CHARACTERIZATION OF ELECTROLESSLY PLATED GRAPHITE FOAMS WITH PARTICLE ADDITIONS

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Abstract

This project investigates the feasibility of electrolessly plating a thin, uniform copper coating on modified graphite foam, a highly conductive material used in applications such as heat exchangers, radiators, and evaporative cooling systems. Previous research shows that the addition of nanoparticles to graphite foams significantly increases the amount of open porosity in the material. Therefore, the permeability increases, allowing the plating solutions to permeate the foam more easily. In this study silver, ceria, alumina, tungsten, and nickel particles were added to mesophase pitch at the same weight percent concentrations and processed to create graphite foams. A characterization study was performed both before and after the foams were electrolessly plated with a copper layer throughout the thickness of the foams. Findings include images from a scanning electron microscope as well as the impact of the copper coating on the heat transfer and permeability of the foam.

Introduction

With low weight and very high thermal conductivity, graphite foams exhibit many valuable properties for thermal applications. The foam has a high capacity for bulk thermal conductivity due to its structure of highly aligned graphite planes that typically run parallel to the pore structure as seen in Figure 1. These graphite ligaments have extremely high thermal conductivity, greater than 1700 W/mK. With the material's low density and high ligament conductivity, graphite foams exhibit similar bulk thermal conductivity to that of aluminum but at 1/5th the weight.

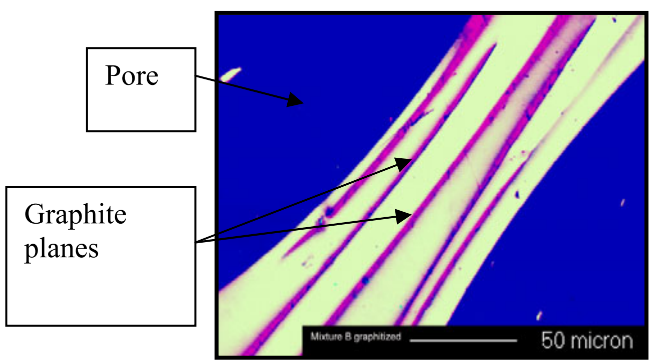

Figure 1. Optical image of graphite foam showing highly aligned graphite planes

The foams are typically used in applications such as air to air and air to water heat exchangers, radiators, and evaporative cooling systems for computers. However, the performance of the foams is limited due to the large amount of closed porosity in the foam, restricting its permeability and heat transfer capabilities. Increasing the amount of open porosity significantly improves the material's performance in these applications by increasing the thermal capabilities, permeability, and overall efficiency of the system.

Previous research shows that the addition of nanoparticles to the mesophase pitch precursor creates foam with more open porosity, and therefore increased permeability. The earlier study involved carbon nanoparticles at varying concentrations, whereas this study involved one concentration of 5 weight percent of different types of particles.

Knowing particle additions creates a foam with more open porosity and increased permeability, a study was conducted to find if these foams could be copper coated throughout its thickness using an electroless plating technique. A uniform copper coating throughout the foam could enhance solderability, strength, durability, and corrosion resistance.

Procedure

Foam Preparation

Ceria, nickel, tungsten, silver, and alumina particles were added to the mesophase pitch precursor and processed to create graphite foam. The mesophase pitch precursor was heated in an oxygen-free atmosphere to approximately 50 °C above the pitch's softening point. The pressure and temperature in the furnace are raised after the pitch has melted. In its molten stage, the pitch forms bubbles at nucleation sites, and mesophase crystals form. The mesophase begins to polymerize and the bubbles are trapped in place, creating a foam. After the foaming process, the material is carbonized up to 1000 °C, typically at a very slow rate. Finally, the carbonized foam is graphitized at 2800 °C in an atmosphere of nitrogen and argon.

Electroless Plating

The foams were electrolessly plated using three major steps, which were sensitizing, activating, and plating. The sensitizing step adsorbed the readily oxidized materials to the surface, and the activating stage provided a catalytic surface with nucleation sites. The final plating stage deposited a uniform layer of copper on the surface of the material.

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.

Permeability

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

Heat Transfer Coefficient

In the same apparatus as the permeability tests, heat transfer was studied through measuring the heat dissipated, air inlet, air outlet, and heater temperatures. First the log mean temperature difference was calculated using equation 1 (Klett and McMillan), and then, the heat transfer coefficient was calculated using equation 2 (Gallego and Klett, 2003).

$$\Delta T_{LM} = \frac{T_e - T_i}{\ln\left(\frac{T_h - T_i}{T_h - T_e}\right)}$$

Equation 1. Log mean temperature difference

where:
T_e is the exit air temperature
T_i is the inlet air temperature
T_h is the heater temperature

$$h = \frac{q}{A\Delta T_{LM}}$$

Equation 2. Heat transfer coefficient

where:
h is the heat transfer coefficient
q is the heat dissipated
A is the area of the foam touching the heater

Results and Discussion

After electrolessly plating the graphite foams, each were cut to see if the copper coating fully infiltrated the thickness of the foam. The cross section of the foam as seen in Figure 2 shows that the copper coating plated throughout the thickness.

Figure 2. Cross sectional view of electrolessly plated graphite foam

Scanning Electron Microscopy

A scanning electron microscope was used to view each of the foams, and an Energy Dispersive X-ray Spectroscopy (EDS) analysis showed that the pores were 100% copper and ligament was 99.96% carbon as seen in Figure 2.

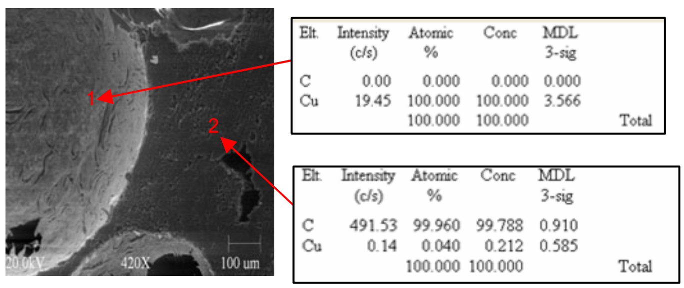

Figure 3. Energy Dispersive X-ray analysis showing pores are 100% copper

Figure 3 shows a large number of pores coated with copper. A possible explanation for the uncoated is that the copper might have fallen out of the pore during the cutting of the foam or that closed porosity prevented the plating solution from penetrating a pore. Also through using the SEM, the coating was too thin to measure and was in the nanometer range.

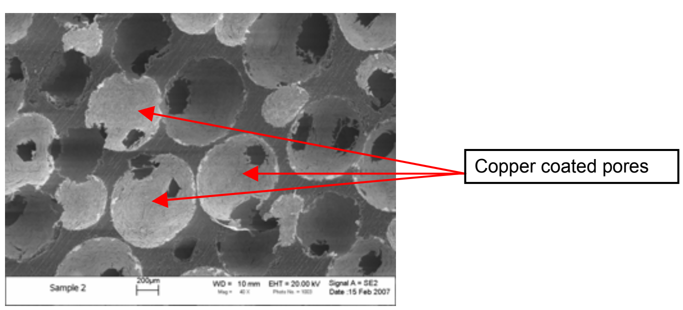

Figure 4. SEM image indicating a large number of pores coated with copper

Permeability

The foams with the metallic coating had a lower pressure drop compared to the uncoated foams (Figure 5). This indicates an increased permeability, which is most likely explained by the coating creating a more laminar flow rather than turbulent.

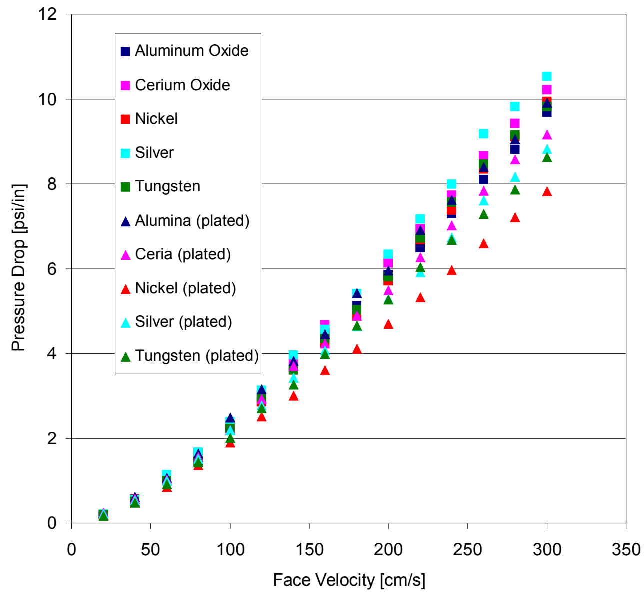

Figure 5. Copper coated foams had lower pressure drops than uncoated foams, indicating increased permeability

Heat Transfer Coefficient

Because the copper coating is only in the nanometer range, the heat transfer coefficient did not change with the copper coated foams compared to the uncoated foams (Figure 6). Even though the thermal conductivity of copper (400 W/mK) is higher than the bulk thermal conductivity of the graphite foams (183 W/mK), the thermal conductivity of the graphite ligaments is significantly higher (1700 W/mK). Therefore, the heat travels primarily through the graphite ligaments, and the thin copper coating has no effect.

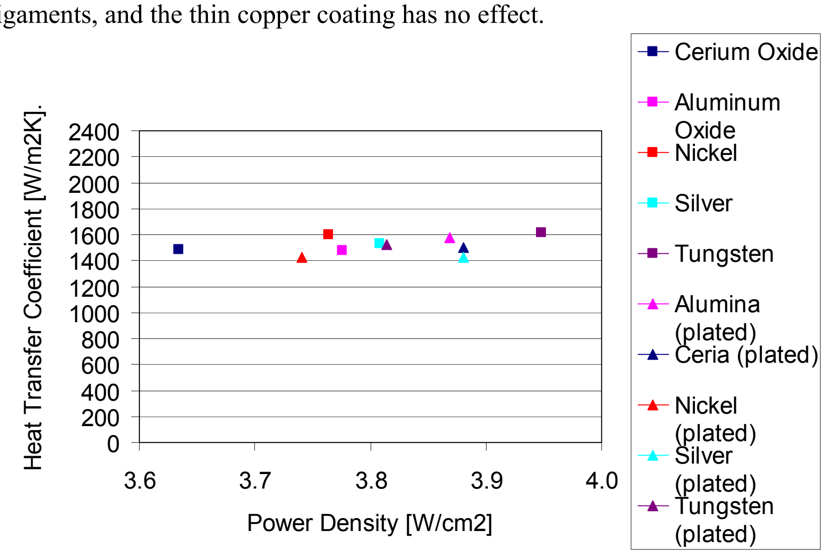

Figure 6. The heat transfer coefficient of coated and uncoated foams were similar

Conclusions

The feasibility of electrolessly plating graphite foams with copper was shown. The thin metallic coating had little effect on the heat transfer coefficient compared to the same foams tested before the coating was applied. The permeability increased slightly with the metallic coating, which was most likely due to creating a smoother surface and more laminar flow.

References

Gallego, Nidia C. and Klett, James W. 2003. Carbon Foams for Thermal Management. *Carbon* 41: 1461-1466.

Klett, James W. High Thermal Conductivity Foams One Pager. Available at: http://www.ms.ornl.gov/researchgroups/CMT/cmt.htm, Accessed on October 12, 2006.

Klett, James and McMillan, April. Modeling Convective Heat Transfer with Graphite Foams. Available at: http://www.ms.ornl.gov/researchgroups/cmt/foam/Convective%20Heat%20Transfer.pdf. Accessed on April 2, 2007.

Klett, James W. High Conductivity Graphite Foams and Applications." Available at: http://www.ms.ornl.gov/researchgroups/CIMTECH/foam/one-pagers.pdf, Accessed on April 2, 2007

Klett, J. W., McMillan, A. D., Gallego, N. C., Walls, C. A. 2004. The Role of Structure on the Thermal Properties of Graphitic Foams *Journal of Materials Science* 39: 3659-3676.