CARBON FOAMS

Photo above shows CFoam carbon foam exposed to a 1650°C (3000°F) acetylene flame.

Engineered carbon foams are lightweight, high-temperature materials with tailorable strength and resistance to fire and chemicals.

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Carbon and graphite foams offer properties such as chemical inertness, ultra high service temperatures, low coefficient of thermal expansion, and tailorable electrical/thermal conductivity. Carbon foams generally fall into two categories – graphitic and non-graphitic. The graphitic carbon foams offer high thermal and electrical conductivity, but considerably lower mechanical strength than the non-graphitic foams. Non-graphitic carbon foams are generally stronger, act as thermal insulators, and cost far less to manufacture.

Graphitic foams typically are produced from petroleum, coal tar, or synthetic pitches. These precursors may be easily converted to the highly ordered graphitic crystal structure during the manufacturing process. Carbon foams produced directly from coal or organic resins are generally highly amorphous and thus do not form the graphitic microstructure.

Although the highly graphitic foams offer unique properties such as high thermal and electrical conductivity and low density, they are currently not produced competitively on either a cost or a volume basis. Therefore, these foams are best suited for low volume, high-end applications such as heat exchangers and thermal management components.

On the other hand, carbon foams made from less expensive precursor materials such as coal are currently being made on a larger scale, and are now competitively priced in such applications as composite cores, fire and thermal protection, composite tooling, electromagnetic shielding, and radar absorption. These applications depend on one or more critical characteristics such as weight, mechanical properties, fire resistance (See photo above), low smoke toxicity, or coefficient of thermal expansion (CTE).

This article focuses on non-graphitic carbon foams, describing process technology and applications.

Process technology

To make carbon foam, high pressures and temperatures thermally decompose the raw material, which is typically coal. The process must be carefully controlled, as the carbon foam properties depend on both the raw material characteristics and the selected process conditions.

Carbon and graphite foams are usually made from synthetic polymeric stock that is not very different from the materials used to make pencil leads or electric furnace electrodes. In another approach, coal is the feed stock. When the stock is subjected to specific pressures and temperatures, foaming gases or volatiles within the stock create carbon bubbles that impinge on each other and fracture. The result is an open cell foam.

Through careful control of the gas evolution during this process, the shape, size, and number of pores can be manipulated. After the foaming process has been completed, a secondary heat treatment is applied. During this step, any remaining volatile material is removed, and properties such as electrical conductivity or electromagnetic properties can be tailored.

The finished foam material is essentially an interconnected cellular network of open pores with the mechanical properties dictated by the density and by the thickness of the pore walls. Comprised almost entirely of carbon, the foams are chemically inert to almost all other materials, are noncombustible, and have unique electrical and thermal properties.

Foams can be made with uniform small or large pores, or a combination of large and small pores. In addition, functionally graded carbon foams can be produced with a surface of one pore size and an interior of another. A photomicrograph and scanning electron micrograph of a carbon foam are shown in Fig. 2.

As an example, commercially available carbon foam produced from coal has typical properties shown in the Table. Additionally, carbon foams with densities of 3, 7, and 12 lb / ft^3 (0.048, 0.112, and 0.192 g / cm^3) are currently under pilot scale testing and will soon be available in production quantities. Preliminary results indicate compressive strengths of about 200 psi for carbon foam with densities of 3 to 7 lb / ft^3 (1.4 MPa for density 0.048 and 9.112 g / cm^3) and up to 500 psi for density of 12 lb / ft^3 (3.5 MPa for density 0.192 g / cm^3). Strengths over 6000 psi have been demonstrated where the density is approximately 50 lb / ft^3 (41 MPa for density 0.8 gm / cm^3).

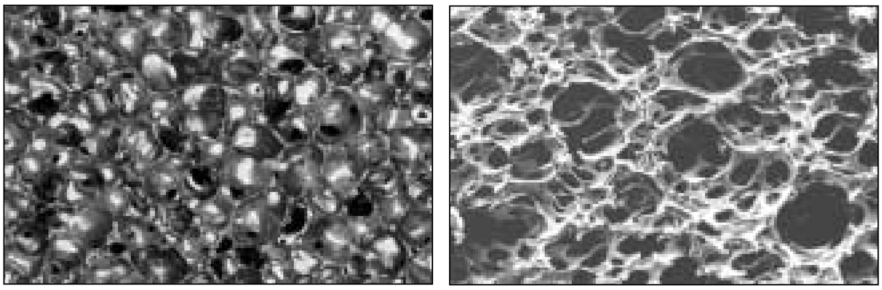

Fig. 2 — Photomicrograph (left) and SEM micrograph (right) of carbon foam.

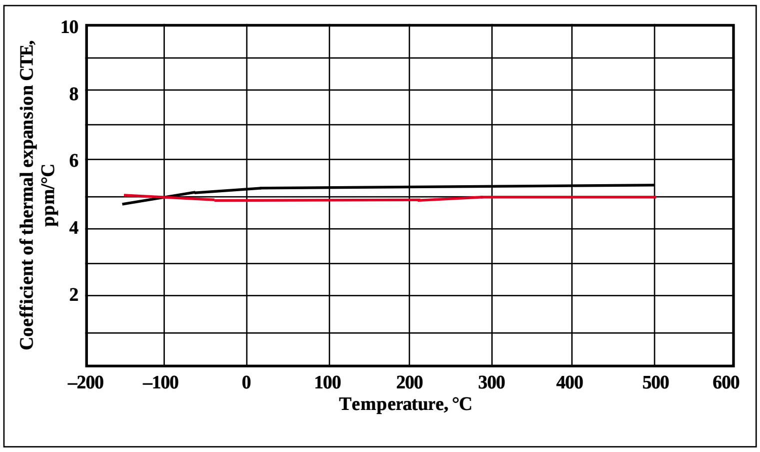

Fig. 3 — CFoam carbon foam shows nearly constant coefficient of thermal expansion over a wide temperature range.

Composite tooling

Aircraft components, missile surfaces, and structures made of carbon fiber-reinforced thermoset and thermoplastic resins provide higher strength-to-weight ratio and less susceptibility to corrosion and fatigue than metals. However, tooling for these materials is critically important: It must be rigid, durable, and compatible with the CTE of the composite material. Typically, advanced fiber-reinforced composites are laid up at room temperature, but are cured at temperatures over 150°C (300°F). Consequently, it is difficult to match the expansion of a carbon composite with anything other than another carbon composite, or specialty metal alloys such as Invar.

Fortunately, the CTE values of carbon foams are

Typical properties of CFoam carbon foam

Property	CFoam 17	CFoam 25
Nominal density	17 lb / ft^3, 270 kg / m^3, 0.27 g / cm^3	25 lbs / ft^3 , 400 kg / m^3 , 0.4 g / cm^3
Compressive strength	>700 psi, >4.8 MPa	>2000 psi, >15 MPa
Compressive modulus	30 ksi, 200 MPa	80 ksi , 550 MPa
Tensile strength	>250 psi, >1.7 MPa	>500 psi , >3.5 MPa
Tensile modulus	30 ksi, 200 MPa	80 ksi, 550 MPa
Shear strength	>200 psi, 1.4 MPa	>300 psi, 2.1 MPa
Coefficient of thermal expansion (RT to 500°C)	2.7 x 10^{-6} / °F, 5.0 x 10^{-6} / °C	3.2 x 10^{-6} / °F, 5.8 x 10^{-6} / °C
Thermal conductivity	0.25 to 25 W / m °K	-
Operational temperature	1200°F Air, 650° C Air 5500°F Inert, 3000°C Inert	-
Electrical resistivity	0.01 to 10^7 ohm-cm	-
Fire resistance	Passes: ISO 1182, ASTM E1354, ASTM E 1515, MIL-STD-1623, Coast Guard IMO FTP Code Part I and III	-
Noise reduction	0.1 to 0.4 absorption coefficient	-

close to those of carbon fiber prepregs (Fig. 3), and densities of carbon foam are much lower than those of aluminum, steel, or nickel-iron alloys. The reduction in tooling mass provided by carbon foam has many advantages over other materials, including easier tool handling, repair ability, and shorter machining and curing times. An example of a prototype carbon foam composite tool is shown in Fig. 4.

The ease with which carbon foams can be machined also contributes to the success of composite tooling. Intricate shapes can be machined in little time with standard equipment, as shown in Fig. 5.

Foam-core composites

Currently, lightweight core materials are needed for applications such as aircraft and ship interior panels and non-structural bulkheads, structural insulation, sound absorption panels, and radar or electromagnetic shielding / absorption panels for ship topside structures. Although many materials may offer one or two properties that exceed those of any other material for these panels, no single material has been deemed suitable for all.

For example, polymer foams, honeycombs (polymer, paper, or metal), and balsa wood exhibit excellent specific strength (high ratio of strength to density). Up to now, in applications that must resist fire or chemicals, only metal honeycombs would likely be suitable, but at a very high cost.

However, the new low-cost carbon foams have shown promise in replacing existing core materials where stringent fire regulations cannot be met with other materials. Additionally, they are suitable for defense-related applications in which fire resistance must be combined with low weight and radar / electromagnetic shielding and absorption.

Application range

Carbon foam has shown promise for electromagnetic shielding and absorption for reasons that are both mechanical and electrical in nature. Electromagnetic shields are typically made from conductive metals, which are heavy and corrode in salt water. For instance, a carbon foam shield must be thicker than a conventional copper shield, but its lower areal density will make the weight of both shields nearly equal.

The primary electrical advantage of carbon foam is that its permittivity is tailorable over a wide range of values. For shielding applications, this wide range of conductivity means that carbon foam can be made conductive enough to make an effective shield.

CFoam carbon foam has passed tests as a noncombustible material under ISO 1182, ASTM E1354, and ASTM E162 Cone Calorimeter and Radiant Panel standards. ISO 9705 and UL 1709 room-corner burn tests are currently being carried out. Although carbon foam does not burn, it does slowly oxidize at elevated temperatures in the presence of oxygen. In applications above 650°C (1200°F) for an extended period of time, surface coatings of refractory metals or ceramics may be easily and inexpensively applied by conventional thermal spray techniques.

EMI shield testing has recently been conducted for CFoam, and standard shielding parameters for certification were run from 100 MHz thru 18 GHz, with successful results. Further testing in this area is expected to provide the military with a lighter, more corrosion-resistant material than is currently available.

Fig. 4 — CFoam composite tool with low coefficient of thermal expansion.

Fig. 5 — Machinability of carbon foams is shown on this mirror backing.

Potential applications

Low-cost carbon foams have also been identified as possible candidates in applications such as spaceborne mirror substrates and thermal protection; fuel cell anode / cathode gas diffusion layers and catalyst support; and lithium-ion batteries. Currently, research into these areas is ongoing with promising results. Touchstone has developed a working fuel cell and batteries, and is in the process of creating lightweight mirrors and thermal protection panels with CFoam technology.

As materials engineers increasingly focus on lower costs and improved performance, carbon foams will surely be selected more frequently, resulting in the generation of additional service data. Through this growth, a database of properties will continue to expand and be made available to overlapping industries in the next decade. Moreover, this growing database will be combined with ongoing research into ways of improving the mechanical properties of carbon foams through improved processing and reinforcing materials. ■

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