

Performance of Alternate Precursors for Graphite Foam

James Klett, Claudia Walls
Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN, 37831,
klettjw@ornl.gov

Tom Golubic
Koppers, Inc. 1005 William Pitt Way, Pittsburgh, PA 15238

Background

By combining an open cellular structure with a thermal conductivity to weight ratio (κ/ρ) of greater than 200 (compared to 45 for copper), graphite foam presents a unique opportunity to radically change the approach to solving many heat transfer problems. This graphite foam has been examined for the core of heat transfer devices such as radiators and heat sinks, evaporative cooling and phase change devices.

Currently, there is only one commercial precursor for the production of the foam, specifically AR Mesophase. This is a synthetic precursor made from methyl-naphthalene and is rather expensive, more than 10\$/lb. In addition, the resultant foam, while extremely thermally conductive, is rather fragile and exhibits a low compressive modulus and strength (180 MPa and 2.1 MPa respectively). Recently, an alternative mesophase precursor has been developed by Koppers Inc. This research describes the use of this precursor for producing graphite foams.

Experimental

Two Koppers mesophases were evaluated, Koppers 334 and Koppers 364. The Koppers 334 mesophase has a melting point of 334C and a 88% anisotropic content [1], while the Koppers 364 has similar anisotropic content, but a 364C melting point. Both mesophases exhibit a carbon yield at 1000C in atmospheric nitrogen between 85 and 90%, compared to around 77% for AR mesophase [2]. At low shear rates, it has a similar viscosity performance to the AR mesophase, Figure 1, albeit slightly lower. However, above 1 s^{-1} it experiences shear thickening behavior. The precursor was foamed according to the standard ORNL process [3-5], carbonized at 0.2C/min to 1000C and then graphitized under Argon to 2800C at a heating rate of 1C/min. Cubes 15mm on a side were machined from the samples and characterized for density, compressive strength, thermal conductivity, and scanning electron microscopy. For comparison, a block of PocoFoam® was sectioned and characterized under the same conditions.

Figure 2 shows a typical image of the foams made from the Koppers mesophase. As can be seen, the foam is not as open celled as the standard foam made from AR mesophase (Figure 3). The cell sizes appear to exhibit a wider distribution of sizes than the AR mesophase, however further examination with optical microscopy will be needed to validate this conclusion. While the density of the Koppers derived foams have a higher density than the standard AR derived foams, 0.7 vs. 0.54, it is believed that the viscosity behavior of the pitch is responsible for preventing the cells from opening to their neighbors during processing. In addition, a significant advantage in processing the Koppers mesophase is that there was no density gradient in the foam, like that produced from the AR mesophase. This is significant as there will be less waste and, hopefully, reduced costs.

The compressive strength of the Koppers foam was significantly higher than that of the AR derived foams (Figure 4). The average strength was approximately 5.1 MPa for both mesophase derived foams compared to an average of 2.1 MPa for the AR derived foams. More importantly, the modulus of the Koppers 334 foams was significantly higher than that of the AR foams (Figure 4). However, it appears that the Koppers 334 derived foam exhibited a higher modulus than the Koppers 364 (428 MPa vs 146 MPa). One possible explanation is that there appears to be fewer microcracks in the Koppers derived foams compared to that of the AR derived foams. While there are undulations in the surfaces of the bubbles, these do not manifest themselves into cracks, even after graphitization (Figure 5). This possibly could increase the load transfer and stiffness of the foams. It is unclear why the lower melting point Koppers mesophase exhibited a higher modulus. Further research is planned.

The samples were measured for thermal diffusivity using a Xenon laser flash system built and calibrated at ORNL. The average thermal conductivity of both Koppers derived foams are nearly identical, Table I. These values are comparable to that of the AR derived foams (Figure 6).

Conclusions

The Koppers mesophase is a suitable precursor for the manufacture of highly thermally conductive graphite foam. In addition, the resultant foam exhibits thermal conductivities similar to that of the foams made from the standard commercial precursor (AR mesophase). The Koppers derived foams exhibited similar cell sizes, although it appears to exhibit a wider distribution in cell sizes. More importantly, the compressive strength and modulus of the Koppers 334 are more than 2.5 times higher than the standard graphite foams. However, while the strength of the Koppers 364 was 2.5 times higher than AR derived foams, the modulus was slightly lower. Therefore, many applications which cannot utilize the foam due to its inherent weak mechanical properties may be able to utilize the Koppers 334 derived foams. However, the lack of a large fraction of interconnections (openings) between the cells of the foam may prevent this variety from being used in heat transfer applications where fluids are passed through the pores. This, of course, will be avoided if the Koppers derived foams can be made to be more open by varying the process conditions, or even blending the AR and the Koppers mesophases.

References

1. Koppers I, Koppers Product Data Sheet, Vol.: 2004:
2. Klett JWH, R.; Romine, E.; Walls, C.A.; Burchell, T.D. High Thermal Conductivity Mesophase Pitch-Derived Carbon Foams: Effect of Precursor on Structure and Properties. Carbon 1999;
3. Klett J. Process for Making Carbon Foam. US Patent 6,033,506. 2000.
4. Klett J. Pitch-Based Carbon Foam and Composites. US Patent 6,261,485. 2001.
5. Klett J. Pitch Based Carbon Foam and Composites. US Patent 6,387,343. 2002.

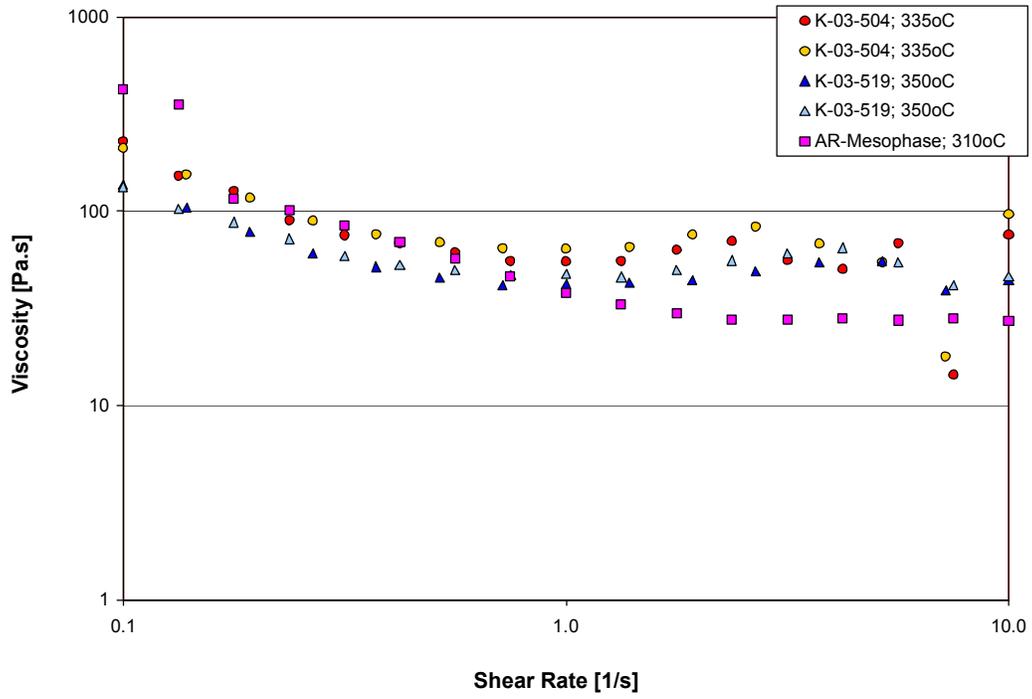


Figure 1. Viscosity behavior of the Koppers precursors compared to AR mesophase.

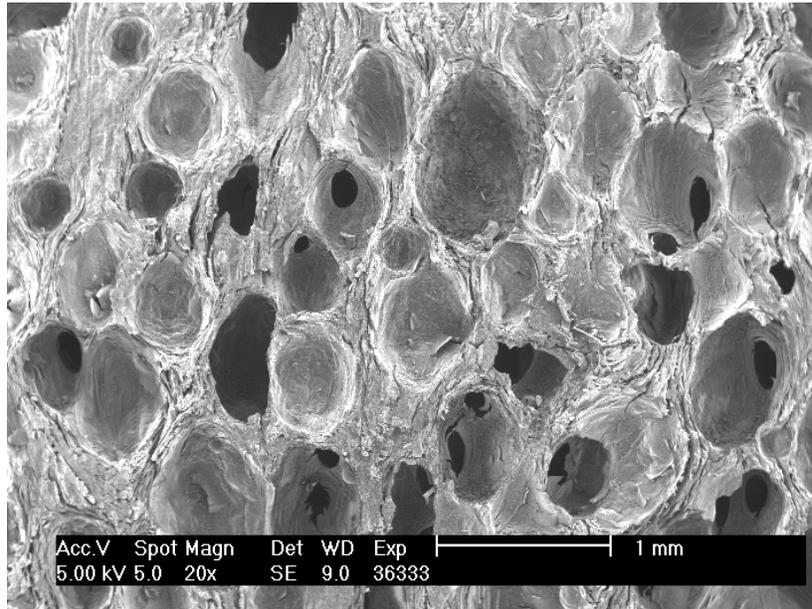


Figure 2 SEM Image of the Koppers 334 mesophase derived graphite foam.

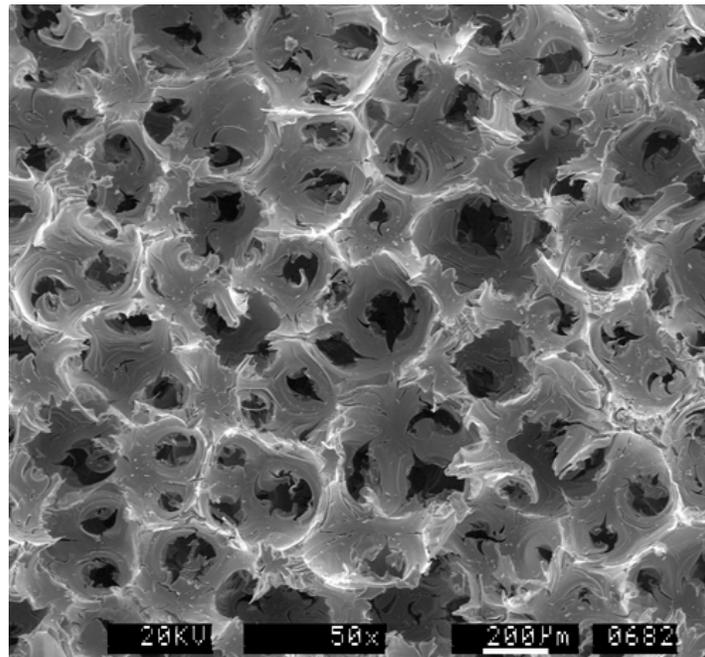


Figure 3. SEM Image of AR mesophase derived graphite foam.

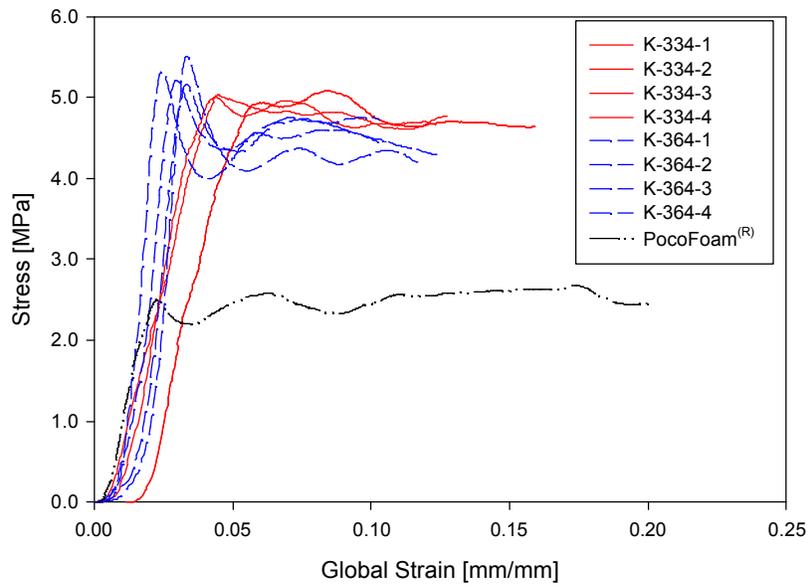
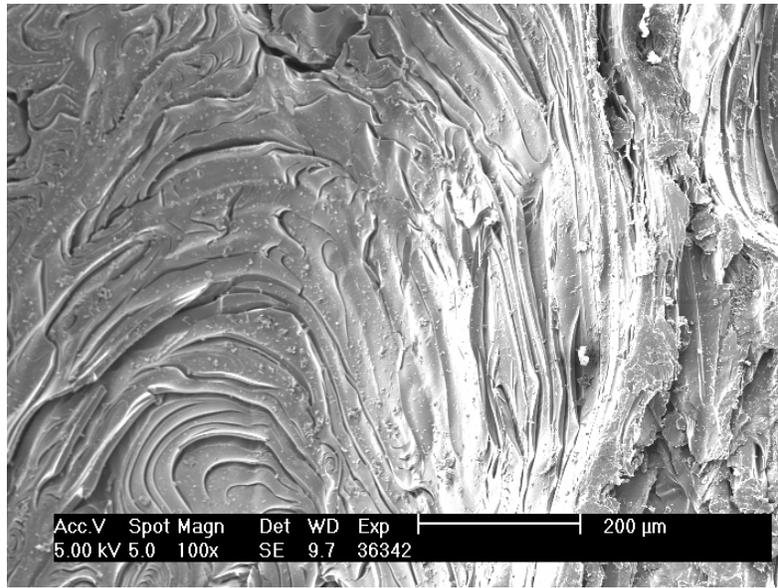
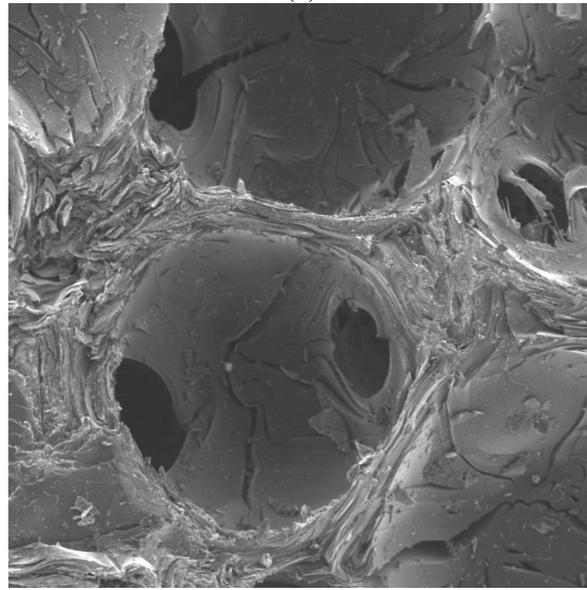


Figure 4 Compression properties of the Koppers derived foams compared to that of PocoFoam[®].



(a)



(b)

Figure 5. High resolution images of Koppers derived foam (a) and AR derived foams (b) showing fewer microcracks in the Koppers derived foams. Areas in Koppers foams that appear to be cracks, are really surface ripples that do not have fissures.

Table I. Thermal Properties of Koppers derived mesophase foams compared to PocoFoam®.

Mesophase Precursor	Average Density [g/cm ³]	Thermal Conductivity [W/mK]
Koppers 334	0.70	167
Koppers 364	0.69	164
PocoFoam®	0.62	152

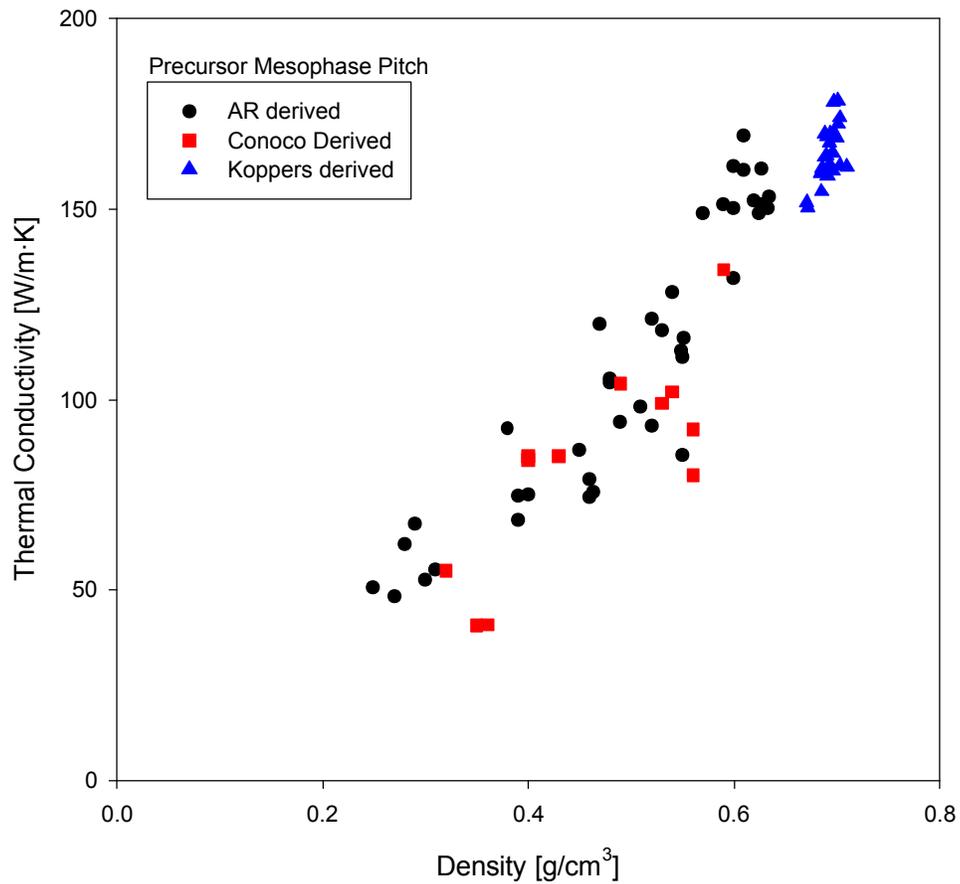


Figure 6 Thermal properties of Koppers mesophase derived graphite foams compared to Conoco® mesophase and AR mesophase derived graphite foams.

1. Koppers I, Koppers Product Data Sheet, Vol.: 2004:
2. Klett JWH, R.; Romine, E.; Walls, C.A.; Burchell, T.D. High Thermal Conductivity Mesophase Pitch-Derived Carbon Foams: Effect of Precursor on Structure and Properties. Carbon 1999;
3. Klett J. Process for Making Carbon Foam. US Patent 6,033,506. 2000.
4. Klett J. Pitch-Based Carbon Foam and Composites. US Patent 6,261,485. 2001.
5. Klett J. Pitch Based Carbon Foam and Composites. US Patent 6,387,343. 2002.