Structure and Properties of UHMWPE Fiber/Carbon Fiber Hybrid Composites

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ABSTRACT: Ultrahigh molecular weight polyethylene (UHMWPE) fiber/carbon fiber hybrid composites were prepared by inner-laminar and interlaminar hybrid way. The mechanical properties, dynamic mechanical analysis (DMA), and morphologies of the composites were investigated and compared with each other. The results show that the hybrid way was the major factor to affect mechanical and thermal properties of hybrid composites. The resultant properties of inner-laminar hybrid composite were better than that of interlaminar hybrid composite. The bending strength, compressive strength, and interlaminar shear strength of hybrid composites increased with an increase in carbon fiber content. The impact strength of inner-laminar hybrid composite was the largest (423.3 kJ/m^2) for the UHMWPE fiber content at 43 wt % to carbon fiber. The results show that the storage modulus (E'), dissipation factor (tan δ), and loss modulus (E'') of the inner-laminar hybrid composite shift toward high temperature remarkably. The results also indicate that the high-performance composite with high strength and heat resistance may be prepared by fibers' hybrid. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 101: 1880–1884, 2006

Key words: polyethylene; fibers; composites; mechanical properties

INTRODUCTION

Ultrahigh molecular weight polyethylene (UHMWPE) fiber is the new generation high-performance fiber after carbon fiber and aramid fiber.[1–3] UHMWPE fibers have many excellent properties, for example, high strength and modulus, excellent toughness, chemical resistance and impact, low moisture absorption, good wave transmission, and electrical insulation.[4,5] As a result, the fiber have gained considerable attention in recent years and were applied to various industrial fields. In addition, UHMWPE fiber is thought as the ideal reinforced fiber for composites with high performance and lightness. The composites will possibly be applied in aerospace and aviation, such as making airplane tails, rocket shells, and radar covers. Unfortunately, the inclusion of UHMWPE fiber in composite materials has been limited by their poor adhesion to polymer matrices and poor heat resistance.[6–13] To improve the fiber-matrix adhesion and to utilize the properties of the UHMWPE fiber efficiently, hybrid of UHMWPE fiber and other high-performance fibers such as carbon fibers and aramid fibers is needed.

In this study, to obtain mechanically and thermally improved polymer materials, fibers hybrid composites have been prepared with UHMWPE fiber and carbon fiber as reinforced fiber and VE resin as matrix. VE resin was chosen because this resin has excellent interfacial properties with fiber and has been applied in various Industrial fields. The carbon fiber T300 was chosen because it has good adhesive and compatibility with VE resin. The carbon fiber T300 also has good thermal property and high impact resistance. The effect of hybrid way and hybrid degree on the thermal and mechanical properties of the hybrid composites have been investigated. The results show that mechanical properties of hybrid composites were improved remarkably and the composite with thermal resistance and high strength can be prepared by fibers' hybrid.

EXPERIMENTAL

Materials

T300 fiber (Mitsui chemical industries, Ltd., Tokyo, Japan) was used as the Carbon fiber. The fiber density was 1.83 g/cm^3 with the filament diameter of 6.5 μm. DC88 fiber (Ningbo Dacheng Advanced material Co.

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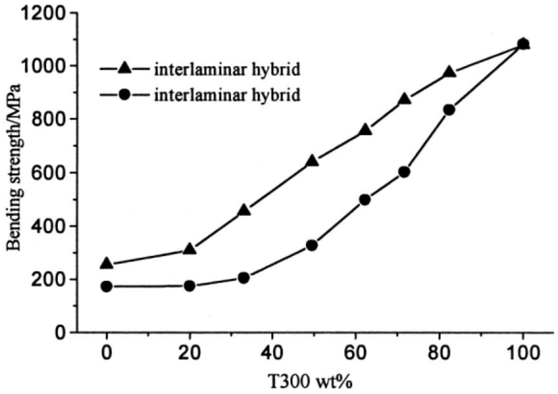

Figure 1 The blending strength of UHMWPE fiber/Carbon fiber hybrid composites.

Ltd., China) was used as the UHMWPE fiber. The fiber density was 0.97 g/cm^3 with the filament diameter of 28 μm. The UHMWPE fiber was used for the experiment after being surface treated with chromic acid. The matrix was VE resin and curing agent was benzoyl peroxide (Shanghai Resin industries, Ltd., China). The curing agent was added to the VE resin in mass ratio of 1 : 100.

Preparation of nonwovens

The nonwovens of UHMWPE fiber and carbon fiber for interlaminar hybrid composites were prepared using the two fibers through VE resin respectively, and twining it on a roll respectively. The nonwovens for inner-laminar hybrid composites was prepared using UHMWPE fiber and carbon fiber through VE resin and twining at same time. The hybrid degree was controlled by the number of fibers and twisting rate of roll.

Preparation of hybrid composites

Three types of high strength fiber reinforced composite sheets were made by compression molding at a constant temperature and a pressure. Sheet I was prepared by only UHMWPE fibers and VE resin. Sheet II was prepared by the compression molding of laid alternate UHMWPE fiber nonwovens and carbon fiber nonwovens, respectively. Sheet III were prepared by laid alternate inner-laminar hybrid UHMWPE fiber/carbon fiber nonwovens. The compression molding conditions were 120°C, 4 h, and 20 MPa.

Measurements

The inter-laminar shear strength (ILSS) was measured according to GB3357–1982 (the People's Republic of China National Standard Methods), bending strength was measured according to GB3356–1982, impact strength was measured according to GB/T2571–1995, and compression strength was measured according to GB1448–83. Dynamic mechanical analysis (DMA) was carried out on a DMTAV model Mark III (Rheometric Scientific Co. Ltd.) at 5°C/min and 3 Hz. The morphological characteristics of the cross and fracture sections of composites were examined by scanning electron microscopy (SEM). The composites were cut with a tool or fractured in bend test and then coated with gold. They were then examined with a HITACHI S-570 instrument.

RESULTS AND DISCUSSION

The effect of carbon fiber T300 content and hybrid way on the bending strength and inter-laminar shear strength (ILSS) of the UHMWPE fiber/carbon fiber hybrid composites are shown in Figures 1 and 2. It was found that bending strength and ILSS of the hybrid composites increased rapidly with an increasing T300 content. The value of the bending strength and ILSS for the inner-laminar hybrid composites are higher than those of interlaminar hybrid composites. Therefore, the hybrid way is the most important factor in influencing the mechanical properties of hybrid composites. The effect of T300 contents and hybrid way on the impact and compressive strength are shown in Figure 3. The compressive strength increased with an increasing T300 content. The impact strength is the largest when the T300 content is 57 wt % (mass fraction) to UHMWPE fiber and then decreases with a further increase in T300 fiber content.

The storage modulus (E'), dissipation factor (tan δ), and loss modulus (E'') of the UHMWPE fiber/T300 hybrid composites versus temperature are shown in Figures 4-6, respectively. It is observed in the figures that the dynamic mechanical properties of the hybrid composites have significantly changed. The E', tan δ, and E'' of inner-laminar hybrid composites shift to-

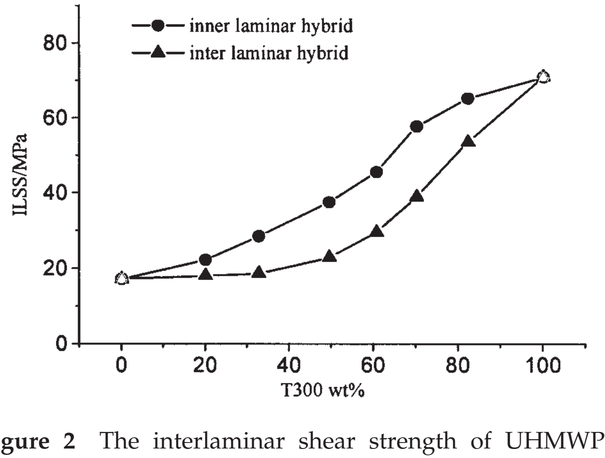

Figure 2 The interlaminar shear strength of UHMWPE fiber/Carbon fiber hybrid composites.

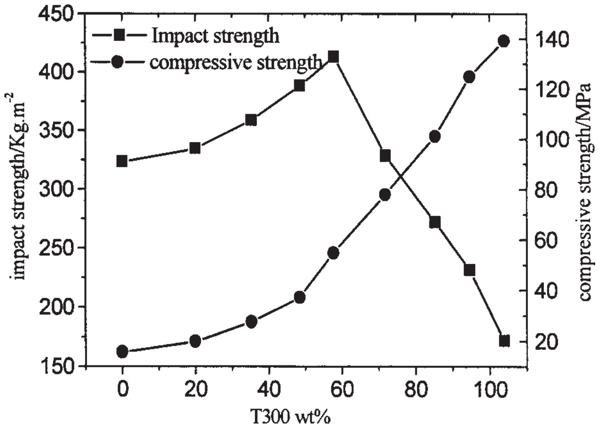

Figure 3 The impact strength and compressive strength of UHMWPE fiber/Carbon fiber hybrid composites.

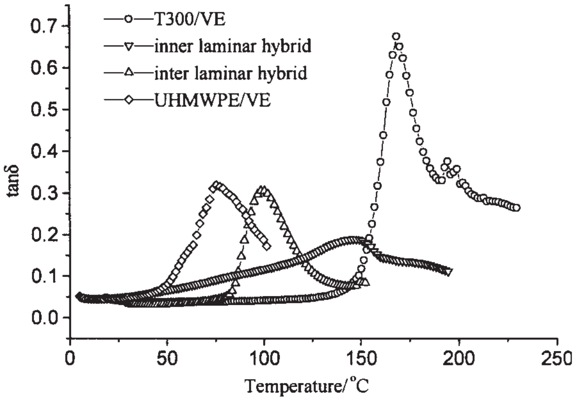

Figure 5 The influence of temperature on loss factor (tan δ)of hybrid composites.

ward higher temperature with the interlaminar and inner-laminar hybrid way. The increase in E' of inner-laminar hybrid composites was 90–300% when compared with those of UHMWPE fiber/VE interlaminar composites. As described by Akay,[14] the temperature at E'' peak can be considered as the glass transition temperature (T_g) of composites. Two different T_g for the hybrid composites are shown in Figure 5. It can be seen from the figure that the T_g of UHMWPE fiber/VE is 71.5°C, the T_g of the interlaminar hybrid composites is 96.5°C, and the T_g of the inner-laminar hybrid composites is 148.7°C. This temperature (148.7°C) is proven to be the melting point of the UHMWPE fiber. The results show that the heat resistance of inner-laminar hybrid composites increased remarkably. The explanation for the above findings is that the carbon fiber is introduced, which improved adhesion between the UHMWPE fiber/carbon fiber and VE resin. The carbon fiber is a kind of rigid polymer that adheres well with the matrix. Therefore, the motion of the molecular chains of the UHMWPE fibers dispersed in the matrix and carbon fibers are restrained, leading to shift of the glass transition temperature of the UHMWPE fiber toward high temperature.

The schematic illustration of hybrid fibers dispersion in the composites are shown in Figure 7. The small circular fibers in Figure 7 are carbon fibers, whose diameter is 7.5 μm. The larger circular fiber is UHMWPE fiber, whose diameter is 28 μm. Type (a) and type (b) in Figure 7 are two hybrid fibers dispersion diagram in inner-laminar hybrid composites. Type (a) is the single fiber inner-laminar hybrid of two fibers. It is found from type (a) that the hybrid fibers dispersed uniformly in the matrix and the matrix uniformly filled around fibers after molding compressive. Therefore, there is no void in composites. Type (a) hybrid way was extremely beneficial to improve heat resistance and mechanical properties. Type (b) is fiber bound inner-laminar hybrid of two fibers. In the heating molding pressure processes, a greater pressure was put on the wide fibers, leading the fibers to be close to each other. Some small voids are seen along

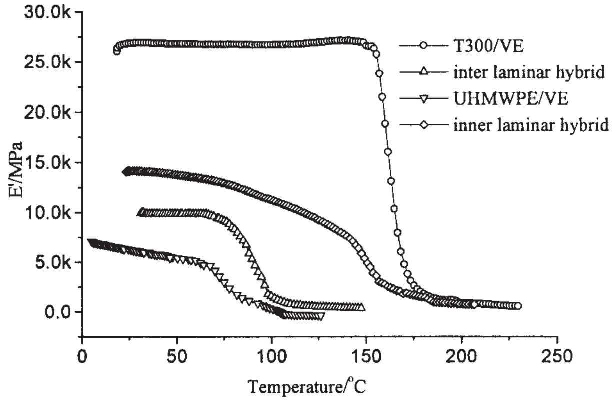

Figure 4 The influence of temperature on storage modulus (E') of hybrid composites.

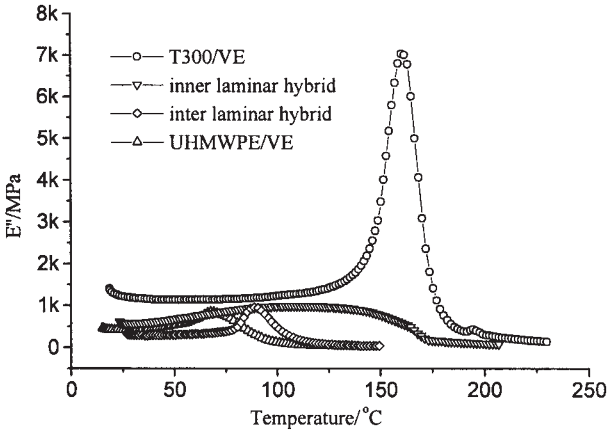

Figure 6 The influence of temperature on loss modulus (E'') of hybrid composites.

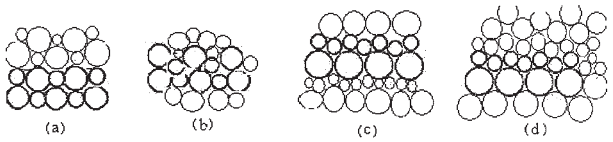

Figure 7 The schematic diagram of hybrid fibers dispersion in the composites: (a) single fiber inner-laminar hybrid; (b) two fibers bind inner laminar hybrid; (c) single fiber layer interlaminar hybrid; (d) fibers inter-laminar hybrid.

the boundary of wide fibers, which leads to nonhomogeneous dispersion of hybrid fibers in the matrix. Therefore, the mechanical properties of type (b) composites are worse than type (a) (Figs. 1 and 2). The inner-laminar hybrid composites were usually prepared by two fiber-bound hybrids because the preparation of single fiber inner-laminar hybrid is difficult in practical processes. Type (b) hybrid effect is worse than that of type (a) in the dispersion degree of fibers, but it is better than that of type (c) and type (d), which are the interlaminar hybrid fibers dispersion diagram. The composites easily split from UHMWPE fibers/VE interface because of weak adhesive strength between UHMWPE fiber and matrix, leading to poor mechanical properties.

Figure 8 shows SEM of the cross and fracture surfaces of the composites in a bending test. Figure 8(a) is the longitudinal cross section of T300/VE composite. It can be seen from Figure 8(a) that the surface of fracture section is very neat and clear and exhibit that the matrix resin disperses uniformly around carbon fibers. This is because the carbon fiber is brittle, indicating that there is strong adhesive force between carbon fiber and matrix. Figures 8(b) and 8(c) are typical cross section and fracture section of inner-laminar hybrid composites respectively, which cut along perpendicular to the fiber axis direction and break in a bending test, respectively. From the cross section of inner-laminar hybrid composites, it can be seen that the cross section is not uniform and clear because the UHMWPE fiber has excellent toughness. Figures 8(d, e, f) show the fracture sections of interlaminar hybrid composites. The split surface can be seen in the UHMWPE fiber layers of the composites [Fig. 8(d, e)], suggesting weak adhesive strength between UHMWPE fiber and matrix. On the other hand, it can be seen from the Figure that the UHMWPE fibers are dispersive and carbon fibers still adhering together closely after the composite fractured, which indicates that there is better adhesion between carbon fibers and matrix than between UHMWPE fiber and matrix. The E' of inner-laminar hybrid composites in this study (Fig. 4) is the highest value of hybrid composites. This fact, combined with result in Figure 8, indicates that hybrid way is an important factor to achieve high mechanical properties and dynamic mechanical properties of hybrid composite.

CONCLUSIONS

UHMWPE fiber/carbon fiber hybrid composites were prepared by inner-laminar and interlaminar hybrid way. The mechanical properties, DMA, and morphologies of the composites were investigated and compared with each other. The results show that hybrid way was the major factor to affect hybrid composite properties. The resultant properties of inner-laminar hybrid composites were better than those of interlaminar hybrid composites. The bending strength, compressive strength, and interlaminar shear strength of hybrid composites increased with an increase of carbon fiber content in the composites. The impact strength of inner-laminar hybrid composites was the

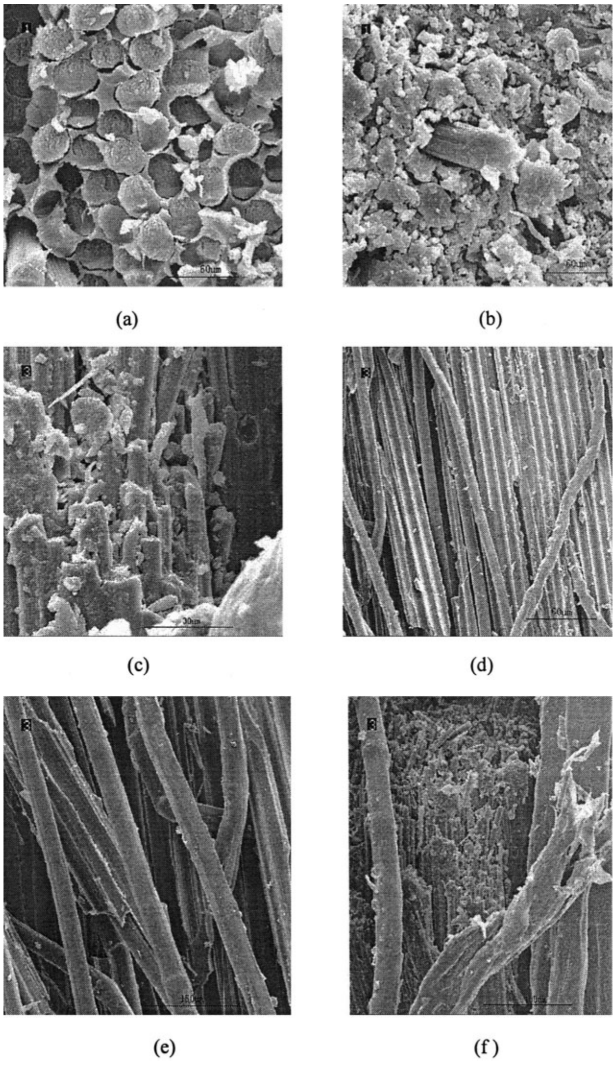
(a) (b)
(c) (d)
(e) (f)

Figure 8 The SEM of cross and fracture section of the composites: (a) fracture section of carbon fiber composite; (b) cross section of inner-laminar hybrid composite; (c) fracture section of inner-laminar hybrid composite; (d) split section of UHMWPE fiber composite; (e) split section of interlaminar hybrid composite; (f) fracture section of inner-laminar hybrid composite.

largest (423.3 KJ/m^2) when the UHMWPE fiber content at 43 wt % to carbon fiber. DMA results show that storage modulus (E'), dissipation factor (tan δ), and loss modulus (E'') of the inner-laminar hybrid composites shift toward high temperature remarkably. The results also show that the high-performance composites with high strength and good heat resistance may be prepared by fibers' hybrid. The explanation for the earlier mentioned findings is that carbon fibers are introduced, which improved adhesion between the UHMWPE fiber/carbon fiber and VE resin. The carbon fiber is a kind of rigid polymer that adheres well with the matrix. Therefore, the motion of the molecular chains of the UHMWPE fibers dispersed in the matrix and carbon fibers are restrained, leading to the glass transition of the UHMWPE fiber shift toward high temperature. The hybrid composites have a potential application in airplane tail, rocket shell, and radar cover.

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