

New applications for carbon fibers

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The outstanding properties and characteristics of pitch-based carbon fibers have been exploited for use in a variety of products.

A unique carbonizable pitch known as A-240 is obtainable from a heavy, specially selected feedstock from crude oil refining operations. Its primary use is as a binder and densifier for carbon and graphite electrodes, which are consumed in steel and aluminum smelting processes. Although additional uses of A-240 pitch have been explored, one of the most promising is its conversion into a low-cost carbon fiber. Over the past 15 years, intensive research and development efforts resulted in novel methods of forming fibers into a nonwoven mat and in stabilizing and carbonizing treatments which allow substantial reductions of manufacturing expenses to be realized, compared with conventional processes which convert polyacrylonitrile (PAN) precursor fibers into PAN-based carbon fibers. This paper will be limited to discussing certain developing applications of pitch-based carbon fiber forms in composite materials.

Properties of carbon fibers

The unusual characteristics of pitch-based carbon fibers point to their use in a variety of applications. As indicated in **Tables I and II**, carbon fibers are strong, lightweight, abrasion resistant, and self-lubricating, all of which combine to provide excellent mechanical properties. They conduct heat, have a low coefficient of thermal expansion, retain their mechanical properties at elevated temperatures, and resist oxidation at temperatures up to 500°C. Pitch-based carbon fibers are good electrical conductors, and they are highly chemical resistant and biologically inactive.

Nonwoven carbon fiber products

While high-cost, high-performance carbon fibers find wide application in aerospace and sporting goods, multipurpose pitch-based carbon fibers having the aforementioned properties are now available for cost-efficient products. The carbon fiber product forms attracting the most attention are the low-priced nonwovens such as mat, stitched mat, paper, and needled felt.

Nonwoven mat is a three-dimensional material comprised of semicontinuous fibers and may be used in this form for insulation and shielding purposes. The nonwoven mat may

I. Outstanding characteristics of pitch-based carbon fiber

Property	Characteristic
Mechanical	Strength
	Low density
	Stiffness and rigidity
	Fatigue resistant
	Abrasion resistant
	Tribological
Thermal	Heat conductive
	Dimensional stability
	Thermal stability
	Oxidation resistant
Electrical	Electrically conductive
	Nonmagnetic
	X-ray transparent
Biological	Biologically inert
Chemical	Chemically inert
	Chemically resistant

II. Selected properties of pitch-based multipurpose carbon fiber

Typical fiber properties (filaments)	Units
Density	1.6 g/cm ³
Electrical resistivity	0.005 ohm/cm
Diameter	12 microns
Tensile strength	4–6 x 10 ⁶ Pa (6–8 x 10 ⁴ psi)
Tensile modulus	30–40 GPa (5–6 x 10 ⁶ psi)

also serve as a flame barrier in certain automotive and military applications.

Stitched mat can be an economical alternative to woven or unidirectional tapes for hand layups or preforming. When

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III. Physical properties of standard ACF product forms

Specific surface area, m ² /g	700	1000	1500
Pore diameter, Å	17	20	21
Pore volume, mL/g	0.3	0.5	0.8
Toluene adsorption, wt%	22	38	62
Iodine adsorption, mg/g	900	1200	1500
Methylene blue decoloring, mL/g	...	130	260

used in a matched mold and impregnated by resin transfer molding (RTM) or reaction injection molding (RIM) techniques, the stitching prevents fiber washing or movement associated with the nonwoven mat during injection, and the stitching itself provides additional reinforcement of the composite. In the case of composite tooling, the stitched mat provides a uniform and efficient heat transfer surface for rapid heating and cooling, which is due in part to the low specific heat and density of carbon fibers. Close tolerances can be maintained through molding cycles because of the slightly negative coefficient of thermal expansion of carbon fibers.

Another application under development is using stitched carbon fiber mat as an abrasion-resistant undersurface for boats and canoes. Certain high-wear areas, for example, in the rear undersurface of a canoe, can be made less susceptible to damage from rocks and sand when stitched mat protects the primary reinforcing fibers.

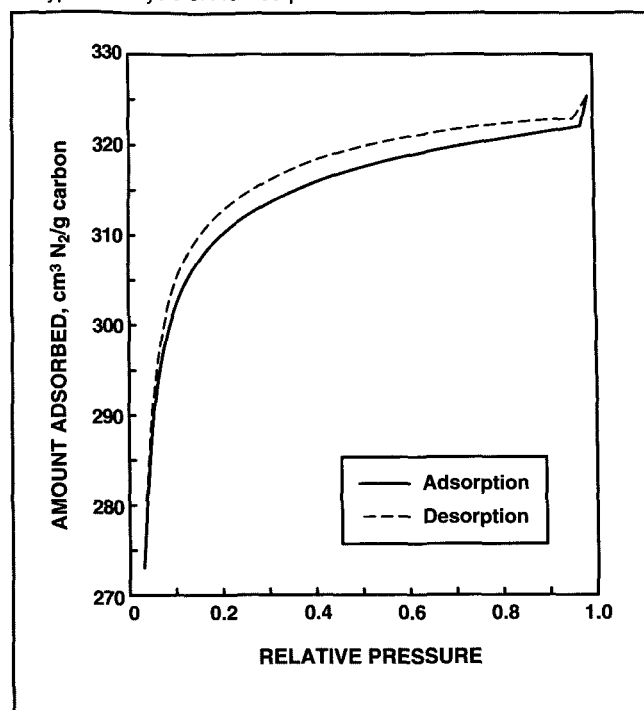
Pitch-based carbon-fiber paper or veil ranging in weights from 25 g/m² to 200 g/m² can be made in wet systems from chopped carbon fibers. Binders can be used that are compatible with the matrix system. Situated at the surface of a composite, carbon-fiber paper creates an electrically conductive layer for static dissipation. Effective electromagnetic interface and RFI shielding can be accomplished in composite materials for protecting sensitive electronic equipment. The uniform quality of carbon-fiber paper makes it an excellent surface finishing material for eliminating show-through of reinforcing fibers in the composite. Carbon-fiber veil is also useful in applications where corrosion resistance and abrasion resistance are required.

Needled felt is the most recent form developed from nonwoven mat. Consolidation of the nonwoven mat and needling together of multiple layers of nonwoven mat can be accomplished by punching a certain percentage of the fibers into the z-direction. The pull strength of the needled felt is many times greater than that of the nonwoven mat. Although the primary use of needled felt is for high-temperature furnace insulation in both rigid and flexible forms, evaluations are underway in carbon/carbon fiber composites for brake and ablative applications.

Activated carbon fiber

Considerable interest has developed recently in the use of activated carbon fiber (ACF) for a variety of adsorption applications (1-3). ACF can differ considerably from "normal" granular activated carbons (GACs). ACF exhibits rapid and efficient adsorption/desorption properties and is capable of

1. Typical analysis of ACF sorption isotherm



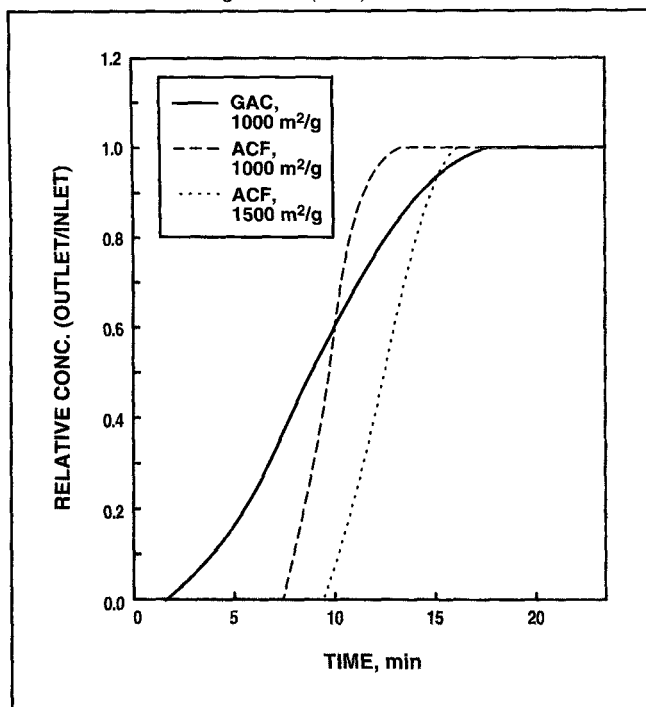
achieving surface areas in excess of 2000 m²/g. The availability of an activated carbon in fibrous form often simplifies article manufacturing, as the fiber can be uniformly dispersed or co-woven into molds or fabrics, or both. Because of these and other unique features, superior performance has been realized in a number of applications, including air purification, solvent recovery, deodorization, and water purification. Products are available as needled felts, papers, molded elements, milled fiber, chopped fiber, and nonwoven mat. Physical properties of ACF are listed in Table III.

Figure 1 is a representative sorption isotherm for an isotropic carbon fiber with a specific surface area of 1000 m²/g. The initial steep rise at low relative pressures followed by a leveling of the curve implies that the fiber is predominantly microporous (<2 nm). The desorption curve of the isotherm essentially replicates the adsorption curve. This suggests a simple pore structure (e.g., slit-shaped) within the fiber that is easily accessible from the outer surface (3). Because the pores of ACF are more accessible from the surface than those of GAC, the ACF can adsorb and desorb solvents and gases more quickly and efficiently.

An example of the effectiveness of ACF in an air purification application is illustrated in Fig. 2. The benzene breakthrough curves demonstrate superior performance of ACF relative to GAC. In addition, the 1500-m²/g ACF retarded the onset of benzene breakthrough more effectively than either of the 1000-m²/g activated carbons.

The superior adsorption/desorption properties of ACF in a solvent recovery application are shown in Fig. 3. For a given adsorption time, 1500-m²/g ACF adsorbed about three times as much Freon 113 as did 1000-m²/g GAC. Also, the ACF is able to desorb the entrapped solvent to completeness, at a significantly faster rate.

2. Benzene breakthrough curve (20°C)



In a variety of adsorption applications, activated carbon fiber products have demonstrated superior performance characteristics when evaluated relative to conventional granular activated carbon products. The availability of an adsorbent carbon in a fibrous form creates a unique opportunity for novel article design.

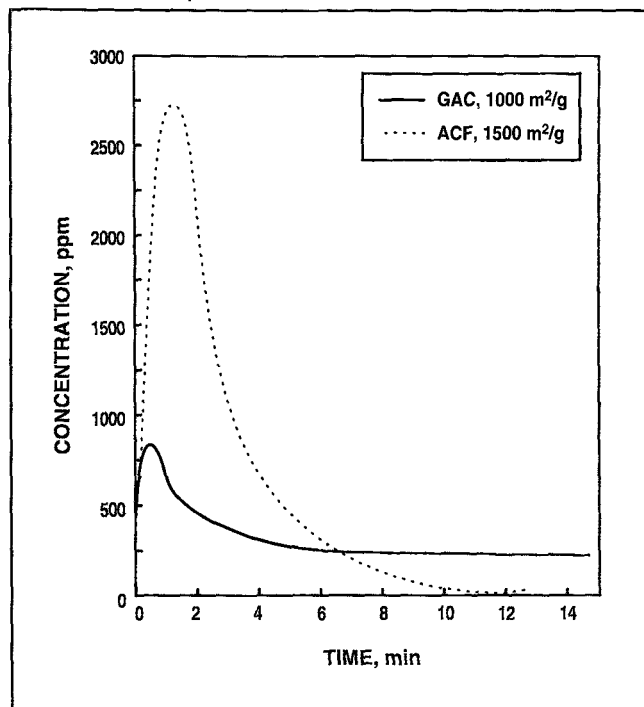
Abrasion-resistant polyester laminates

One of the most interesting applications for nonwoven, pitch-based carbon-fiber veil is its use as a surfacing veil in polyester laminates. Polyester systems are used to construct tanks, pipes, ducts, and numerous other products. In most cases, the ability of these materials to resist corrosion and abrasion is of utmost importance.

Carbon-fiber veil, glass-fiber veil, and a synthetic veil were all used for comparison in this work. Using American Society for Testing and Materials ASTM-581 guidelines, polyester laminates were fabricated using multiple layers of the various barrier veils along with a polyester resin system. In all cases, an effort was made to limit laminate thickness to 3.2 mm (1/8 in.). Each layer of the composite construction was saturated with resin and rolled with a weighted roller to remove air bubbles. The resulting laminate was allowed to cure for at least four hours at room temperature to obtain a cross-linked polyester product. All of these products were then post cured in an oven at 120°C for two hours. Samples were machined into test specimens and evaluated for abrasion resistance.

Table IV shows the results obtained in this study. Impact abrasion tests were performed using a relative comparison sandblasting technique. Taber abrasion test results were obtained using a Taber Abraser apparatus. Both of these testing methods measure abrasion resistance in terms of total weight

3. Freon 113 desorption curve



loss for each sample evaluation.

Results obtained by the Taber testing method indicate that pitch-based carbon-fiber veil is considerably more abrasion-resistant than "C" glass veil, polyester veil (Nexus), or PAN carbon-fiber veil. However, the impact abrasion results show that only Nexus veil and pitch carbon veil contribute to impact abrasion resistance. While the Nexus laminate showed the lowest weight loss by this impact method, it also had the highest fiber content.

Conclusion

Our discussion of pitch-based carbon fibers has focused on their use in filtration applications and abrasion-resistant plastic laminates. However, many other applications are being explored for low priced carbon fiber, including:

- Brakes: aircraft, industrial, automotive, racing, carbon/carbon fiber composites
- Friction materials: clutch plates
- Packings, gaskets, high-temperature insulation
- Plastics: carbon fiber composites with thermoplastics and thermosets, injection and compression molding, and reinforcement, shielding, and conductance
- Electrostatic dissipant: fabrics, carpets, circuit boards, electrical equipment
- Electromagnetic shielding and communications equipment: computers, typewriters, telephones
- Ablatives and ablative coatings, paints
- Battery electrodes

IV. Abrasion testing of polyester laminates

Laminate ^c system	Fiber veil, wt%	Taber abrasion ^a loss, wt%	Impact abrasion ^b loss, wt%
Resin only, no fibers	None	0.76	3.60
Seven layers of 0.9-oz/yd ² glass veil	5.2	0.78	5.70
Eight layers of 0.9-oz/yd ² Nexus veil	8.1	0.68	2.62
Five layers of 1.0 oz/yd ² pitch CF veil (PVA)	4.0	0.18	3.25
Four layers of 1.5 oz/yd ² PAN CF veil (PVA)	6.4	0.30	4.15

^aTaber test conditions: 1000 g weight, 1000 cycles, 14 min, H-22 Calibrade wheel. ^bSandblast conditions: 18-in. distance, 30 min, 50 psi, glass oxide beads, 90° angle of impact. ^c"C" glass veil, Nexus synthetic polyester veil, pitch-based carbon fiber veil, PAN-based carbon fiber veil, and Hetron 992 polyester resin were used in this study.

- High temperature, chemical inertness
- Cement reinforcement
- Conductive paints
- Heating tapes, strips, walls

- Fire retardants, fire protection equipment, clothing.

Some of the most promising of these uses are in friction materials, packings, gaskets, ablatives, fuel cells, injection molding compounds, and static dissipant materials (4, 5). □

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