilibrium equation, we have

$$F=\sigma\cdot\pi\ r^2=2\pi rL\tau \tag{2}$$

Here σ and τ are the normal and shear stress of the optical fiber respectively. If $L<Lc$, where Lc is the critical length for the fiber to be broken instead of be pulled out, the fiber can be pulled out. Thereby the interface shear stress can be determined as the value of the pull out load is captured.

3.EXPERIMENTAL PROCEDURE

3.1 Material

To study property influence of interface on composite, laminates with optical fibers were produced from Toray T300C/ epoxy prepreg. The optical fiber used in the experiments was multimode optical fiber from Lucent® Company. The core diameter is 62.5μm. With clad, the diameter is 125.2μm. The coating is FLEX-10 of 60μm thick. The fiber is under 100 KPSI proof tested when manufacturing.
The stacking sequence chosen for specimens was [0/-45/45/90]s. During the lamination process, optical fibers were embedded in different layers. Five different types of plates were produced.
They are :

typeA: no embedded optical fiber(considered as reference material) ;
type B: two optical fibers embedded in the 0/-45 ply(one in each layer), along the 0° direction;
type C: two optical fibers embedded in the -45/45 ply (one in each layer), along the 0° direction;
type D: two optical fibers embedded in the 45/90 ply(one in each layer), along the 0° direction;
type E:one optical fiber embedded in the 90/90 ply, along the 0° direction.

3.2 Experimental procedures

Impact tests were carried out on the designed five material types to study the mechanical influence. For each kind of the type, 6 specimens were prepared for the impact test. The samples for impact tests had the size of 120mm×12.5mm×1mm. The tests accomplished on a pendulum machine equipped with a swing hammer of 50kg. Fig.4 showed the tests setup.

Fig.4 Impact tests setup

In order to find strength effects of interface on the generic structure, interface between the optical fiber and material was studied. Because the interface came into being around the optical fiber and the resin, one end of the optical fiber was embedded into resin to study the shear strength. Two kinds of samples were designed, with the embedded lengths at 10mm and 5 mm. After the resin cured, it was fixed on a platform. The free end of optical fiber was fixed too. The platform moved at the velocity of 1mm/s. Interface shear stress between the resin and the embedded optical fiber was tested experimentally. Twenty optical fibers with the same embedding length were tested.

4.RESULTS AND DISCUSSIONS

4.1 Bending strength study

The average impact work of 6 test pieces was calculated for five different material types. Fig. 5 shows the testing results.

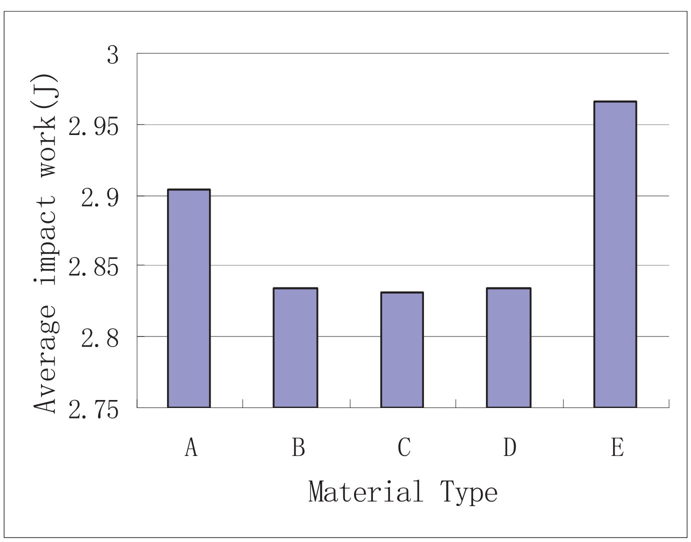


Fig.5 Average impact work of different material types

It can be observed that the work drops for material type B. The work increases for type E compared with type A. According to Eq. 2, the normal stress applied on the embedded optical fiber is almost zero for type E as the fiber was embedded along longitude in the middle of the neutral layer. For type B, two optical fibers were embedded at the facial layer. Thereby, the value of normal stress on the optical fiber for the type B was the biggest. That could be the reason for type B to weaken the bending strength mostly.

4.2 Single fiber pull-out test

No matter how long the optical fiber was embedded inside resin, it was pulled out from the cured resin. Even the fiber with 2 to 3 mm was tried, the same phenomenon was observed. Putting the pulled out fiber under microscope, it can be found that part of the coating was missing. The length of the missing part was the same as the fiber embedded length. The coating material of the studied optical fiber is polypropylene. The coating combines with resin. The coating was brushed on the clad when producing the optical fiber. The interfacial shear strength between the coating and the clad is the weakest when the optical fiber is embedded in resin. Therefore, the coating stayed in the cured resin, while the clad was pulled out from the coating.

The maximum pull loads during the tests were recorded for the specimen with the same embedded length. The average value of 20 tests was 3.2N. Hence, the interfacial shear strength between the coating and the clad can be calculated according to Eq.1. Accordingly, the interfacial shear strength between the coating and the clad is near to 0.8MPa.

Suppose that the optical fiber used in Surgeon's study was the same as what used here. For type B, the embedded length of the fiber was 25mm. According to Eq.2, the maximum tensile stress for the optical fiber to carry should not exceed 640 MPa. Otherwise crack will appear at the interface between the coating and the clad of the optical fiber. Usually, the optical fiber fabrication procedure and the used materials are similar. Consequently, the interfacial shear strength between the coating and the clad is close.

5.CONCLUSIONS

Some conclusion can be obtained from above discussion.

When embedding optical fibers into a structure, the interfacial shear strength between and the coating and the clad is the weakest among all the formed interfaces. Therefore, when the optical fiber is subject to tensile, the clad could be pulled out from the coating. The shear strength for the interface is 0.8MPa.

If the optical fiber is embedded in the middle of the laminate, it is free of bending normal stress. The embedded optical fiber has less affect on the strength of generic structure. However, if it is embedded between the layers close to the surface, it subjects to the maximum bending normal stress. So does the interfacial layer between the coating and the clad of the optical fiber. Therefore, the optical fiber breaks from the weakest part, namely rebinding happens at the interface. As interface cracks appear, it weakens the finally strength of the formed smart structures. This should be avoid in the future design of smart structures.

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