MATERIALS BASED ON PYROGRAF-III™ CARBON FIBER

J.-M. Ting,[a] R. L. Alig,[a] and K. Lafdi[b]

a: Applied Sciences, Inc., Cedarville, OH 45314

b: Southern Illinois University, Carbondale, IL 45314

Introduction

Pyrograf-III™ carbon fiber is a version of vapor grown carbon fiber (VGCF) produced through the pyrolysis of hydrocarbon gases in the presence of a transition metal catalyst. Historically, the metal catalyst was supported on a substrate, which was then placed at room temperature in a reactor for subsequent fibre growth at higher temperatures. [1] This method involves a time-intensive batch process with a low equipment duty cycle. The floating catalyst method was developed in order to reduce the time and, therefore, the cost of carbon fiber production. This method eliminates the need for supporting the catalyst and for cooling the furnace prior to removing the fibers and their supports. Instead of supporting the catalyst on a substrate within the furnace, the catalyst is injected into the flowing gas, where it nucleates and grows VGCF. [2] [3] Low cost VGCF with excellent physical properties can then be produced. This enables the use of Pyrograf-III™ carbon fiber in several material systems. Among them, structural engineering plastics, rubbers, friction and wear materials, and super-capacitors are presented.

Structural Engineering Plastics

Polypropylene (Profax6329, Motell) composite based on Pyrograf-III™ carbon fiber were fabricated using an injection molding process. Specimens were prepared from the composites and then and measured for tensile and flexural properties. Composite density and porosity were determined to be 1.101 g/cc and 1.5%, respectively. Table I lists the test results along with properties of Profax6329 supplied by the manufacturer. An improvement of 55.8% on tensile strength and 330% on flexural modulus were obtained.

Rubber Compounds

A natural rubber formulation reinforced with 28%, by weight, of Pyrograf-III™ carbon fiber was tested for tensile properties. Two versions of fibers were used. They are as-grown fiber and fiber treated with nitrogen and oxygen *in-situ*. The test results are given in Table II. For comparison, a control rubber compound with N650 Carbon Black was included. It is seen that with the reinforcement of Pyrograf-III™ carbon fiber, the tensile modulus was increased by 153%.

Friction and Wear Materials

Composite brake pads with and without the addition of VGCF were subjected to wear test and measurement of thermal diffusivity. Results of wear tests is given in Table III. The fact that VGCC enhances wear performance is attributed to the fact that VGCF also increases the high thermal conductivity of the resulting composites. Brake pads with a better thermal conductivity would reduce the temperature during braking action and thus reduce the oxidation rate of the pad. High thermal conductivity would reduce the so-called "brake fade". The wear of brake materials is related to the heat conduction throughout the materials.

Super-Capacitors

Figure 1 shows the voltage charge and discharge characteristics of carbon electrodes as function of time at 10, 20 and 30 mA. During the charge state, the capacitor was charged to 2.5 volts and then switched to the discharge state, where the capacitor voltage dropped to 0.1 volt. The cycle was then repeated as shown in Fig. 1. Early in the test cycle, the initial rate of voltage change is very rapid as shown in Fig. 1. The rapid rise in voltage is due to the low capacity of the ultracapacitor separator and represents the internal resistance characteristic which is about 14.4 ohms. When the electrode reaches internal steady state charging conditions, the terminal voltage of the ultracapacitor then increases linearly with time.

Figure 2 shows the time delay for application of the current. The linear slope region in this electrode was approximately 40 seconds. Figure 2 shows the capacitance versus time for the VGCF electrode (raw material). Capacitance was calculated from the voltage curves in Fig. 1. As a result, the specific capacitance was determined to be 1.2 F/g, which is higher than that of any other carbon fibers in their as-grown states. This result strongly indicates that VGCF holds a very high potential for use as an electrode material in ultracapacitor.

Conclusions

Various materials based on Pyrograf-III™ carbon fiber were fabricated and evaluated. In general, the use of Pyrograf-III™ carbon fiber enhanced the material properties.

References

[1] J.-B. Donnet and R.C. Bansal, *Carbon Fibres* (Marcel Dekker, Inc., New York, USA, 1990), 2nd ed., pp. 70.
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[3] G.G. Tibbetts, D.W. Gorkiewics and R.L. Alig, Carbon **31,** 809 (1993).

Table I. Mechanical properties of Pyrograf-III™/polypropylene composite.

Material	Fiber %	Test	Strength, ksi	Modulus, msi
Comp.	30	Tensile*	6.7	0.82
Comp.	30	Flexural**	7.59	0.753
Profax	0	Tensile	4.3	-
Profax	0	Flexural	-	0.175

* ASTM 638. ** ASTM 790.

Table II. Tensile properties of rubber with different additives.

Additive	Strength, psi	Modulus, psi	elongation, %
N-650 Black	1453	1008	203
As-grown VGCF	1625	1990	155
Treated VGCF	1700	2554	134

Table III. Wear of brake pads with different compositions.

ID	VGCF	Kevlar	Coke	Resin	Wear (%)	
					1050 rpm 300 stops	3000 rpm 300 stops
Kev 10	10%	20%	15%	55%	0.0271	0.0491
Kev 11	10%	20%	10%	60%	0.0246	0.0602
Kel 25	0%	50%	0%	50%	0.3062	0.3818
S	-	-	-	-	0.3610	0.4871
O	-	-	-	-	0.3642	0.7725

* Commercially available semi-metallic.
** Commercially available organic.

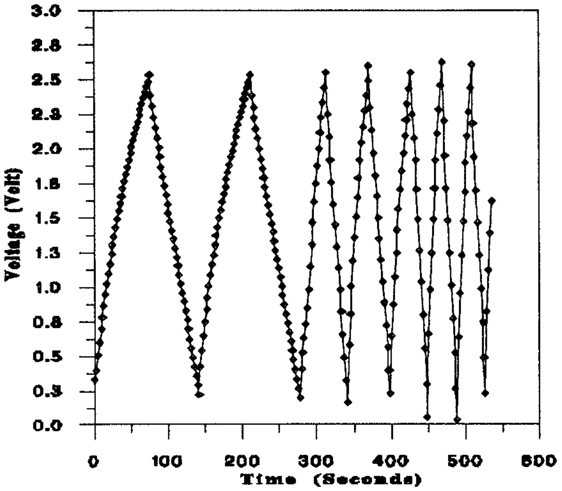

Fig. 1. Voltage as a function of time.

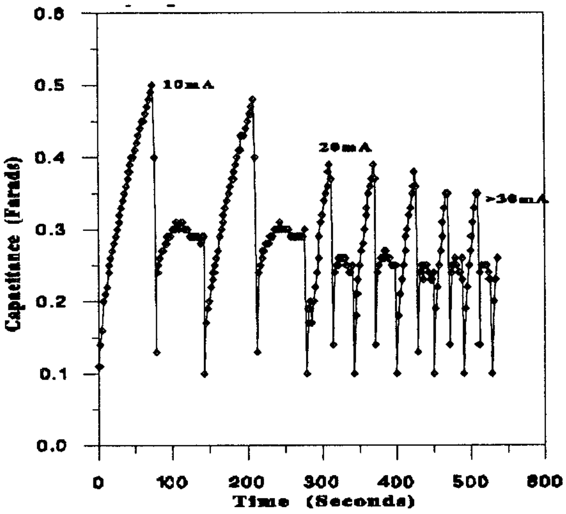

Fig. 2. Capacitance as a function of time.