NOTE

Effect of Interface Properties on the Static and Dynamic Properties of Unidirectional Composites

INTRODUCTION

Interface is the heart of composite materials. It plays an important role in the performance of composite materials since the load is transferred from the fiber to the matrix at the interface. The interfacial properties are determined by the extent of chemical, physical, and mechanical bondings at the interface.[1] The physical bondings come from the van der Waals' force between the fiber and the polymer matrix. The mechanical anchoring or mechanical bonding results from the difference in thermal shrinkage between the carbon fiber and the polymer that gives rises to a pressure at the interface. This pressure can be expressed by the following equation:

$$P = \frac{(\alpha_m - \alpha_f)\Delta T E_m}{(1 + V_m) + (1 + V_F)E_m/E_f} \qquad (1)$$

where α is the thermal expansion coefficient, V is the poisson's ratio, E is the young's modulus, and ΔT is the difference between the glass transition temperature and the room temperature.[2] Thus, mechanical bondings can be increased either by increasing radial pressure or by increasing the surface roughness of the fiber.

In this paper, the effect of chemical bonding and mechanical bonding on the static and dynamic properties of unidirectional composites will be discussed.

EXPERIMENTAL

Materials

Carbon fibers, Besfight HTA-7-12000, were from Toho Rayon Co.; the fibers were thoroughly washed in chloroform at room temperature to remove the epoxy sizing. Polyethersulfone (PES-300 P; I.C.I.) and polyetherimide (ULTEM, General Electric Plastics) were chosen as the matrix systems for the interface studies of high temperature thermoplastic composites.

Unsized type 30 Pristine E-fiberglass roving was provided by the Owens-Corning Fiberglass Corp. The as-received fiberglass was dipped into a 0.2 wt % aqueous so-

lution of AAPS for 10 min, followed by drying at 115°C for 30 min. N-(2-aminoethyl)-3-aminopropyltri-methoxy-silane (AAPS) was from Dow Corning.

The crosslinked epoxy matrix under investigation is a polyester formed by reaction of a diglycidyl ether of bis-phenol-A epoxy resin (Epon 828, Shell) and the cyclic anhydride, Nadic methyl anhydride (NMA, Fisher). The copolymerization is catalyzed by 0.5 wt % benzyldime-thylamine (Eastman Kodak). The ratio of epoxy resin, anhydride, and accelerator for making the composites is 200 : 200 : 2 by weight.

Experimental Details

A microbond method[3] was used to measure the interfacial shear strengths. The procedure involved the deposition of a small amount of resin on the surface of a fiber as shown in Figure 1. After the curing process, the fiber specimens were pulled out of the microdroplet at a rate of 2 mm min^{-1}, using a Shimazu tensile tester. The arrangement is shown in Figure 2. The interfacial shear strength was calculated from the following equation:

$$\tau = F_p/\pi D L$$

where F_p = pullout force, D = fiber diameter, and L = embedded length. The fixture for the dynamic properties (fatigue) is shown in Figure 3. The stress distribution during the four-point reverse bending is shown in Figure 4.

RESULTS AND DISCUSSION

Interfacial Shear Strength of High Temperature Thermoplastic Composite System

Figure 5 shows the debonding load as a function of embedded area. The interfacial shear strengths for high temperature thermoplastic composite are shown in Table I. The radial stress was calculated from eq. (1). It is seen in Table I that the radial pressure for the PEI system is larger than that for the PES system. Therefore, the reason for the higher interfacial shear strengths for PEI compared with PES is the higher mechanical bonding at the interface. In eq. (1), the radial stress (P) is proportional to the difference between the glass transition temperature
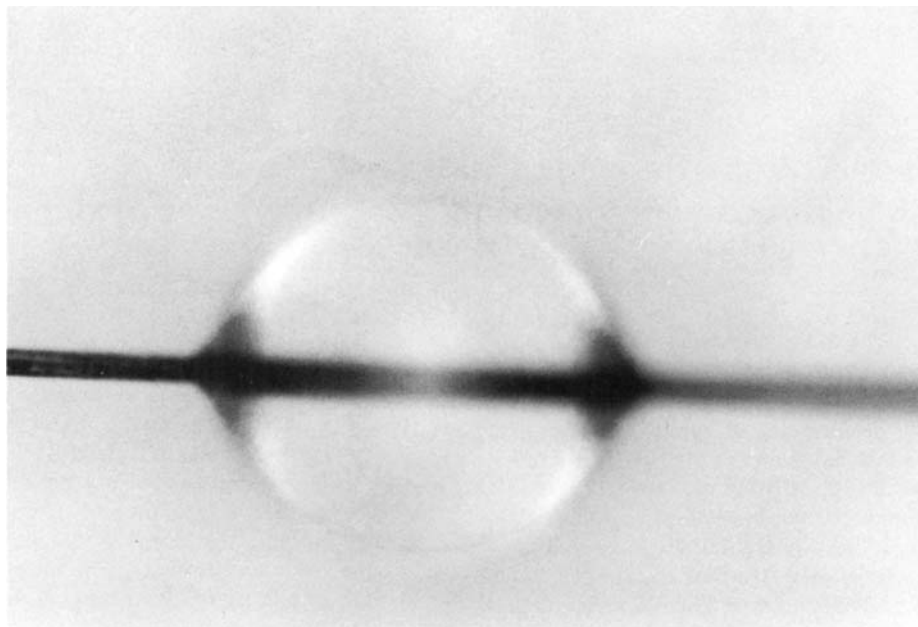
Figure 1   Droplet shape on the carbon fiber.

and the room temperature (ΔT). A high radial pressure will increase the mechanical bonding. Therefore, the effects of mechanical bonding will become significant for a high temperature thermoplastic composite system because of the large difference between the glass transition temperature and the room temperature. On the other hand, chemical bonding exists at the interface in addition to

Figure 2   Arrangement for the shear debonding of a resin droplet.

Side View of a Sample Subjected to
Four-Point Bending Fatigue.

Figure 3   The fixture for the dynamic properties.

mechanical bonding for thermosetting polymer composites. The effect of chemical bonding on the interfacial shear strength usually become more important than the mechanical bonding for thermosetting polymer composites.[4,5]
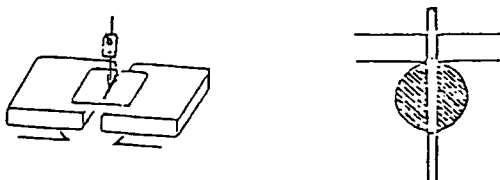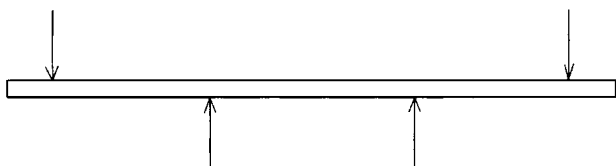
Effect of Interface Strength on the Dynamic Properties of Composite Material

Figure 6 shows the effect of interface properties on the dynamic mechanical properties (fatigue) of unidirectional composites. Table II also shows the static mechanical properties of the same composite material. It is obvious that the interfacial properties affect the dynamic properties significantly. A linear relationship between the fatigue life and the shear strength is shown in Figure 7.
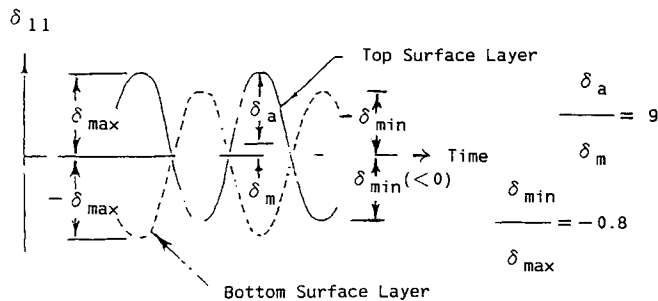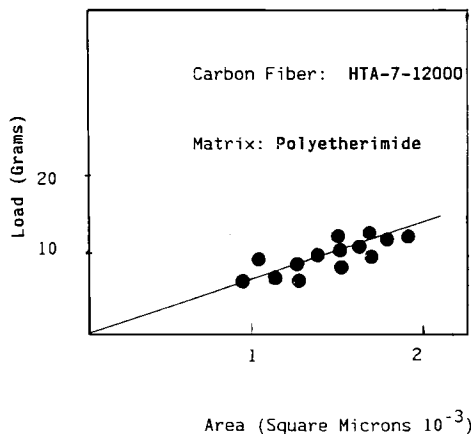

$$\frac{\delta_a}{\delta_m} = 9$$

$$\frac{\delta_{min}}{\delta_{max}} = -0.8$$

**Figure 4**   The stress distribution during the four point reverse bending.

Figure 5   Debonding load as a function of embedded area.

Effect of Chemical Bonding and Mechanical Bonding on the Dynamic Properties

The silane treatment will provide chemical bonding between the fiber and the matrix. From Figure 6, the fatigue life of a composite material increases greatly after fiber surface treatment. Others have modified the thermal expansion coefficient of the polymer to reduce the radial stress at the interface in order to improve the fatigue
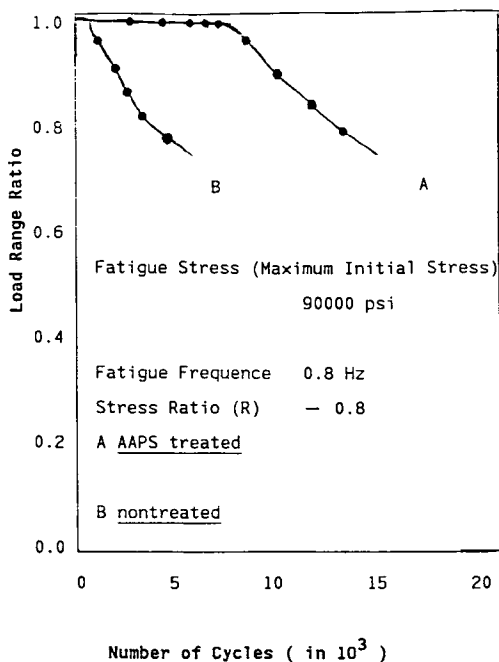
Figure 6   The effect of interface strength on the dynamic mechanical properties.
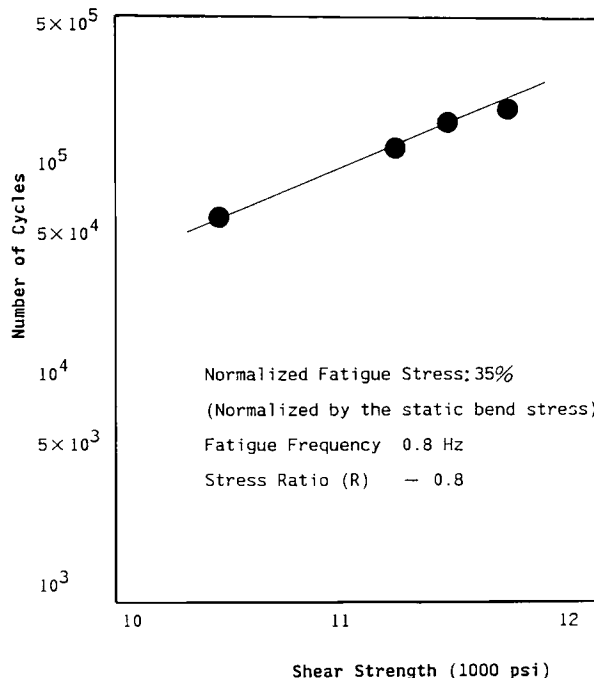
Figure 7   A linear relationship between the fatigue life and the shear strength.

properties of the composite.[6] Therefore, an increase of the radial pressure at the interface will increase the mechanical bonding and decrease the fatigue life of the composites.

Chemical bonding increases both the interfacial shear strength and the fatigue life of composite materials,

Table I   The Interfacial Shear Strengths for High Temperature Composite System

Materials	Interfacial Shear Strength $(g/m^2) \times 10^9$	Radial Stress on Carbon Fiber Due to Thermal Shrinkage $(N\ mm^{-2})$
PEI	4.2 ± 0.3	19.2
PES	3.0 ± 0.2	15.2

Table II   Static Properties of Composite Materials

	Flexural Strength (ksi)	Shear Strength (ksi)
APPS-treated	146.2 ± 4.9	10.89 ± 0.45
Nontreated	147.4 ± 4.8	10.35 ± 0.49

whereas mechanical bonding decreases the fatigue life in spite of increasing the interfacial shear strengths.

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