Characterization of Electrolessly Plated Graphite Foams with Particle Additions

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Abstract

With a low density and high bulk thermal conductivity, graphite foams are ideal for thermal management systems such as computer heat sinks, radiators, and heat exchangers. Previous work has shown it is possible to improve the foams performance by opening the porosity with nanoparticle additions in the foams precursor, an oil based mesophase pitch.[1] The open porosity allows more fluid, such as air or water, to pass through the foam and carry heat away. The original study, performed by Jennifer Mueller at Oak Ridge National Labs (ORNL), considered the concentrations of nanoparticle's used. The present study looked to determine the effects of using different types of nanoparticles at a range of sizes from the nano- to micro- level. The study began by adding, respectively, silver, ceria, alumina, tungsten, and nickel to different batches of mesophase pitch at a single weight percent concentration to create graphite foams with a significant amount of continuous porosity. The pitch was foamed, carbonized, and graphitized. The final foam products were then measured in a variety of ways including thermal conductivity, permeability, and scanning electron microscope (SEM). As a side project, an electroless copper plating solution was passed through the foams to determine if a continuous and uniform copper coating could be built up. The copper coating that was eventually obtained coated the foam walls without filling the open porosity and may help to increase the foams solderability, strength, durability, and corrosion resistance.

Keywords: Carbon, Foam, Thermal, Electroless

1. Introduction

Graphite foams are an excellent material for use in thermal management systems such as computer heat sinks, radiators, and heat exchangers. The graphite ligaments themselves have a thermal conductivity of >1700 W/mK.[2] As can be seen in Figure 1, they are usually aligned parallel to the pore structure, which gives the bulk foam a thermal conductivity on par with aluminum. The foams also exhibit a very low density of approximately 0.5g/cm^3, one-fifth that of aluminum.[2]

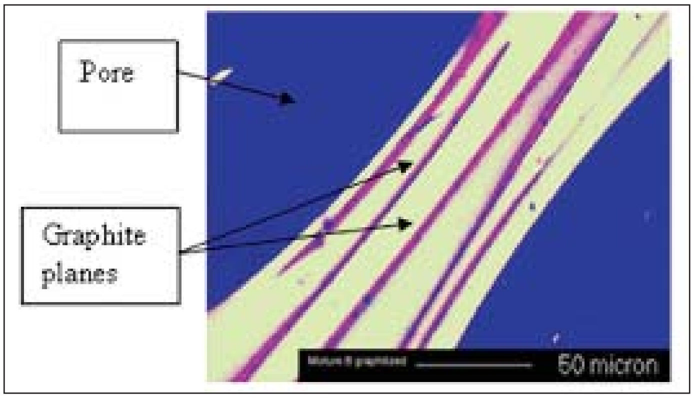


Figure 1. Optical image of graphite foam showing highly aligned graphite planes

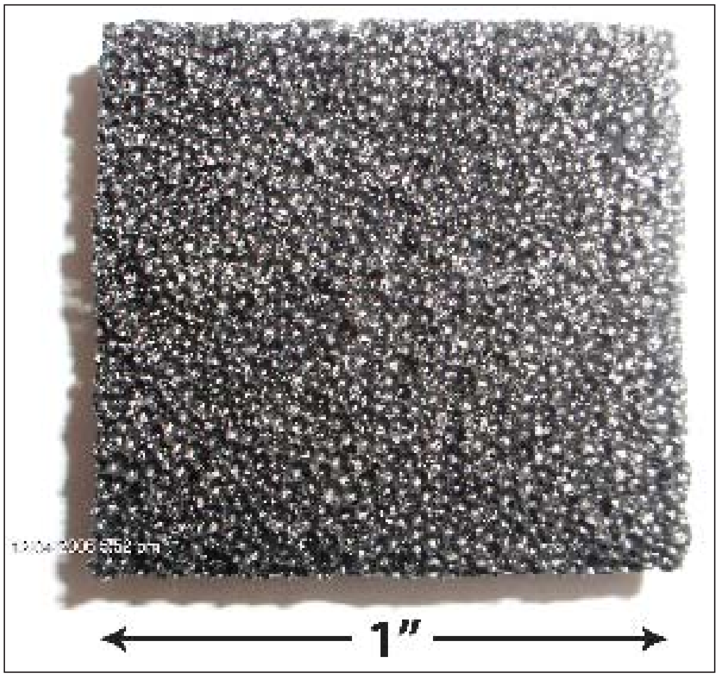


Figure 2. Photograph of graphite foam

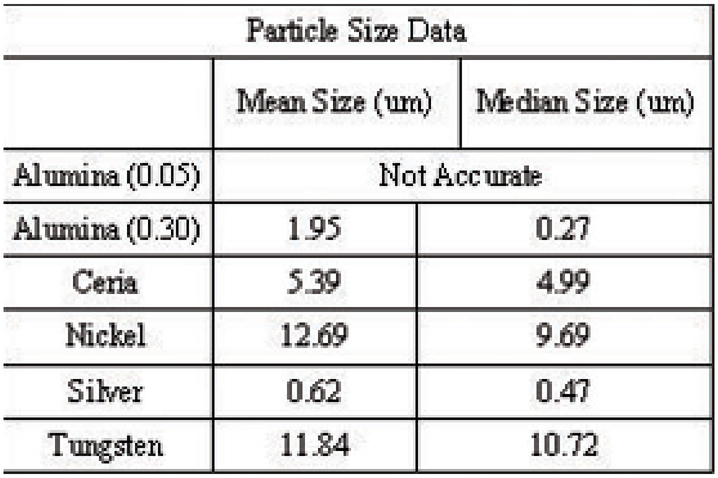
Previous work has shown that the addition of carbon nanoparticles to the foam precursor, an oil based mesophase pitch, will act as nucleation sites for pore windows during the foaming process. The open porosity will create a more permeable foam with a greater capacity to let fluid move through it; this will create a better performing system with greater overall efficiency. Whereas the previous work looked at the effects of varying the concentrations of the nanoparticles, the new work looked to determine how particles of different materials and varying sizes at the same concentration, 5 weight percent, would effect the pore structure.

A side project looked to explore the feasibility of passing an electroless copper plating solution though the foam with the increased open porosity. A copper layer could help to improve the foams solderability, strength, durability, and corrosion resistance. The electroless plating side project culminated in a continuous and uniform copper coating throughout the surface of the foam without filling the open porosity.

2. Procedure

2.1 Foam Preparation

Ceria, nickel, tungsten, silver, and alumina particles were each added to the mesophase pitch precursor, at 5 weight % concentrations, and processed to create graphite foam. Their measured particle size can be seen in Table 1 where the particles ranged from 11um to 50nm



Particle Size Data		
	Mean Size (um)	Median Size (um)
Alumina (0.05)	Not Accurate	
Alumina (0.30)	1.95	0.27
Ceria	5.39	4.99
Nickel	12.69	9.69
Silver	0.62	0.47
Tungsten	11.84	10.72

Figure 3. Particle size data

(the analyzer used was unable to get an accurate reading on the 50nm alumina because the particles were too small). The pitch-particle mixture was heated in an oxygen-free atmosphere to approximately 50°C above the pitch's softening point. The pressure and temperature in the furnace were then raised after the pitch had melted. In its molten stage, the pitch formed bubbles at nucleation sites, and mesophase crystals formed. The mesophase pitch began to polymerize and the bubbles were trapped in place creating a foam structure. After the foaming process the material was carbonized by slowly ramping a furnace up to 1000°C. Finally, the carbonized foam was graphitized at 2800°C in an inert atmosphere of nitrogen and argon.

2.2 Permeability

Tests were conducted at Oak Ridge National Laboratory on an apparatus developed to measure the face velocity of air flowing into and out of the system, thus giving a pressure drop. A (2 x 2 x 0.25 inch) block of graphite foam was placed into the system and the lid tightly sealed. The flow rate was manually adjusted to obtain face velocities varying from 0 to 300 Ipm and the corresponding pressures were recorded.

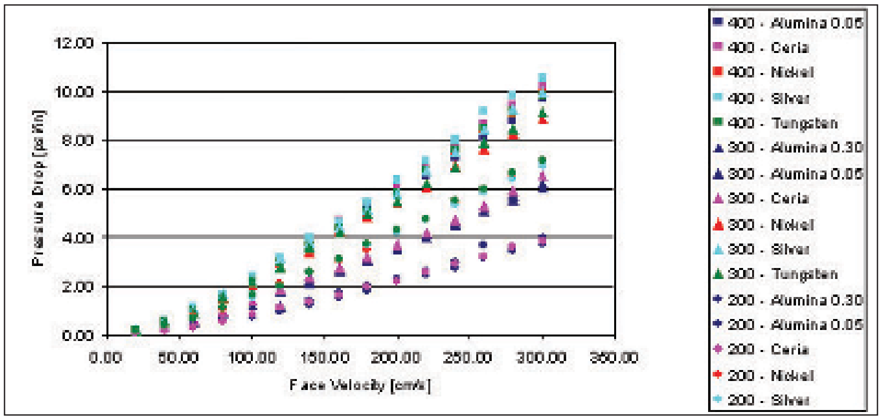


Figure 4. The effects of the type of particle and processing pressure on the foams permeability

2.3 Scanning Electron Microscopy (SEM)

Samples were viewed with a LEO 1550 Field Emission SEM with an accelerating voltage of 5 kV to view the graphitized samples. Since the carbon foam is already electrically conductive, the samples did not need to be sputtered with a metallic coating before being analyzed.

2.4 Electroless Plating

Electroless plating consists of three major steps: sensitizing, activating, and plating. Sensitizing helps to gather all the readily oxidized material on the surface. The activating step lays down a layer that provides catalytic nucleation sites. The final plating stage builds a uniform autocatalytic layer on the surface that will continue to thicken as long as new solution is passed over the surface.

2.5 Thermal Conductivity

Thermal diffusivity was measured using a xenon flash diffusivity technique and thermal conductivities were calculated using Equation 1.[5] The technique involves a bulb flashing for less than 1 millisecond and releasing a small amount of heat on one side of the sample. An IR camera at the other side measures the change in temperature.

$$\alpha = \frac{\kappa}{\rho C_p} \qquad (1)$$

Where:

α is the thermal diffusivity

κ is the thermal conductivity

ρC_p is the heat absorbed by the material

3. Results and Discussion

3.1 Particle Additions

The foams that were processed at higher processing pressures had a higher pressure drop, meaning there was less open porosity, compared to the foams processed at lower pressures for a given material (Figure 4). Interestingly though, the ceramic particles caused more open porosity than the metal particles at the two lower processing pressures, but were about equal at the 400psi processing pressure.

At the 400 psi pressure level, very little change can be seen in the thermal conductivity of the foams. The 200 and 300 psi runs, however, show significant differences between the metal and ceramic particles. See Figure 5.

The larger of the alumina and silver particles had respective median sizes of 0.3um and 0.5um. The nickel and tungsten particles had a median size of approximately 10um. As can be seen in Figure 5 below, the trend in these numbers is not consistent with the trend in thermal conductivity. This means that cheaper particles of larger sizes can be used to increase the thermal conductivity just as effectively as the smaller particles.

3.2 Copper Plating

As can be seen in Figure 6 a copper coating was obtained. The EDS analysis in Figure 7 shows that the pores are indeed copper while the ligaments remain pure carbon. Figure 8 shows a picture of the copper plated foam taken with the SEM. The non-coated pores could have occured either because no plating solution reached the pore or the copper fell out during the cutting process.

4. Conclusions

Adding particles to the foam precursor helped to increase the amount of open porosity and thus allow

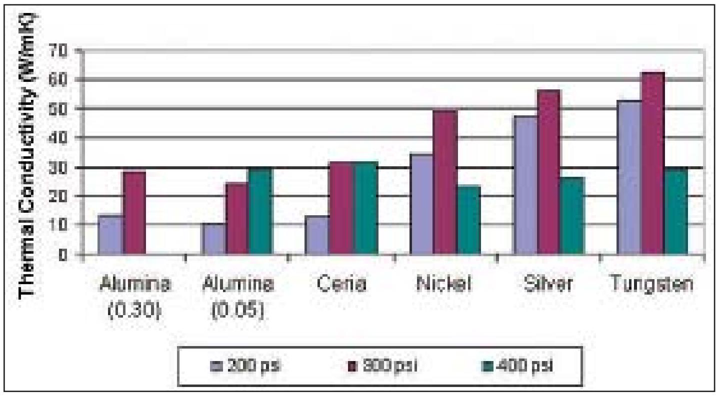


Figure 5. The effect of the type of particle on the thermal conductivity

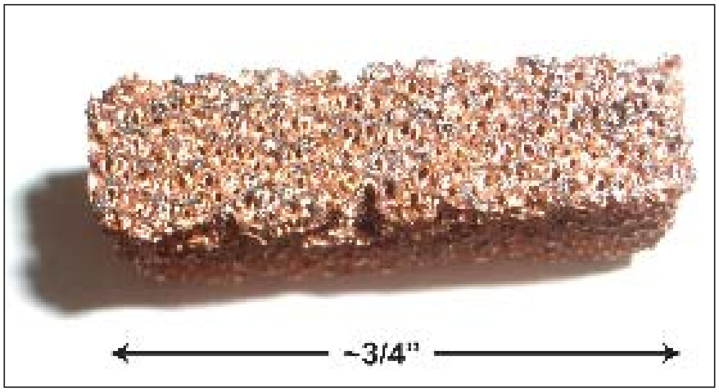
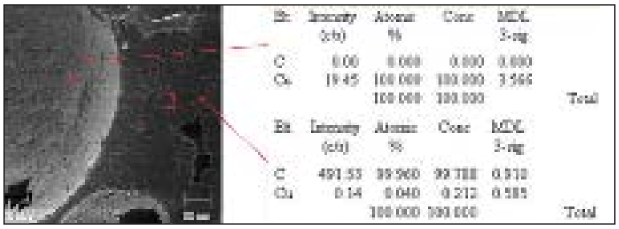


Figure 6. The inside of a piece of foam that was coated with copper



Elt	Intensity (c/s)	Atomic %	Conc	MDL 3-sig	
C	0.00	0.000	0.000	0.000	
Cu	19.45	100.000	100.000	3.566	
		100.000	100.000		Total

Elt	Intensity (c/s)	Atomic %	Conc	MDL 3-sig	
C	491.53	99.960	99.788	0.918	
Cu	0.14	0.040	0.212	0.585	
		100.000	100.000		Total

Figure 7. EDS analysis showing the pore as 100% copper and the ligament as 99.96% carbon

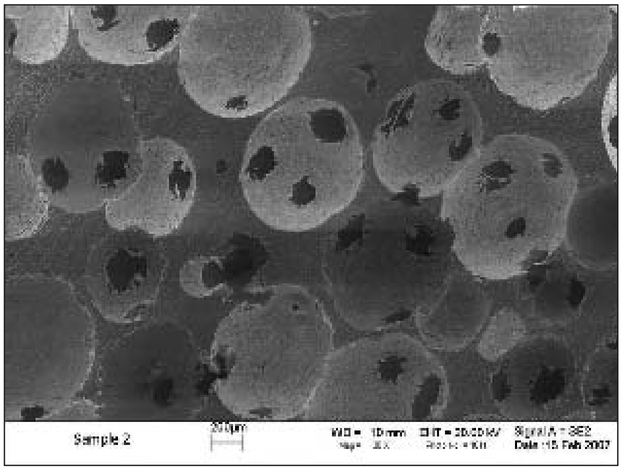


Figure 8. An SEM image showing numerous pores coated with copper

more heat to be dissipated into the atmosphere more quickly. The specific properties of the particles that affect the amount of porosity have yet to be determined, but there is a very clear trend that at lower processing pressures (less than 400 psi), ceramic particles have a much greater effect than metal ones. Thermal conductivity of the foams was also aided by the addition of particles at the lower processing pressures, but the specific properties that are most important are still unknown.

The feasibility of coating the foam with a uniform layer of copper was shown. Other plating materials should be possible but at this point are untested.

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About the Author

Michael Asaro is a senior at Virginia Polytechnic Institute and State University in Blacksburg, VA. After graduation this spring he will begin graduate work in Materials Science and Engineering at Virginia Tech as well as a career at Nanosonic, Inc., a company also located in Blacksburg.