Effect of the pitch particle size on the thermal property of carbon foams

Jing Xia*, Junqing Liu, and Wenbin Liang
National Institute of Clean and Low Carbon Energy, Beijing, 102211, China

*Corresponding author e-mail: jing.xia.e@chnenergy.com.cn

Abstract. In this research, the influence of the pitch particle size on the thermal diffusivity of the carbon foam was studied. The results indicate that the thermal diffusivity increases from 12.3 mm²/s to 23.09 mm²/s with an increasing pitch particle size from <500 mesh to 100-200 mesh, because the carbon foam produced by using larger pitch particle has highly aligned graphitic structures with less cracks and folded texture and its degree of graphitization is higher.

1. Introduction
Carbon foam is a porous material with various unique properties like high porosity, low density, low thermal expansion coefficient, and high thermal conductivity [1-5]. Nowadays, it has wide applications in catalyst, energy storage devices, thermal management materials, water purification and so on [6-11]. Mesophase pitch which is fluid in high temperature, anisotropic, and graphitized after heating, is a good option as the raw material to produce carbon foams [12, 13]. Since the Wright Patterson Air Force Base Material Lab reported the first mesophase pitch based carbon foams, an increasing number of researchers have been focusing on such foams [3, 14].

As a thermal management material, the capability of heat conduction of the carbon foam is significant and many attempts have been made to adjust its capability of heat conduction. Recently, several methods have been developed to improve the heat transfer of carbon foams, such as addition of carbon nanotubes, heat treatment, and pre-oxidation of mesophase pitch [3, 7, 15]. The factors to affect the capability of heat conduction are various and complicated, which include density, heat treatment, microstructure and degree of graphitization [13]. To improve our understanding of the heat transfer of the carbon foam, the effect of pitch particle sizes on the thermal diffusivity of carbon foams was studied in this work. Furthermore, the microstructures of carbon foams were analyzed to explain the change in thermal diffusivity.

2. Experimental

2.1. Materials
The mesophase pitch was bought from Jining Keneng Carbon Material Co., Ltd. Its softening point is 365 °C. The mesophase content, quinolone insoluble, and toluene insoluble of the mesophase pitch are 100%, 81.8% and 82.7%, respectively. In this work, mesophase pitch was crushed and ground to make the particle size 100-200 mesh, 200-500 mesh, and <500 mesh. Tris-2, 4, 6-(dimethyloaminomethyl) phenol (DMP-30), Dodecenyl succinic anhydride (DDSA), methyl-5-norbomene-2, 3-dicarboxylic
anhydride (NMA), and 1, 2, 3-Propanetriol glycidyl ethers (SPI-PON 812) were purchased from SPI SUPPLIES.

2.2. Fabrication of the carbon foam

A resin solution contains 9.93 g SPI-PON 812, 2.75 g DDSA, 7.04 g NMA, and 0.28 g DMP-30 were first mixed at room temperature (RT). Secondly, 10 g <500 mesh pitch particles, 200-500 mesh pitch particles, and 100-200 mesh pitch particles were added into the resin solution, respectively. After curing at 80 °C for 4 h, the mixture was heated at 700 °C under nitrogen for 30 min. Finally, the mixture was graphitized at 3000 °C to produce the carbon foam.

2.3. Characterization

The field emission scanning electron microscope (FESEM, FEI Nova nanoSEM 450) was employed to observe the microstructures of carbon foams. The crystalline structures of carbon foams were analyzed by X-ray diffraction (XRD, Bruker D8 Advance) spectroscope. The degree of graphitization (g%) was calculated by the equation: 

$$g\% = \frac{(0.3440 - d_{002})}{(0.3440 - 0.3354)} \times 100 \quad [13]$$

In this equation, 0.3354 is the interlayer spacing of the ideal graphite crystallite, 0.3440 is the interlayer spacing of turbostratic graphite, and $d_{002}$ is the interlayer spacing of carbon foams prepared in this research. The $d_{002}$ is calculated according to the XRD pattern.

3. Results and discussion

![Figure 1. Typical SEM images of carbon foams fabricated by using a) <500 mesh, b) 200-500 mesh, c) 100-200 mesh pitch particles. Enlarged SEM images of carbon foams fabricated by using d) <500 mesh, e) 200-500 mesh, f) 100-200 mesh pitch particles.](image-url)
Figure 1a-c shows the SEM images of carbon foams prepared by using different sizes of pitch particles. All these carbon foams show a three dimensional network structure with open, interconnected pores between most of the cells (Figure 1a-c). However, the pore sizes increase as the increased pitch particle sizes. As shown in Figure 1a-c, the carbon foam fabricated by using <500 mesh pitch particles has a minimum pore size of about 10-25 μm (Figure 1a). A slight increase in pore size (10-35 μm) is observed when the pitch particle size is 200-500 mesh (Figure 1b). While the pore size of the carbon foam fabricated by using 100-200 mesh pitch particle is approximately 35-70 μm (Figure 1c). In the foaming process, larger pitch particle may release more gases and cause formation of larger bubbles, leading to the growth of pores with larger size.

![Figure 1. SEM images of carbon foams.](image)

**Figure 2.** Thermal diffusivity of carbon foams.

The thermal diffusivity of carbon foams was examined and results are shown in the Figure 2. It clearly indicates that the thermal diffusivity gradually increases with an increasing pitch particle size (Figure 2). When the pitch particle size is less than 500 mesh, the thermal diffusivity is 12.3 mm²/s. As the pitch particle increases to 100-200 mesh, the thermal diffusivity reaches 23.09 mm²/s (Figure 2).

To understand the reason for the increase of thermal diffusivity with an increasing pitch particle size, the microstructure of the carbon foam was analyzed. As shown in the enlarged SEM images of carbon foams (Figure 1d-f), aligned graphitic structures are observed. However, the graphitic structure of the carbon foam prepared by using <500 mesh pitch particle is less aligned and possesses more cracks and folded texture (Figure 1d). As the particle size increases to 100-200 mesh, the foam contains highly aligned graphitic structures with less cracks and folded texture (Figure 1f). Moreover, the carbon foam fabricated by using 100-200 mesh particle has a higher degree of graphitization (Table 1). Thus carbon foams fabricate by using larger pitch particles show higher thermal diffusivity (Figure 2).

| Particle size (mesh) | Degree of graphitization (%) |
|---------------------|-----------------------------|
| <500                | 82.56                       |
| 200-500             | 82.56                       |
| 100-200             | 86.05                       |

**Table 1.** Degree of graphitization of carbon foams.
4. Conclusion
In this work, a series of carbon foams were produced by using <500 mesh, 200-500 mesh, 100-200 mesh pitch particles. Their capability of heat transfer was studied. When the pitch particle is <500 mesh, the thermal diffusivity of the carbon foam is 12.3 mm²/s. The thermal diffusivity raises to 23.09 mm²/s as the pitch particle size increases to 100-200 mesh, because the carbon foam produced by using larger pitch particle has highly aligned graphitic structures with less cracks and folded texture and its degree of graphitization is higher.

Acknowledgments
The authors are very grateful for the financial support from the National Institute of Clean and Low Carbon Energy.

References
[1] Z. Chen, C. Xu, C. Ma, W. Ren, and H.-M. Cheng, "Lightweight and Flexible Graphene Foam Composites for High-Performance Electromagnetic Interference Shielding," Advanced Materials, vol. 25, pp. 1296-1300, 2013.
[2] M. Moeini Sedeh and J. M. Khodadadi, "Thermal conductivity improvement of phase change materials/graphite foam composites," Carbon, vol. 60, pp. 117-128, 2013/08/01/ 2013.
[3] M. Inagaki, J. Qiu, and Q. Guo, "Carbon foam: Preparation and application," Carbon, vol. 87, pp. 128-152, 2015/06/01/ 2015.
[4] Klett J, Hardy R, Romine E, Walls C, Burchell T. High-thermal-conductivity, mesophase-pitch-derived carbon foams: effect of precursor on structure and properties. Carbon 2000;38(7):953–73.
[5] Lafdi K, Mesalhy O, Elgafy A. Graphite foams infiltrated with phase change materials as alternative materials for space and terrestrial thermal energy storage applications. Carbon 2008;46(1):159–68.
[6] C.-G. Lee, S. Lee, J.-A. Park, C. Park, S. J. Lee, S.-B. Kim, et al., "Removal of copper, nickel and chromium mixtures from metal plating wastewater by adsorption with modified carbon foam," Chemosphere, vol. 166, pp. 203-211, 2017/01/01/ 2017.
[7] J.-H. Kim, E. Jeong, and Y.-S. Lee, "Preparation and characterization of graphite foams," Journal of Industrial and Engineering Chemistry, vol. 32, pp. 21-33, 2015/12/25/ 2015.
[8] J. Quintana and T. Mower, "Thermomechanical behavior of sandwich panels with graphitic-foam cores," Materials & Design, vol. 135, 09/01 2017.
[9] Agrawal PR, Kumar R, Teotia S, Kumari S, Mondal DP, Dhakate SR. Lightweight, high electrical and thermal conducting carbon-rGO composites foam for superior electromagnetic interference shielding. Compos B Eng 2019;160:131–9.
[10] Chen Z, Xu C, Ma C, Ren W, Cheng H-M. Lightweight and flexible graphene foam composites for high-performance electromagnetic interference shielding. Adv Mater 2013; 25(9): 1296–300.
[11] Jang Y-I, Dudney NJ, Tiets TN, Klett JW. Evaluation of the electrochemical stability of graphite foams as current collectors for lead acid batteries. J Power Sources 2006;161(2):1392–9.
[12] Lü Y, Ling L, Wu D, Liu L, Zhang B, Mochida I. Preparation of mesocarbon microbeads from coal tar. J Mater Sci 1999;34(16):4043–50.
[13] R. Kumar, H. Jain, A. Chaudhary, S. Kumari, D. P. Mondal, and A. K. Srivastava, "Thermal conductivity and fire-retardant response in graphite foam made from coal tar pitch derived semi coke," Composites Part B: Engineering, vol. 172, pp. 121-130, 2019/09/01/ 2019.
[14] A. Yadav, R. Kumar, G. Bhatia, and G. L. Verma, "Development of mesophase pitch derived high thermal conductivity graphite foam using a template method," Carbon, vol. 49, pp. 3622-3630, 2011/09/01/ 2011.
[15] J. Lee, J. Kim, and T. Hyeon, "Recent Progress in the Synthesis of Porous Carbon Materials," Advanced Materials, vol. 18, pp. 2073-2094, 2006.