CARBON AEROGELS AS HIGH TEMPERATURE THERMAL INSULATION MATERIALS

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Abstract

Carbon aerogels, monolithic, highly porous materials synthesized via the sol gel route and subsequent pyrolysis of the organic precursor are promising materials for a new generation of thermal insulations for temperatures up to 2500°C. A carbon aerogel consists of a three-dimensional network of spherical interconnected carbon particles. The particle size and the size of the interstitial spaces (the pores) can be specifically tailored via the synthesis conditions in a range from about 10 nm to some microns. Total porosities up to about 90% can be achieved.
The thermal conductivity of porous materials comprises three contributions: the solid conductivity, the gaseous conductivity and the heat transfer via thermal radiation. Systematic investigation of the thermal conductivity of aerogels with well defined morphology under different external conditions (temperature, gas pressure) allows separating the three heat transport mechanisms. The key parameters identified for an effective reduction of the thermal conductivity are an optimised bulk structure and density and a high infrared extinction. Based on that knowledge we synthesized a carbon aerogel with an outstanding thermal insulation performance. The thermal conductivity determined for the carbon aerogel was below 0.12 W/(m·K) for temperatures up to 1500°C in argon atmosphere. Currently commercially available carbon fibre felts yield a factor of two to three higher thermal conductivity values under the same conditions.

Keywords: carbon aerogel; heat treatment; porous carbon

Sol-gel derived carbons with high porosity and a tailorable morphology of their open porous backbone are excellent candidates for high temperature thermal insulations. The classical type of sol-gel derived porous carbons, so called carbon aerogel, is synthesized from an aqueous solution of resorcinol and formaldehyde (Pekala 1989; Pekala and Kong 1989). While the concentration of these reactants in the starting solution determines the meso- and macroporosity of the resulting porous carbon, the catalyst used and its concentration control the size of the interconnected particle-like entities that form the carbon backbone (Figure 1).
The thermal conductivity of a porous solid is essentially given by the superposition of the contribution of the heat transfer along the solid phase, the transport within the gaseous phase (pores) and radiative heat exchange. While at low temperatures the heat transfer via the solid and the pore phase dominates, these contributions become only a minor effect at high temperatures where heat transport via radiation is the dominant factor.

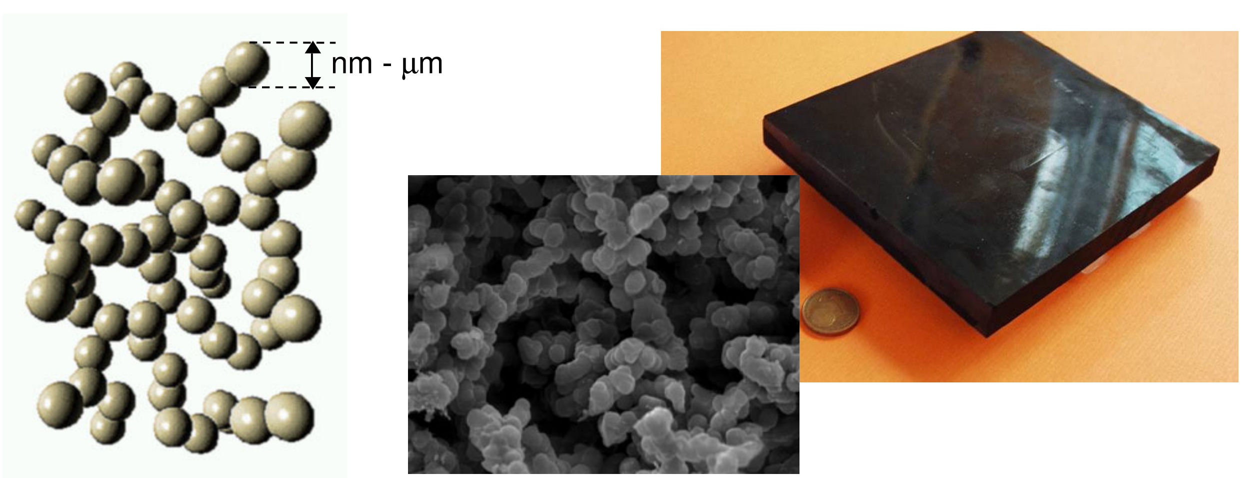

Figure 1. Left: Schematic representation of a carbon aerogel backbone; center: SEM image of a carbon aerogel; right: macroscopic carbon aerogel tile.

Commercially available thermal insulations for high temperature furnaces and process chambers consist of carbon fiber felts. Depending on the felt density, the orientation of the fibers and the presence of additional connections between the fibers as a results of a stabilization with pyrocarbon deposits, the available materials cover a range in thermal conductivity (Figure 2). The same plot shows the thermal conductivity λ for a carbon aerogel determined from the thermal diffusivity a measured via a Laser-flash experiment and the heat capacity c_p determined with a differential scanning calorimeter (Wiener, Reichenauer et al. 2006):

$$\lambda = a \cdot \rho \cdot c_p ; \qquad \textbf{(1)}$$

while at temperatures below 500°C the aerogel yields values for the thermal conductivity that are in the same range as the values for the best felts, the sol-gel derived carbon aerogel shows a factor of up to four better insulation properties for temperatures beyond 1500°C. These are accompanied by a mechanical stability of the carbon aerogels that also provides self supporting properties and easy machining. Carbon aerogels are therefore expected to be a preferred high temperature thermal insulation material for ambitious applications in the future.

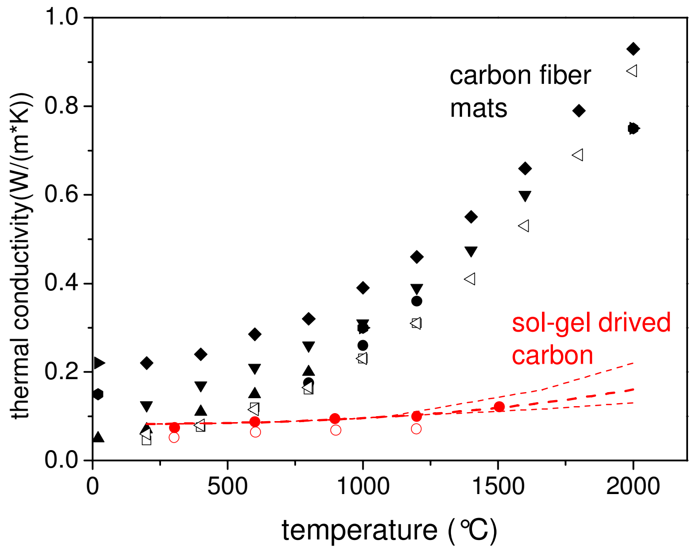

Figure 2. Total thermal conductivity of commercially available carbon fiber felts for thermal insulation (black symbols) and a carbon aerogel (red symbols). The closed symbols represent the thermal conductivity at ambient pressure, while the open symbols indicate the figures for the evacuated materials. The dashed lines in case of the aerogel mark the expected range in thermal conductivity at high temperatures where no experimental values are available yet.

References

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