STRUCTURE AND PROPERTIES OF CARBON FOAMS DERIVED FROM PITCH AND PHENOLIC PRECURSORS

J. W. Hager[*], A. K. Roy[**] and D. P. Anderson[**]

* P.O Box 82, Dayton, OH 45434
** University of Dayton Research Institute, 300 College Park Avenue, Dayton, Ohio 45469-0168

INTRODUCTION

Carbon fiber reinforced composites have become well established as structural materials and are valued, particularly in aerospace applications, for their high mass specific mechanical properties. In fact, the prevailing concept of advanced composites accepts the notion that these structural materials will by definition be carbon fiber reinforced.

The extraordinary properties of advanced carbon fibers are directly attributable to the orientation of liquid precursor molecules in the filament spinnerets, and the preservation of this alignment in the graphitic morphology of the resultant carbon fiber artifact If it were possible to control graphitic morphology as successfully in other carbon artifacts, it is possible to conceive of carbon reinforced solids based on these structures. Carbon foam artifacts derived from blown liquid precursors are an example of an interconnected microstructural network in which there can be local control of morphology.

The mechanical properties of foams can be predicted from the properties of the bulk material and the porosity using relationships given by Gibson and Ashby [1]. On this basis, the performance limits of hypothetical graphitic foams and foam core sandwiches derived from anisotropic pitch have been favorably compared with conventional composites and honeycomb-core sandwiches in stiffness-critical applications [2,3]

The objective of this project is to compare the microstructures and properties of carbon foams derived from thermosetting and thermoplastic precursors. Thermosetting polymers such as phenolic are known to yield glassy carbon artifacts following pyrolysis while thermoplastic precursors such as anisotropic pitch yield graphitic morphology [4]. Since morphology plays a significant role in the determination of mechanical and physical properties of the carbon char, it is suspected to have a signicant effect on the properties of the carbon foams.

EXPERIMENTAL

A detailed description of the processing of carbonaceous mesophase pitch into graphitic foam is given elsewhere [5,6]. The mesophase pitch used in these studies is produced by catalytic polymerization of naphthalene by Mitsubishi Gas Chemical Co. and is marketed under the trade name AR Resin. In the blowing process, nitrogen gas at 1000 psig is first dissolved in the pitch which has been heated to 300°C. Following a gas saturation period, the pressure is released and the resultant foam is rapidly cooled. Oxidation stabilization of the foam is performed in an oven with circulating air at 220°C for forty-eight hours. The foam is then carbonized in a nitrogen-filled retort by heating to 800°C using a heating rate of one degree per minute. Graphitization is performed in a vacuum induction furnace at a temperature of at least 2800°C.

The processing of phenolic into carbon foams proceeds as follows: An open-celled phenolic foam with an average cell concentration of 100 pores per inch was acquired from American Foam Technology. The foam is blown using a two part mixture which foams spontaneously upon contact and reaction of the two components. The as received foam has a density of approximately 0.25 g/cm^3., reflecting porosity and pore size similar to that of the graphitic foam. Since the phenolic is a thermoset, no oxygen stabilization is required. Carbonization and graphitization are performed under identical conditions to those experienced by the graphitic foams.

Following processing, the foams were subjected to a battery of microstructural evaluations and a series of compression tests.

RESULTS AND DISCUSSION

The fracture surface of a typical ex-pitch foam following graphitization is depicted at two magnifications in the SEM micrographs of Figure 1. Using image analysis on the micrographs, we were able to quantify the porosity at 71%. The cells appear uniform with an average cell size of about 80

µm. The cell density was evaluated by the method described by Kumar and Weller [7] and was determined to be about $10^8/cm^3$. Wide angle x-ray diffraction of the crushed foam sample revealed a highly graphitic structure. When polished surfaces of the foam samples are viewed in a polarizing microscope, preferential alignment of the graphite crystallites in the cell walls of the bubbles is observed.

The optical and electron micrographs of the ex-phenolic carbon foams appear very similar to the graphitic foams. This is not surprising since both types of foam possess similar bubble sizes and have similar porosities. As expected, the x-ray diffraction patterns for the graphitized ex-phenolic carbon foams do not exhibit the sharp peak structure of the ex-pitch foams. These glassy carbon structures also do not exhibit the same type of optical activity in the cell walls.

Compression testing of the foams resulted in brittle fracture and crushing of both types of foams. In the linear portion of the stress-strain curve, the modulus of the foam was found to be 834 MPa (about 120 kpsi). Using the relationship of Gibson and Ashby described earlier [1], one can estimate the elastic modulus of the bulk carbon material. Since the porosity for this foam is about 70%, the elastic modulus of the glassy carbon is estimated to be about 9.3 GPa (1.3 Msi).

CONCLUSIONS

As predicted by the Gibson-Ashby relationship, the stiffnesses of carbon foams are much greater than for more familiar polymer foams. Because of their low densities, high intrinsic stiffness and high temperature stability, carbon foams may become suitable constituents of hybrid composite structures [8].

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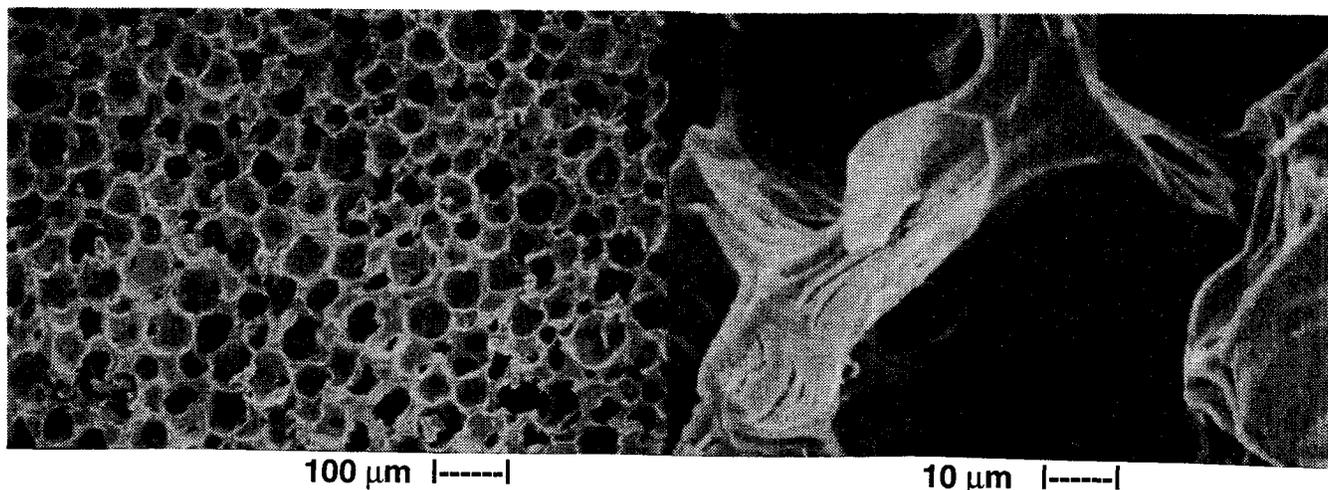
100 µm |------| 10 µm |------|

Figure 1 Scanning electron micrographs of graphitic carbon foams derived from anisotropic pitch at two magnifications.