Industry Developments:

Carbon and Graphite Foams for Thermal Management

Certain materials, such as diamond, provide substantially higher heat spreading capabilities compared with others. However, issues that include cost, availability and application make most of these materials unsuitable for conventional electronic cooling needs. One substance with excellent heat spreading properties is carbon. Improvements in carbon materials are increasing industry interest as cooling needs mount for components and PCBs. Carbon-based heat sink materials have included graphite strands, carbon nano-fibers and metal-graphite matrices.

Another of these carbon-derived materials is carbon foam, along with its heat-treated product, graphite foam. The cell walls of these foam materials are made of highly oriented graphite planes, similar to high performance carbon fibers, which have been estimated to exhibit a thermal conductivity greater than 1700 W/mK (by comparison, copper is 400 W/mK). [1]

The first of these foam materials was developed in the 1960s by the pyrolysis of thermosetting polymer foams to obtain a carbonaceous skeleton or reticulated vitreous carbon (RVC) foam. These materials are still used in many aerospace and industrial applications, including thermal insulation, impact absorption, and metal and gas filtration. [2]

In the 2000s, researchers at the Oak Ridge National Laboratory, ORNL, in Tennessee developed highly thermally conductive graphite foam using a significantly reduced number of processing steps. Their base material was mesophase pitch, a material produced from coal tar and petroleum. Taking advantage of this advance, the researchers used a proprietary process to produce foams of varying density at high temperatures. It was found that the thermal conductivity of the materials could be varied with density, and that lightweight materials with high thermal conductivities could be produced.

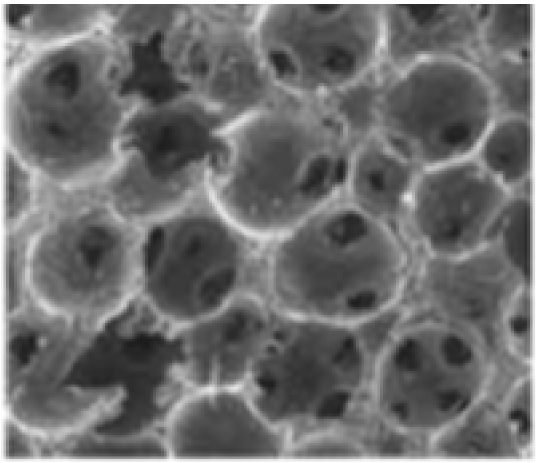

Figure 1. Foam Microstructure at 600 micron of Carbon Foam [2]

The foam produced by the ORNL process develops highly aligned graphitic ligaments, responsible for the high thermal conductivity of the carbon foam. ORNL researchers found that the key to the foam's conductivity is its unusual graphite crystal structure. It has a skeletal structure full of air pockets, making it only 25% dense and thus relatively light.

The network of ligaments in the foam wicks heat away from its source better than high-performance graphite fibers. Testing showed the new carbon foam to possess 4x the thermal conductivity of copper and 8x the conductivity of aluminum. With its foam-expanded structure, heat spreads out over a larger surface area and heat transfer is more efficient. The internal surface area is up to 50,000 m^2/m^3.

In addition, the material demonstrated 65% better heat storage per unit weight than copper. The foam could transfer heat away from hot spots about 15 times faster than copper, making it an ideal heat spreader. [3]

Graphite Foam Heat Sinks

To evaluate graphite foam as a viable material for heat sinks, tests have been conducted to compare the thermal performance of geometrically identical heat sinks made of copper, aluminum, and graphite foam respectively.

Foam experiments by Coursey et al. [4] used solder brazing to attach a foam heat sink to a heated component. The solder method reduced the problematic interfacial resistance when using foams, due to their porous nature. Directly bonding the heat sink to a component has two potential drawbacks. First, the high temperatures common in brazing could damage the electrical component itself. The other issue concerns the complicated replacement or rework of the component. Due to the low tensile strength of foam there is a greater potential for heat sink damage than with aluminum or copper [5]. If the heat sink is damaged or the attached component needs to be serviced, direct bonding increases the cost of rework.

To avoid these problems, the foam heat sink can be soldered to an aluminum or copper carrier plate. This foam-and-plate assembly can then be mounted to a component in a standard fashion. The carrier plate allows sufficient pressure to be applied to the interface material, ensuring low contact resistance.

At ORNL a heat sink with fins made of the special graphite foam has been cooling a Pentium 133 chip in a desktop computer since December 12, 1998. Researchers have also explored their possible application would be in evaporative cooling, in which the high specific surface area (>4m^2/g) combines with the high thermal conductivity to produce very efficient cooling as water evaporates from the foam surfaces. [6]

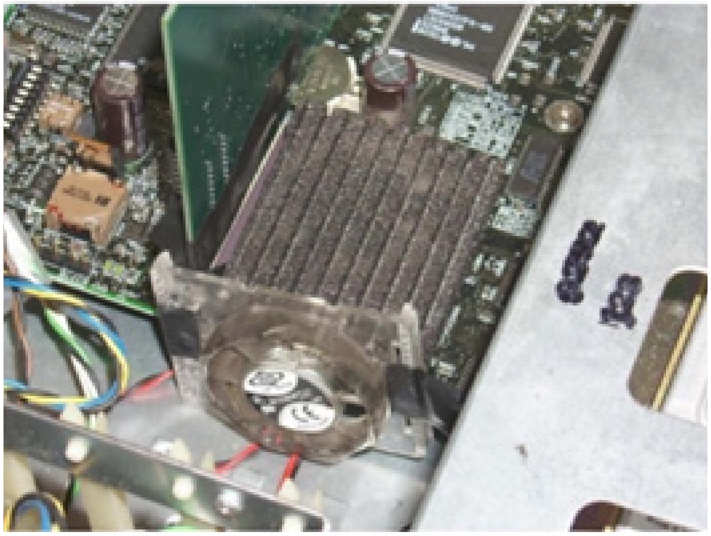

Figure 2. Foam Heat Sink Cools Pentium 133 Microprocessor [6]

Graphite foam-derived heat sinks show promise in specific applications, but exhibit several drawbacks in mainstream electronics cooling. Due to the frail nature of graphite foam, unique precautions must be taken during the handling and use of these heat sinks. When coupled to a copper base plate, graphite foam can perform with acceptably small thermal spreading resistances. However, the foam's lower thermal conductivity reduces thermal performance at high flow velocities compared to a traditional copper heat sink.

The mechanical attachment needed to ensure acceptable thermal interface performance without soldering or brazing also hinders foam-based heat sinks from being explored in mainstream applications. Despite these challenges, the thermal performance-to-weight ratio of foam is very attractive and well-suited to the aerospace and military industries, where cost and ease of use come second to weight and performance. [7]

Cooling Applications in Hybrid Vehicles

Researchers from ORNL, Ford Motor Company and the University of Michigan studied graphite foam for the cooling of automotive power electronics. [8] In particular, they looked at how carbon foam could be applied to improve heat removal in hybrid and fuel cell vehicles. The researchers used carbon foams with different pore structures which were produced by varying the foam pressure during manufacture.

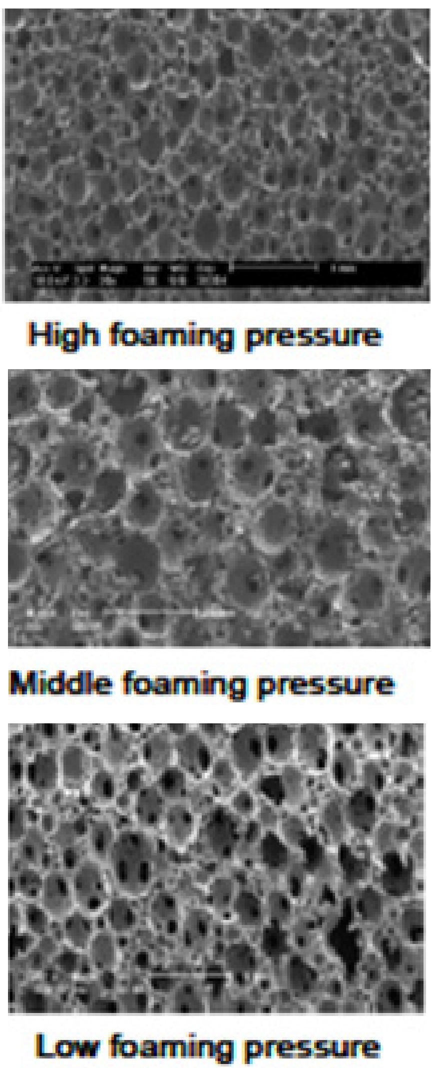

Figure 3. SEM Images of Pore Carbon Foam Pore Structures Produced at Different Foaming Pressures [8]

The vehicles under study featured high power electronics dissipating enough heat that a heat exchanger and separate radiator were required for thermal management. Gallego et al. studied the application of carbon foam in different cooling approaches, including forced air convection and a water-cooled heat exchanger. Cooling performance with the carbon foam materials was lower than expected, given the high thermal conductivity and very high specific surface area of open cell structures as found in ORNL. But this attributed to various mechanical and control issues in the test set-ups rather than to the carbon foam itself. [8]

Commercializing Graphite Foam

POCOFoam, provided by Poco Graphite, Inc., is produced by a patented foaming process that creates a structure of highly aligned graphitic ligaments within the foam's cell walls. These ligaments are the key to the material's high thermal conductivity, wicking heat away from the source. Per its manufacturer, POCOFoam's heat transfer efficiencies have been tested to be significantly greater than aluminum or copper. [9]

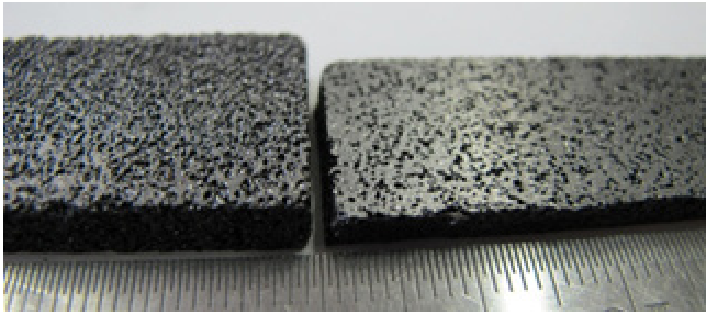

Figure 4. POCOFoam is a Lightweight Graphite Material for Applications that are Encapsulated or Free of Vibration [10]

Conclusion

The unique thermal properties of graphite foams, together with their continuous graphitic open celled structure, should continue to attract interest in these materials for specific applications in electronics thermal management. As Klett and Conway advise "the foam will be most useful and efficient when not used simply as a replacement for existing thermal management materials, but rather when the full potential of its unique structure is utilized in out-of-the-box designs." [6]

References:

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