HIGH TEMPERATURE PROPERTIES OF CARBON FIBERS

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Introduction

The increased utilization of recently developed carbon fiber reinforced carbon composites, called carbon-carbons, has highlighted the need for physical, mechanical and thermal properties of carbon fibers at temperatures up to 2800°C. This work describes the experimental data collected on six carbon fibers.

Experimental

The fibers selected for this study were:

Thornel-50	(Union Carbide Corp.)
Thornel-75	(Union Carbide Corp.)
VS0022(Pitch)	(Union Carbide Corp.)
CX-2	(Polycarbon, Inc.)
HM-1000	(Hercules, Inc.)
HM-1000(2400°C)	(Hercules, Inc.)

Density, denier, acoustic modulus, and electrical resistivity were determined for each spool of fiber using standard techniques.

To determine the effect of gauge length on the tensile strength of the bare fiber (not coated with epoxy resin), twenty tensile tests were conducted for each yarn at gauge lengths of 1.3, 2.5, 5.1, 10.2, 20.3, 40.6, and 81.3 cm.

The effect of four thermal cycles up to 2800°C was determined by measuring the density (ρ) and denier (D) of three of the fibers after thermal cycling. The results were compared to the density (ρ_o) and denier (D_o) collected on fiber without heat treatment.

Tensile strength and modulus of the fibers at high temperatures were measured by conducting tensile tests on bare fiber inside a graphite tube furnace capable of 2800°C. Values at each test temperature were compared to the room temperature values for that fiber. Additional room temperature tests were conducted on fiber samples that were preconditioned by various numbers of 2800°C thermal cycles.

The longitudinal thermal expansion of the carbon fibers was determined by measuring the movement of flags attached to fiber samples heated in four consecutive cycles to 2800°C.

Results

Table 1 shows the results of the density, denier, acoustic modulus and resistivity measurements on the fibers. The wide range of values was in the modulus which was 37 GPa (5.4×10^6 pso) to 503 GPa (72.9×10^6 psi). Table 2 shows the effect of thermal cycling on the density and denier for three fibers. The density of Thornal 50 and 75 increased by 4.4% and CX-2 increased only 1%. Conversely the denier decreased by 4% and 7% for Thornel-50 and Thornel-75, respectively. The denier of CX-2 decreased by 35%.

It was found that the measured tensile strength of the fibers decreased as the gauge length of the test increased (Figure 1). HM-1000 was affected most by longer gauge length, -72% (1.27cm to 81.3cm) compared to -29% for VS0022. When the tensile strength of Thornel-50 was measured at elevated temperature (Figure 2), it was found that the strength dropped off by 10% at 1100°C but increased at 2200°C to 10% more than the room temperature value. After the maximum, the strength dropped to 45% of room temperature strength at 2800°C. The modulus of Thornel-50 (Figure 3) was a constantly decreasing function of test temperature with only 20% of the room temperature modulus remaining at 2800°C.

The tensile strength (at 24°C) of Thornel-50 was measured on fiber which had been heat treated by 1, 2, 3 and 4 cycles to 2800°C. Figure 4 shows that the modulus was unaffected by even four cycles. The tensile strength, however, decreased by 35% after four cycles. On similarly heat-treated fiber samples of Thornel-50 the thermal expansion along the fiber axis was measured. Figure 5 shows the thermal expansion of a fiber sample heated by four consecutive cycles to 2800°C. Thornel-50 shrinks sharply on the first cycle and then expanded normally for the second, third and fourth cycles.

Discussion

As was shown in Table 2 the density of Thornel-50 increased by 4.4% and the denier decreased by 4%. This corresponds to an 11% decrease in filament diameter and a 21% decrease in filament cross-sectional area after four 2800°C cycles. Table 2 showed that the density of CX-2 increased by 1% and the denier decreased by 35% which translates into an 18% decrease in filament diameter and a 32% decrease in filament cross-sectional area after four 2800°C cycles.

Figure 1 showed the effect of gauge length on the bare fiber tensile strength. As expected the tensile strength of each decreased as the gauge length increased; however, some fibers had a larger negative slope than others. HM fiber had the largest slope and Thornel-75 the smallest.

When the tensile strength of Thornel-50 was measured at various temperatures up to 2800°C, it was found that the maximum strength occurs at 2200°C. Above that temperature the strength drops sharply as the graphite crystallites become plastic. However in the case of the modulus, which is a constantly decreasing function of temperature, the slope of the line from 0° to 1950°C was -0.40 and -1.85 from 1950° to 2800°C.

It was seen in Table 2 that Thornel-50 experienced an increase in density after four cycles to 2800°C. Figure 5 indicates most of this increase occurs during the first cycle when the fiber undergoes shrinkage.

Summary

It can be concluded from this study that on heat treatment to 2800°C Thornel-50, Thornel-75 and CX-2 increase in density and decrease in denier. The tensile strength of all fibers tested decreased as the gauge length of the test increased. When the Thornel-50 was tested at temperatures up to 2800°C, it was found that the fiber was strongest at 2200°C.

Fiber modulus at 2800°C was only 20% of room temperature modulus. Thornel-50 strength decreased when repititiously cycled to 2800°C, whereas the modulus was unaffected. Any finally, it was found that Thornel-50 shrinks on the first cycle to 2800°C and then expands on the second, third and fourth cycles.

FIBER	DENSITY g/cc	DENIER g/9000m	ACOUSTIC MODULUS GPa	RESISTIVITY 10^{-4} ohm-cm
THORNEL 50	1.66	655	363	9.6
THORNEL 75	1.80	528	503	7.4
CX-2	1.47	1208	37	36.3
VS0022	1.92	2111	305	8.4
HM-1000	1.81	1350	337	9.0
HM-1000(24)	1.81	1308	322	8.8

Table 1 - Carbon Fiber Physical Properties

FIBER	P/P_0	D/D_0
THORNEL 50	1.044	0.959
THORNEL 75	1.044	0.932
CX-2	1.010	0.650

Table 2 - Density and Denier Ratios After four cycles

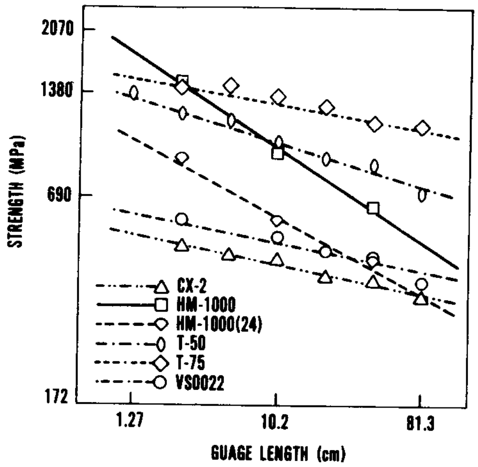

Fig 1 - Fiber Tensile Strength vs Gauge Length

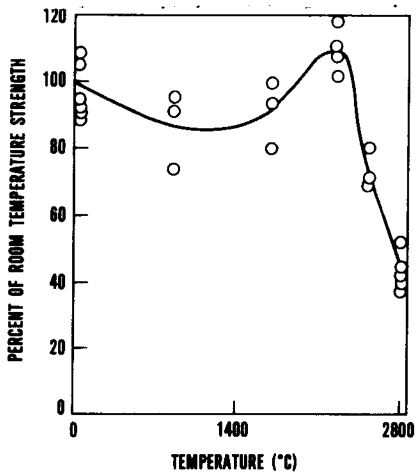

Fig 2 - Thornel-50 Tensile Strength vs Temperature

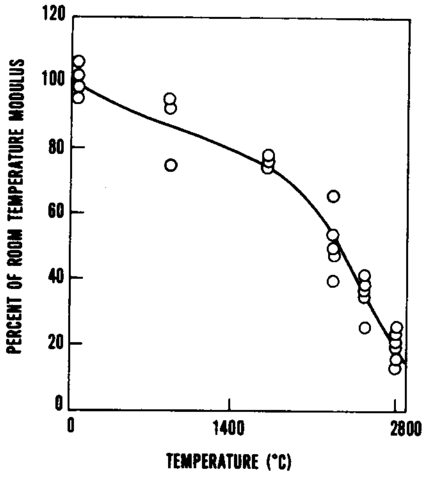

Fig 3 - Thornel-50 Modulus vs Temperature

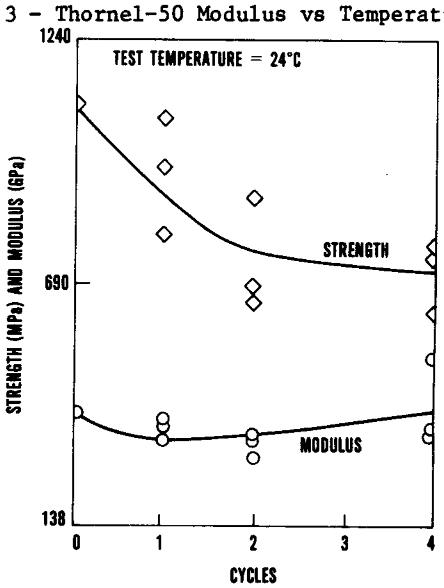

Fig 4 - Thornel-50 Strength and Modulus as a function of Thermal Cycles

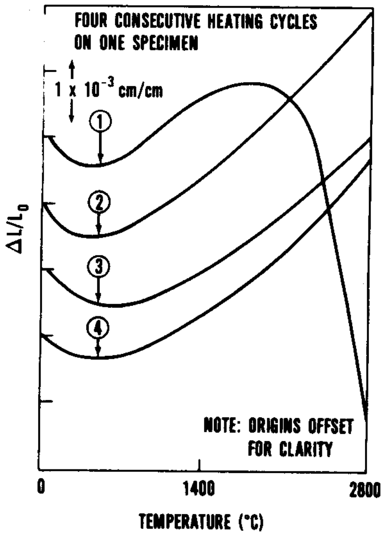

Fig 5 - Thornel-50 Thermal Expansion as a Function of Thermal Cycles