EFFECT OF COPPER COATING ON THERMO-PHYSICAL PROPERTIES OF CARBON FOAM

Mohammad Almajai, Khalid Lafdi, and Paul Prodhomme

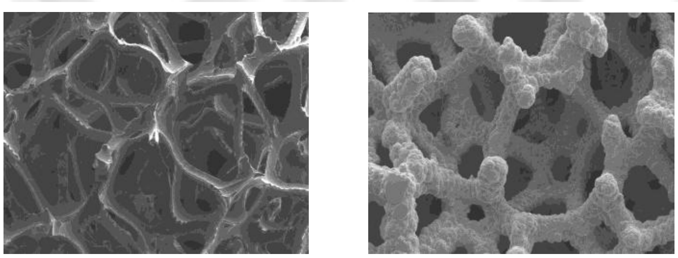
University of Dayton Research Institute, Dayton, OH 45469

Introduction

Significant amount of research has been conducted to investigate and enhance the properties of carbon foam [1-3]. These studies focused on improving the thermal properties of carbon foam for its successful implementation in thermal management applications. Alternatively, it is well known that carbon foam materials in nature are brittle and lack of strength. Researchers have tried to improve the mechanical properties of carbon foam as well as its thermal properties [4-6]. These methods improved the strength of carbon foam, however, they proved costly and to have negative effects on the foam's thermal conductivity. The purpose of this study was to use a novel coating method to improve both the mechanical and thermal properties of carbon foam.

Experimental

Copper electroplating method was conducted to coat carbon foam from inside. Samples of reticulated vitreous carbon RVC foams (97% porosity and 10 ppi) were used. The samples were electroplated with copper for different periods of time to obtain coating with different thicknesses and foams with different final porosities. Deposition of copper via electroplating allows the coating to be nearly uniform on all surfaces of the foam (Fig. 1).



Before coating After coating

Fig. 1 Carbon foam before and after coating with copper

Thermal properties: Once the coated carbon foam was produced, its thermal properties including, the thermal conductivity, specific heat, porosity, and thermal diffusivity, were measured. By using the nano-flash LFA-447, the thermal diffusivity and specific heat capacity values for the samples were determined. Measurement of the thermal diffusivity α and specific heat C_P allowed the calculation of the thermal conductivity K with the additional measurement of the bulk density of the sample material ρ. The relationship between these properties is:

$$K = \alpha \rho C_P \tag{1}$$

Analytical model was formulated to calculate the thermal conductivity and the porosity of the coated carbon foam. Based on the work of Clamidi [3], a new model that can predict the thermal conductivity of coated foams was introduced using the following equation:

$$K_{eff} = (\varepsilon_f - c)K_f + (1 - \varepsilon_f)K_s + cK_c \tag{2}$$

Where K_c represents the conductivity of the coating and c represent the volume ratio occupied by the coating. In order to apply equation (2) to the periodic structure (Fig. 2), initially the geometrical characteristics of the model were determined.

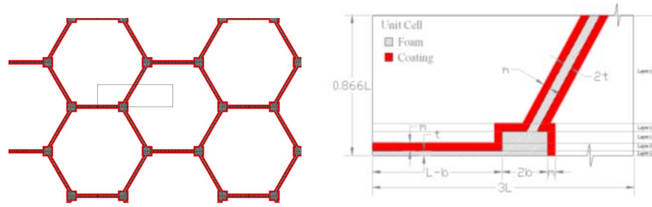


Fig. 2 Hexagonal mesh of coated foam with unit cell

The unit cell was then divided into 5 different layers and the series law of thermal resistances was applied to calculate the effective thermal conductivity of the foam in x-direction. The calculations were based on the volume ratio of the foam, fluid, and coating. Hence, when the thermal conductivities of the carbon foam, copper, and the fluid are found, the effective thermal conductivity of each layer can then be defined as follows:

$$K_{effi} = \frac{(Vc_i Kc + Vs_i Ks + Vf_i K_f)}{Vt_i} \tag{3}$$

Mechanical properties: Compression tests were carried out on four samples of copper-coated carbon foam. The test was run until a 20% strain was reached. Once the whole surface of the sample was in contact with the loading platen, the data could then be used to determine the modulus and the plateau stress. The curves have a saw tooth shape as shown in (Fig. 3). This is due to the fact that every time few ligaments collapse in a brittle manner, the strength is recovered when the next row of ligament is compressed

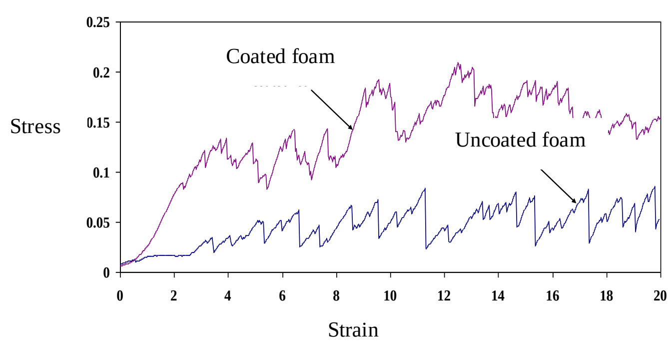


Fig. 3 Stress-Strain curve for uncoated and coated foam

Two mechanical properties of the coated foam were determined; the Young's modulus and the plateau stress. Those two properties are representative of the material tested.

The modulus, E, was calculated by averaging the slope of every linear part of the curve. The modulus varied from 4.5 MPa for the uncoated sample to 8.6 MPa for the sample electroplated for 40 min. The plateau stress, $\sigma_{plateau}$, represents the limit load that the foam could support without entirely collapsing. It was determined by averaging the stress on the saw tooth part of the curve. It varied from 54 kPa for the uncoated foam to 171 kPa for the foam coated for 80 min.

Results and Discussion

When carbon foam is coated, the porosity will decrease while the effective thermal conductivity will increase. The coated carbon foam showed a huge increase in the effective thermal conductivity values. The resulting thermal conductivities were plotted against the porosities (Fig. 4). It can be observed that the effective thermal conductivity of the copper coated carbon based foam increased significantly compared with the thermal conductivity of the uncoated carbon foam. This yields the added benefits of enhanced heat transfer properties of copper coating along with the lower density of carbon foams. The copper coating process will not only increase the foam effective thermal conductivity but also make it an excellent heat exchanger with very high surface to volume ratio. This of course depends on the initial porosity of the foam, the thickness of the coating material and the achieved porosity.

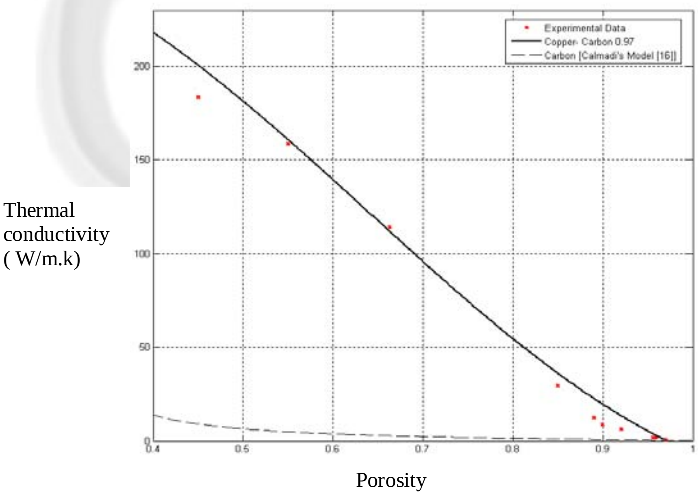


Fig. 4 Thermal conductivity versus porosity for coated foam

The two measured mechanical properties were increased with increasing copper coating inside the foam. The enhancement of the mechanical properties of the carbon foam is apparent (Fig. 5). This figure shows the enhancement of both the modulus and the plateau stress with respect to foam porosity and percentage of copper weight to carbon weight. The modulus increase seems to be linear with the weight of copper added. Since the slope of this line can be determined, the relationship is expressed as:

$$E^* = 0.84 \cdot E_{foam} \cdot \frac{m_{Cu}}{m_C} + E_{foam} \qquad (4)$$

The linear relationship is a poor fit in the case of the plateau stress. Whereas a polynomial relationship gives a good accordance between the experimental data and the equation over the range studied. This polynomial relationship was found to be as follows:

$$\sigma^* = \sigma_{foam} \cdot \left(0.95 \cdot \left(\frac{m_{copper}}{m_{foam}} \right)^2 + 0.64 \cdot \frac{m_{copper}}{m_{foam}} \right) + \sigma_{foam} \qquad (5)$$

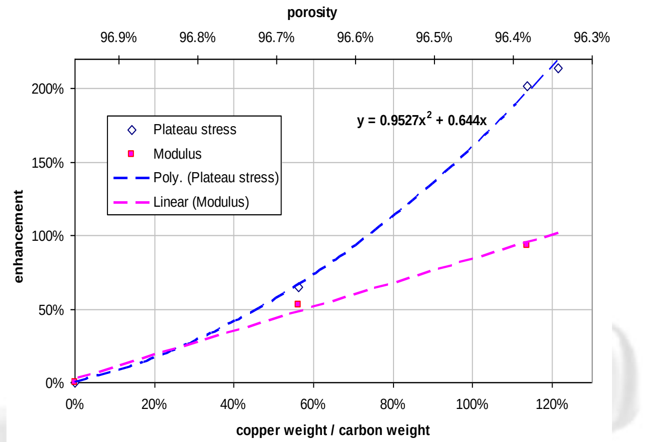


Fig. 5 Increase of mechanical properties with copper coating

Conclusions

Copper coating process improved both thermal and mechanical properties of carbon foam. The thermal conductivity increased significantly and 50% porosity can attain thermal conductivity of 180 W/m.K. With small amount of coating, the elastic modulus increased twice and the plateau stress increased more than three times.

References

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