Production of thermally conductive carbon foams and their application in automobile transport

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Abstract. The report examines the possible methods of synthesis and properties of a new class of carbon materials – thermally conductive foams based on mesophase pitches and their application in automobiles to control the heat flow.

1. Introduction
Currently, in many foreign countries research aimed at the study of such materials as foams based on polymers (foam plastics), inorganic materials including carbon are carried out. The range of application of these materials is extremely wide [1]. The heat-insulating carbon foams on the basis of phenolic resins developed by the Union Carbide company (USA) in the early 60s’ of the 20th century [2] are well-known. One of the examples of a new class of carbon materials is thermally conductive foam based on mesophase pitches [1, 3].

2. Research part
For the first time materials of this class were obtained by Klett in the USA in the year 2000 [3]. Currently, industrial production of thermally conductive carbon foams based on the mesophase pitches is performed by ORNL and Poco Graphite companies. The properties of these foams are shown in table 1.

Table 1. Properties of carbon foams.

| Properties                        | ORNL  | POCO    |
|-----------------------------------|-------|---------|
| Density, g/sm³                    | 0.25 – 0.65 | 0.56 – 0.90 |
| Porosity, %                       | 78 – 88 | 61 – 70 |
| Coefficient of thermal expansion, 10⁻³ K⁻¹ | 2.0    | 0.7 – 0.8 |
| Compressive strength, MPa         | 1.0 – 3.5 | 3.0 – 2.7 |
| Tensile strength, MPa             | 0.7 – 1.6 | 0.6 – 1.9 |
Physical-mechanical properties of carbon foams are sufficiently high. Even at a density of about 0.27 g/sm\(^3\) compressive strength for heat-insulating carbon foams based on polyurethane or phenolformaldehyde resin is 10-15 MPa at thermal conductivity less than 10 W/m · K [4-6]. The strength of thermally conductive foams based on mesophase pitches varies from 1 to 20 MPa at a density of 0.25 to 0.65 g/sm\(^3\). This strength is sufficient to meet not only operational requirements but also to allow the production of large-scale products up to 3 m in length and up to 150 mm thick.

A useful feature of carbon foams is coefficient of thermal expansion which remains constant in a sufficiently wide variation range of temperatures from 200 to 600 °C. Coefficient of thermal expansion at 300 K for the heat-insulating carbon foam based on phenolformaldehyde resin is from 5 to 6 ·10\(^{-6}\)K\(^{-1}\), for thermally conductive foam on the basis of mesophase pitches from 1.2 to 2.6 ·10\(^{-6}\)K\(^{-1}\) [4-6].

The thermal conductivity of graphitized carbon foams based on mesophase pitches significantly changes depending on the nature of the raw pitch and the peculiarities of technological process. As it was shown in work [6] with an increase in the density of thermally conductive carbon foams based on mesophase pitches from 0.25 to 0.65 g/sm\(^3\), thermal conductivity increases from 40 to 210 W/m · K.

Furthermore, carbon foams possess an improved fire resistance [1] and withstand even prolonged exposure to the torch flame in the air [5, 6]. The maximum operating temperature in the air for the thermally conductive POCO carbon foam is 400°C [6].

It is clear that there are significant differences in the structure of carbon foams caused by both the nature of the initial raw material and the applied technologies [1, 4, 6]. First of all we are talking about the microstructure (graphitizability) of carbon foams and their porosity.

The viscosity of the pitches and resins with an increase of temperature at carbonization varies quite widely. The amount of volatile matter discharged with increasing of the processing temperature also varies [1, 4]. Formation of thermally conductive carbon foam from mesophase pitches has a number of significant peculiarities [1, 4]. When carbonizing the pitches at the first stage of heating (up to 350°C) melt viscosity continuously decreases the escaping gases originally form intruding bubbles. If pressure is applied when carbonizing the bubbles of volatile matter begin to inflate the pitch staying within the volume of the carbonized mass.

The size of these bubbles is determined not only by the nature of the pitch but the temperature range of carbonization under pressure. Increasing the temperature and pressure in the lower viscosity range increases the sizes of the formed bubbles. At the final stage (470-530°C) the initial structure of the carbon foam is formed. After the external pressure release the bubbles breakthrough resulting in foam with a structure similar to that shown in figure 1. For comparison, the same figure shows the structure of the heat-insulating carbon foams based on the phenolformaldehyde resin.

It should be kept in mind that in Besides the external differences there is a difference in the microstructure of the carbon material itself. For heat-insulating foams it is non-graphitisable carbon material consisting of polycrystals with the sizes less than 5 nm and an interlayer distance more than 0.342 nm. In contrast, for thermally conductive foam it is a material with high capacity for graphitization having the crystal sizes of 100 nm or more and interlayer distance close to the monocryastl – 0.335-0.336 nm.

![Figure 1. SEM images of heat-insulating carbon foams of non-graphitisable resins (a, b) and thermally conductive (c).](image-url)
conductive carbon foam based on mesophase pitches (c) obtained using different technologies.

The basis of the thermally conductive foam technology (figure 2) is carbonization under pressure of inert gas followed by stabilization of the structure of the foam due to the thermal oxidation or carbonization [1, 4].

![Diagram](image_url)

**Figure 2.** Production stages of thermally conductive foam.

Application of thermally conductive foam to control the heat flows is due to the following: thermal conductivity of carbon foams is 4 times higher than that of copper and 6 times higher than that of aluminium whereas the mass is not more than 20% from the mass of these metals for the surface varying from 5000 to 50000 m$^2$/m$^3$ [4-6]. The carbon foam accumulates heat on 65% less than cooper dissipates heat 15 times faster than copper [4-6].

3. Conclusions
As these papers show the application of foam allows reducing the sizes of the conventional automotive type radiator and making it lighter and more efficient. In this case the radiator does not have to be placed in the front part of the vehicle it will significantly improve its aerodynamics and the released heat can be used, for example, for heating of the passenger compartment. Currently, racing teams of formula A show great interest in such radiators. When producing the armored personnel carriers and armoured vehicles these radiators reduce the vulnerability of the machinery. Application variants of carbon foam for cooling the breaks (the local overheating is eliminated) and also in the cooling systems of oil and transmission fluid are considered.

It is also promising to use carbon foams as cathodes of lithium-ion current supplies and in the acid accumulators as well as in the power supply systems of hybrid vehicles as part of the batteries [7, 8].

**References**

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This work was performed with financial support from Ministry of Education and Science of the Russian Federation in the framework of the Federal Target Program “Research and development in
priority development fields of science and technology sector of Russia for 2014-2020” the agreement No. 14.583.21.0057 on 28th of July 2016 (Project ID RFMEFI58316X0057).