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Robust thermally insulating carbon-gehlenite composite foams from newspaper waste and sucrose by filter-pressing

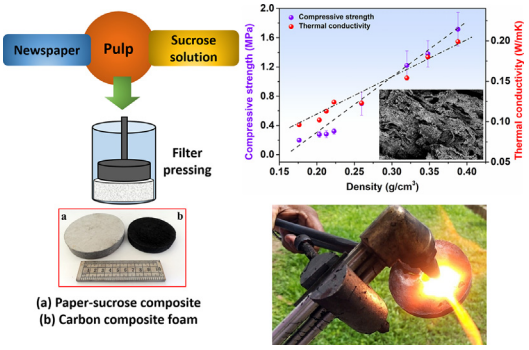
A. Chithra [a,b], Praveen Wilson [a], Sujith Vijayan [a], R. Rajeev [b], K. Prabhakaran [a,*]

[a] Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala, India
[b] Vikram Sarabhai Space Center, Thiruvananthapuram, Kerala, India

HIGHLIGHTS

- Filter-pressing is used for the preparation of composite carbon foams.
- Newspaper waste is used for the preparation of robust carbon-gehlenite composite foams.
- The newspaper-sucrose composites are amenable to machining using conventional tools and equipment.
- The composite carbon foams have a combination of micro, meso and macroporous structure.
- The carbon foams show low thermal conductivity and excellent fire resistance.

GRAPHICAL ABSTRACT



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ABSTRACT

Carbon composite foams containing 13.6 to 41.8 wt% of gehlenite were obtained by carbonizing newspaper-sucrose composites prepared by filter-pressing of waste newspaper pulps in sucrose solution (0 to 700 g/L) followed by drying. The drying and carbonization shrinkages in the filter-pressing direction depend on the sucrose solution concentration. However, the diametrical shrinkage during drying (marginal) and carbonization were controlled by the newspaper micro-ribbons in the pulp oriented perpendicular to the filter-pressing direction. The newspaper-sucrose composites prepared at sucrose solution concentrations in the range of 400 to 700 g/L were amenable to machining using conventional tools and equipment. The density, compressive strength and Young's modulus of the carbon composite foams increased with an increase in sucrose solution concentration with values observed in the ranges of 0.18 to 0.39 g/cm^3, 0.2 to 1.7 MPa and 3.4 to 69.9 MPa, respectively. The carbon composite foams had a hierarchical micro, *meso*, and macropore structure evidenced by SEM analysis and N_2 adsorption-desorption isotherm. The foams showed excellent fire resistance and low thermal conductivity values in the range 0.1 to 0.2 W/m·K. The robust carbon composite foams prepared from the waste newspaper without using any harmful chemicals are a candidate for high temperature thermal insulation.

1. Introduction

Carbon foams are lightweight macroporous carbon materials having excellent fire resistance, tunable electrical and thermal conductivities and capability to absorb sound and electromagnetic waves. Their potential in advanced technological applications such as high temperature

* Corresponding author.
E-mail address: kp2952002@gmail.com (K. Prabhakaran).

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thermal protection, host structure for thermal energy storage materials, electrodes for batteries, EMI shielding, acoustic panel and lightweight fire resistant structural material for ship building have created renewed interest in them [1–6]. They are generally prepared by foaming, setting and carbonization/graphitization of either synthetic polymers such as phenolic resins, furfural resin, polyarylacetylene, polybenzoxazine, cyanate ester, polyimide, or pitches [7–15]. The pitch derived carbon foams are graphitic with high thermal conductivities (40 to 150 W/m·K) whereas the synthetic polymer resin-based foams are amorphous with low thermal conductivities (0.023 to 0.54 W/m·K) [7,10,13,15–17]. Mechanical, thermal and electrical properties of carbon foams are modulated by incorporating additives such as carbon fiber, carbon nanofiber, carbon powder, carbon microspheres, carbon nanotube, graphene, ceramic whiskers, aluminosilicate, and nanoclay. [18–27].

The pitches and monomers of synthetic polymer resin for carbon foam preparation are based on either petroleum or coal which are depleting. Therefore, there is a quest for naturally renewable precursors and non-polluting processing protocols for the preparation of carbon foams for sustainable development. Further, the utilization of biowastes as raw material for the production of carbon materials not only avoids land pollution due to their dumping but also prevents carbon dioxide emission because of their subsequent biodegradation. Natural renewable materials of plant origin such as tannin, olive stone, lignin, liquefied sawdust, starch, and sucrose are used as sustainable precursors for the preparation of amorphous carbon foams with low thermal conductivities (0.025 to 0.348 W/m·K) [28–36]. A considerable improvement in the thermal conductivities of tannin and sucrose derived carbon foams is achieved by incorporating graphite powder as a filler [6,37].

Paper waste, a solid bio-waste creating major concern for most of the municipalities all over the world, is utilized for the preparation of flexible carbon aerogel [38,39]. In these works, cellulose aerogels produced from waste newspaper through a tedious process involving chemical treatment with NaOH/urea solution, refrigeration, thawing, coagulation, solvent exchange and freeze drying are pyrolysed to produce flexible carbon aerogels. The carbon aerogels produced from the paper waste have a very low density (6 to 24 mg/cm^3) and are potential materials for oil absorption [39,40]. However, they do not possess the adequate mechanical strength to be used in any thermo-structural applications. To the best of our knowledge, there are no reports on the preparation of mechanically robust carbon foam from waste paper. In the present work, we report a filter-pressing method for the preparation of mechanically robust carbon foams from waste newspaper pulp produced in sucrose solution.

2. Experimental

The waste newspaper was collected from the author's house. The food grade sucrose was procured from a local market. Distilled water was used for the preparation of solutions. The solutions of various concentrations were prepared by dissolving the sucrose in distilled water. The concentration expressed throughout this paper is in grams of sucrose per liter of water. 50 g of the shredded waste newspaper was soaked in 1.5 L of sucrose solution for 1 h. The newspaper soaked in sucrose solution was thoroughly mixed using a kitchen mixture for 5 min to form a newspaper pulp. The pulp was filter-pressed using a setup fabricated in-house using a filter flask of 1 L capacity, a Buchner funnel and PVC pipe of 10 cm inner diameter and 30 cm length. A photograph of the filter-pressing setup is shown in Fig. 1. The newspaper pulp was poured into the PVC pipe and consolidated to a cylindrical body of 3 cm height and 10 cm diameter by vacuum filtration using a vacuum pump. A gentle pressure was applied towards the end of the consolidation by inserting a mild steel piston (Fig. 1) to prevent the lateral shrinkage at the top of the body. The spent sucrose solution collected in the filter flask was used for the preparation of subsequent samples. The

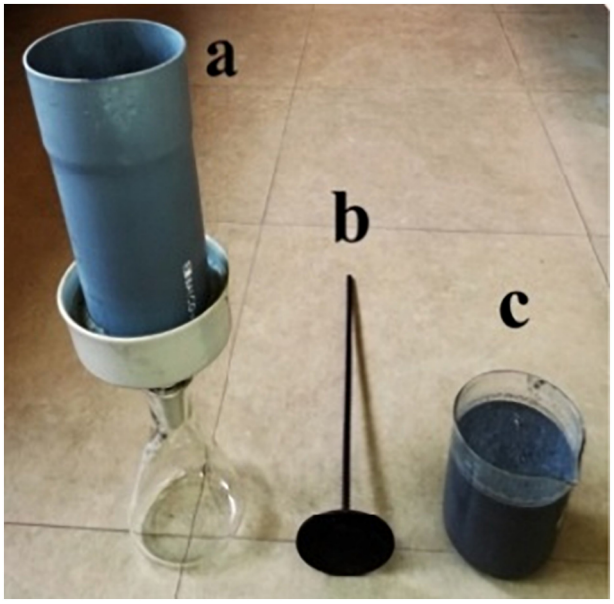

Fig. 1. Photograph of (a) filter-casting setup, (b) mild steel piston and (c) newspaper pulp.

consolidated wet bodies removed from the filter-pressing setup was dried in an air oven at 80 °C to a constant weight and then at 100 °C for 4 h to form newspaper-sucrose composites. The newspaper-sucrose composites were annealed at 160 °C for 12 h in an air oven. The heating rate of 1 °C/min was used from 100 to 160 °C. The annealed newspaper-sucrose composites were heated in an inert atmosphere furnace at 900 °C for 2 h for carbonization. The heating rate was 1 °C/min. High pure argon (99.99%) was used to create the inert atmosphere. The same inert atmosphere was maintained during cooling of the furnace. The shrinkages during drying and carbonization were measured from the respective initial and final dimensions. The density of the newspaper-sucrose composites and carbon composite foams were measured from their weights and dimensions. The rectangular bodies prepared from the newspaper-sucrose composites and carbon foam composites were used for the density measurements.

The viscosity of the newspaper pulp was measured using Brookfield viscometer (RVT model, Brookfield Engineering Inc., Middleboro, MA) with the help of a small sample adapter and a cylindrical spindle (SC21). The compressive stress-strain measurements of the filter-pressed wet bodies, newspaper-sucrose composites, and carbon foam composites were measured using a Universal Testing Machine (Instron5500, Instron USA). Cylindrical filter-pressed wet bodies of 30 mm height and 100 mm diameter were used for the stress-strain measurements. Newspaper-sucrose composite samples of 25 mm × 25 mm × 20 mm size used were prepared by cutting using a hacksaw blade. The carbon foam samples used were of 24 mm × 24 mm × 12 mm size. A loading rate of 0.5 mm/min was used in all the compressive stress-strain measurements. Thermogravimetric analysis (TGA) analysis was carried out in an air atmosphere using a thermo-gravimetric analyzer (Q-50, TA Instruments, USA) at a heating rate of 5 °C/min. The particle size distribution of the gehlenite powder (ash obtained from newspaper) was measured using a particle size analyzer (Master sizer 2000, Malvern, USA). The X-ray diffraction (XRD) analysis of the carbon foam samples was carried out using an X-ray diffraction analyzer (Bruker D8-Discover X-ray diffractometer, Germany). The Raman spectrum of the carbon composite foam samples was recorded using a Raman spectroscope (WITecalpha 300 R confocal Raman microscope, Germany). The skeletal density of the carbon composite foam samples was measured using a helium pycnometer (Micromeritics AccuPyc II 1340). The room temperature thermal conductivity of the carbon foam samples was measured using a transient plane source method