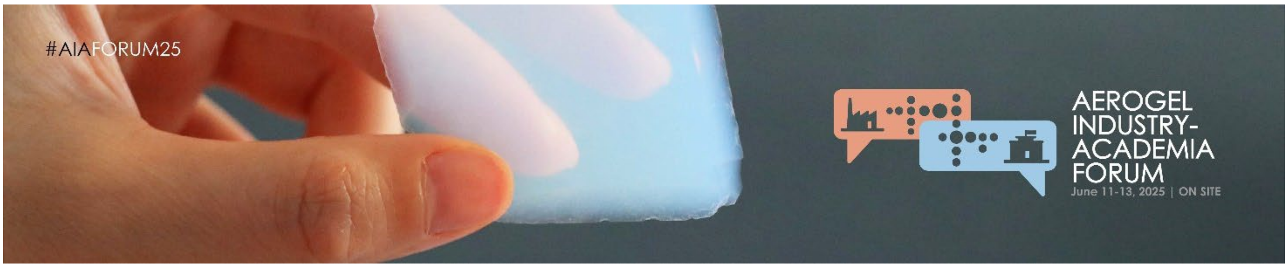


3rd Aerogel Industry-Academia Forum
Processes, Products, Applications & Markets

The aerogel world is undergoing rapid development. On the industry side, new players are entering the market. New aerogel producers, including start-ups but also established materials manufacturers, introduce their products, compete for market share, or aim to develop new applications and markets. In the meantime, traditional manufacturers keep innovating. Silica aerogel remains the most important product, but polymer and biopolymer aerogels are becoming available as well. Other companies focus on developing process technologies or aerogel-based products. On the academic side, there has been a veritable explosion of research into understanding traditional aerogel materials and applications, as well as new aerogel materials combinations, precursors and sustainable raw materials, new aerogel synthesis routes and new potential applications.

5th International Conference on Aerogels for Biomedical and Environmental Applications

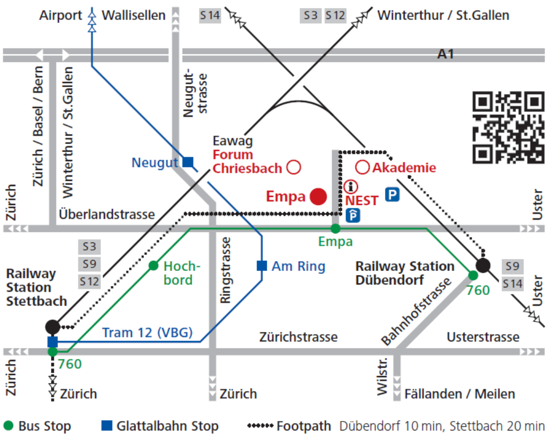
Aerogels are advanced, highly porous materials designed to meet the criteria of biomedical or environmental applications. They can be used as drug carriers, bone grafts, or wound dressings in biomedical applications and as insulators, absorbents, sensors, and catalysts in environmental applications.

Objectives

To strengthen and extend your network in aerogel-related materials, technologies and markets.
To introduce your products and services to the aerogel community through talks, posters or booths.
To learn about the most current research and developments on aerogels.
To meet a pool of newcomers and established specialists in the field as well as potential recruits for your institution.

Who will be there?

Representatives from the aerogel industry (aerogel producers, technology providers, raw material suppliers, formulators), end-users (industrial and building insulation, car industry, pharmaceutical industry), policymakers (NGOs, EC-representatives, funding agencies), regulatory entities and academia (aerogel process engineering field, as well as from application-oriented research in the biomedical, toxicological, environmental remediation, catalysis and thermal insulation).



Practical Information

In-person, on-site event at the Empa Akademie – June 11-13.

Ueberlandstrasse 129, 8600 Dübendorf, Switzerland.

More information and registration details at the event website https://aia-forum.empa.ch/.

Regular participation 570 CHF – Student participation 470 CHF (includes all catering: coffee breaks, 3 lunches, 2 dinners and invitation to the 2025 Aerogel Architecture Award ceremony https://www.empa.ch/web/aaa).

Opportunity to display samples and materials in the Foyer free of charge. Please contact aerogel@empa.ch if this is of interest to you.

Wednesday June 11, 2025

08.15 Registration

09.00 Aerogels for Biomedical Applications (01-07)

09.00 Wim Malfait (Empa)
Opening Remarks

09.10 Stella Plazzotta (University of Udine)
Turning food residues into bioaerogels for fat replacement (Invited)

09.30 Patrina Paraskevopoulou (University of Athens)
AiryBerry: Ready-to-eat snacks based on aerogel and xerogel technology

09.50 Carlos García-González (Universidade de Santiago de Compostela)
Towards novel biomedical uses of aerogels in a sustainable and personalized context (Invited)

10.10 Coffee break

10.40 Tamara Athamneh (Jordan University of Science and Technology)
Preparation and Characterization of Copper-Crosslinked Alginate-Hyaluronic Acid Aerogels as Potential Wound Dressing Materials with Enhanced Antibacterial Properties

11.20 Ana Iglesias-Mejuto (Universidade de Santiago de Compostela, ICMAB-CSIC)
In vivo monitorable aerogel implants for tissue engineering

11.20 Umair Ashraf (Polytechnic of Turin)
pH-Dependent Morphology and Characteristics of Whey Protein Isolate Aerogel: Implications for Biomedical Application

11.40 Clara López-Iglesias (Universidade de Santiago de Compostela)
Green sterilization and disinfection services for aerogels and other sensitive products (Invited)

12.00 Lunch

13.30 Environment and sustainability (08-16)

13.30 Erkey Can (Koç University)
Metal Organic Framework Aerogel Composites (MOFACs) for CO_2 Capture

13.50 Pawel Ziemiański (Empa)
Pushing the hydrophobicity of silica aerogels for direct air capture of CO_2 (Invited)

14.10 Markus Niederberger (ETH Zurich)
Self-Assembly of Nanoparticles into Aerogels (Invited)

14.30 David Kiwic (ETH Zurich)
Palladium-Impregnated Aerogels for Sustainable Chemical Production

14.50 İlkay Turhan Kara (Istanbul Arel University)
Incorporating Environmental Burdens into the Optimization of Mesoporous Material Production Processes

15.10 Coffee break

15.40 Željko Tomović (Eindhoven University of Technology)
Closed-loop recyclable high-performance organic aerogels (Invited)

16.00 Mengmeng Li (Empa)
Recyclable Polyimide Aerogel- Challenges and Opportunities (Invited)

16.20 Eleni Effraimopoulou (MINES Paris, PERSEE)
Next-generation thermal superinsulation with pectin composite aerogels (Invited)

16.40 Ioannis Michaloudis (American University of Cyprus)
Silica Aerogel in Luxury Design: The AirSwipe *bag (Invited)*

17.00 Welcome reception

Thursday June 12, 2025

08.30 Registration

09.00 Batteries, Technology and Processes (17-24)

09.00 Ruben-Simon Kühnel (Empa)
Thermal runaway in lithium-ion and post-lithium-ion batteries (Invited)

09.20 Yunhong Wang (IBIH Advanced Materials)
IBIH Aerogels: From Commercialized Uses to Upcoming Industrial Deployments (Invited)

09.40 Steve Devine (Graphene Composites Ltd)
Evolution in Inherent Vibration-Suppressive Materials (Invited)

10.00 Barbara Milow (German Aerospace Center DLR)
Aerogel Launch Factory – Feasibility Study and Next Steps (Invited)

10.20 Coffee break

10.40 Marcus Worsley (Lawrence Livermore National Laboratory LLNL)
Advances in Aerogels and Additive Manufacturing (Invited)

11.00 Gilberto Siqueira (Empa)
Nanocellulose aerogels – tailored processes for advanced properties (Invited)

11.20 Satoru Takeshita (National Institute of Advanced Industrial Science and Technology AIST)
Recent progress in biopolymer-based aerogels: Microstructure formation (Invited)

11.40 Barbara Milow (German Aerospace Center DLR)
What can complex three dimensional aerogel components achieve and how are they manufactured?

12.00 Lunch

13.00 Poster session

P01 – Harun Venkatesan (IIT Delhi) *Sustainable Aerogel Liners for Thermal Insulation*
P02 - Atelšek Hozjan (U. Maribor) *Exploring the properties of agar aerogels for potential biomedical applications*
P03 – Alberto Saitta (U. Udine) *Conversion of fruit/vegetable waste into bioaerogels for active food packaging solutions*
P04 – Marina Borzova (TU Eindhoven) *Impact of sodium and synthesis parameters on silica aerogel from waterglass*
P05 – Aamir Iqbal (KIST, Empa) *Ultralight, Conductive & Robust $Ti_3C_2T_x$ MXene-CNTs Aerogels for EMI Shielding*
P06 – María Blanco-Vales (USC) *Sustainable production of reprocessed starch aerogels*
P07 – Shanyu Zhao (Empa) *3D printing of aerogels*
P08 – Jaime Lledó (U. Valladolid) *Methodologies to enhance the performance of thermally insulating PLA aerogels*
P09 – Mitchell Barrett (UBC) *Organic Aerogels Containing Chitosan Bio-Polymer From European Green Crab (EGC) Shells*
P10 – Wim Malfait (Empa) *Stable Graphitic Networks on Ultra-porous Polyimide Aerogels via Solvent-Guided Structuring*
P11 – Jessica Kroener (DLR) *Lab-scale and continuous industrial sulfur infiltration methods for metal-sulphur batteries*

14.30 Product development and simulations (25-32)

14.30 Alyne Lamy (Thermulon)
Characterisation Challenges in Aerogel Scale-Up: from Lab to Commercial Scale Manufacturing (Invited)

14.50 Laurens Snels (KU Leuven)
Surface Secrets: Characterizing the Hydrophobicity of Silica Aerogel Granules

15.10 Matthias Koebel (siloxene AG)
QT-polysiloxanes – enabler technology for hybrid nano-materials and sol-gel chemistry (Invited)

15.30 Steve de Pooter (Aerobel BV)
Aerobel: Innovative insulation materials and adhesives (Invited)

15.50 Coffee break

16.20 Stephen A. Steiner III (Aerogel Technologies)
Commercializing Aerogels is Hard. Here's Why. (Invited)

16.40 Nicholas Leventis (Aspen Aerogels Inc.)
Carbon and Graphite Aerogels: Morphology, Properties, Applications (Invited)

17.00 Sandra Galmarini (Empa)
New insights into the 3D structure of colloidal aerogels (Invited)

17.20 Prakul Pandit (German Aerospace Center DLR)
PoreX: Digital Materials Development

18.00 Conference Dinner

Friday June 13, 2025

08.30 Registration

09.00 Insulation (33-37)

09.00 Andreas Gürtler (European Industrial Insulation Foundation)
Understanding and Using the EN 17956 Standard for Technical Insulation – and the Case for Mandating Energy Class C (Invited)

09.20 Stephan Möller (Ultima, Armacell)
From Furnace to Cold Space: Aerogel Insulation System Tests in Extreme Conditions (Invited)

09.40 Beatriz Merillas (University of Burgos, University of Valladolid)
Breaking Down Heat Transfer Mechanisms in Aerogels and Strategies for their Minimization

10.00 Frank Lotter (Center for Applied Energy Research CAE)
Reinforced Carbon xerogels for high temperature insulation applications

10.20 Luisa Durães (University of Coimbra)
Aramid-reinforced silica-cork aerogels for thermoacoustic barriers

10.40 Coffee break

11.00 Round table

12.00 Lunch

13.30 Aerogels for buildings (38-40)

13.30 Amanda Stubbs-Perry (AeroShield Materials Inc.)
Scaling Monolithic Aerogel Sheets for Window Applications (Invited)

14.10 Beat Kämpfen (Kämpfen zinke + partner)
Aerogel: all-rounder for conservation (Invited)

14.20 Mike O'Connor (Keey Aerogel) & Sebastian von Stauffenberg (Agitec AG)
SNUG: EU project to develop sustainable insulation solutions for the building industry - Aerogel-Based Innovations in Residential Retrofitting: Monitoring and Material Development (Invited)

14.50 Wim Malfait (Empa)
Closing remarks

15.30 AAA 2025: Aerogel Architecture Award Ceremony
Optional Tours of NEST

Turning food residues into bioaerogels for fat replacement

S. Plazzotta[1], L. Manzocco[1]
[1] *Department of Agri-Food, Environmental and Animal Sciences, University of Udine, Udine, Italy*

Abstract

Although the relationship between saturated fat consumption and chronic diseases is well-established, its substitution in foods is far from simple, due to its essential structural and sensory roles. A promising strategy is based on the structuring of liquid oil, rich in healthy unsaturated fatty acids, into semi-solid materials with the structural properties of fats. Among oil structuring methods, the aerogel-template approach refers to the use of food-grade bioaerogel particles, able to form a network entrapping large liquid oil amounts. In the last 8 years, our research group has studied the possibility of applying this strategy to develop oil-structuring bioaerogel particles from food residues, in line with the current paradigm of circular processing, allowing for optimal use of food biomass.

This contribution illustrates the progress in the aerogel technology to turn food residues into bioaerogel particles intended as ingredients for fat substitution.

Results show that bioaerogel particles can be produced from a wide variety of food industry residues, given that they can form hydrogels or are themselves hydrogel-like materials. In this case, tasteless and colorless bioaerogel particles can be obtained by subjecting the hydrogels or hydrogel-like materials to ethanol solvent exchange (SE) and supercritical-CO_2-drying (SCD), differently associated with operations able to control particle size. If the obtained particles show dimensions lower than 25 µm, they can be successfully used to structure oil into low-saturated-fat alternatives, without off-flavor or grainy mouth perception.

These results will be illustrated with reference to aerogel particles obtained from: (i) hydrogels produced from compounds extracted from food residues (proteins from milk whey and substandard peas, and cellulose from discarded plant tissues) and (ii) hydrogel-like materials (discarded fruit and vegetable tissues) not requiring extraction of gelling compounds. Production process optimization and costs, characterization of physical properties (porosity, morphology, BET surface area, apparent density) and fat replacement performance (oil holding capacity, attitude to be used in low-SFA cocoa spreads) of bioaerogel particles will be critically presented, discussing venues for progress and current gaps to be filled.

This snapshot on aerogel technology unveils a promising present, worthy of the efforts of an active scientific community to meet the needs of a near-future food market.

Acknowledgments

This work was financed by: the EU-NextGenerationEU projects PRIN2022 UPea (Prot. 20222P5C3E) and UNITED (Prot. 2022P8ZAHW); the Interreg VI-A Italia – Österreich 2021-2027 project NETTLE; the UNIUD DM-737 project UNITED.

AiryBerry: Ready-to-eat snacks based on aerogel and xerogel technology

P. Paraskevopoulou*[1], V. Valdramidis[2], M. Dasenaki[2]

[1] *Inorganic Chemistry Laboratory, Department of Chemistry, National and Kapodistrian University of Athens, Panepistimiopolis Zografou, 15771 Athens, Greece*

[2] *Food Chemistry Laboratory, Department of Chemistry, National and Kapodistrian University of Athens, Panepistimiopolis Zografou, 15771 Athens, Greece*

* *paraskevopoulou@chem.uoa.gr*

Abstract

Overweight and obesity are major risk factors for chronic diseases like heart disease and stroke. They are largely preventable through healthier lifestyles, including better eating habits and regular physical activity. The food industry can support this effort by reducing unhealthy ingredients in processed foods, offering affordable healthy options, and limiting the marketing of unhealthy foods, particularly to youth. According to the World Health Organization, structural barriers to accessing affordable, healthy food contribute significantly to obesity, highlighting the need for nutritious, sustainable, and cost-effective food solutions.

In this work, nutrient-packed solid food compositions containing aerogels or xerogels are introduced for use as healthy snacks, food ingredients, additives, and/or dietary supplements [1]. These products serve as nutritious toppings or ready-to-eat snacks, promoting fullness and aiding in control of calorie intake. Additionally, they utilize edible food industry by-products and surplus fruits or vegetables, helping to reduce food waste and production costs. The food compositions are shelf-stable without refrigeration, rich in fibers, antioxidants, and essential nutrients, completely free of additives, processed sugars, and artificial sweeteners. They are produced without toxic chemicals, solvents, or extreme temperatures and are designed to promote the feeling of satiety. Therefore, they offer a sustainable, eco-friendly alternative for healthy eating.

References

[1] A. Andreou, L. Avdylaj, V. Valdramidis, K.V. Vourliotaki, M. Dasenaki, A.M. Zoi, A. Zoi, A. Kaplanis, E. Kollia, A. Kopsacheili, A. Mastrotheodoraki, P. Paraskevopoulou, G. Prapa, G. Raptopoulos, E. Sigala, *Ready-to-eat shelf-stable food compositions based on aerogel and xerogel technology*, 20240100545, 01-08-2024.

Acknowledgments

The Special Account for Research Grants of the National and Kapodistrian University of Athens is acknowledged for financial support.

Towards novel biomedical uses of aerogels in a sustainable and personalized context

C.A. García-González, S.M. Gomes, M. Blanco-Vales, Carlos Illanes-Bordomás, M. Carracedo-Pérez, A. Iglesias-Mejuto, C. López-Iglesias

AerogelsLab, Dept. Pharmacology, Pharmacy and Pharmaceutical Technology, I+D Farma (GI-1645), Faculty of Pharmacy, iMATUS and Health Research Institute of Santiago de Compostela (IDIS), Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain.

Abstract

Biomedical industry is facing challenges with respect to the rational use of raw materials and the search of patient-specific solutions. Aerogels have intrinsic properties of added value for biomedical uses, including extracellular matrix-like structure, light weight and high drug loading capacity. The engineering of aerogels in terms of format and composition allows their production to specific uses. Recent aerogel advances in biomedicine will be herein presented.

In terms of aerogel format, the production of particles in different sizes (nano, micro and macroparticles) and configurations (spheres, coated particles, core-shell particles) meet several demands. Aerogel microspheres have outstanding aerodynamic properties for pulmonary drug delivery and fluid absorption for wound healing. Coated and core-shell aerogel particles provide tunable drug release profiles of interest in oral drug delivery [1]. Finally, the production of aerogels with personalized macrostructures by 3D-printing and the advent of *in situ* sterilization possibilities allow the use of aerogels for regenerative medicine [2].

Regarding the composition, polysaccharides and proteins are the preferred aerogel matrices in terms of performance and of sustainability. These matrices may have intrinsic biological features and its combination with the incorporation of drugs or inorganic nanoparticles endows the aerogels with several bioactive and imaging properties suitable for diagnostics and therapy. Novel post-processing and reuse approaches for these aerogel sources are currently emerging for economic optimization.

References

[1] C. Illanes-Bordomás et al. Pharmaceutics, vol. 15, 2639, 2023.
[2] M. Carracedo-Pérez et al. J CO2 Util, vol. 86, 102891, 2024.

Acknowledgments

Work funded by MICIU/AEI/10.13039/501100011033 [grants PID2023-151340OB-I00 and PDC2023-145826-I00], Xunta de Galicia [ED431C2022/2023], Xunta de Galicia-GAIN [Ignicia Programme 2021, ECOBONE], Aceleradora USC 2025, ERDF/EU and European Union NextGenerationEU/PRTR. Work carried out in the framework of the ECO-AERoGELS COST Innovators' Grant (ref. IG18125) and funded by the European Commission.

Preparation and Characterization of Copper-Crosslinked Alginate-Hyaluronic Acid Aerogels as Potential Wound Dressing Materials with Enhanced Antibacterial Properties

Tamara Athamneh[a*], Mohammad AA Al-Najjar[b], Raghad Ghreqat[a], Alaa Abuawad[b], Areen Alshweiat[c], Muna Barakat[d], Tasneem Odat[a], Wael Fatehi Abu-Irmaileh[e], Adel Maher Hamdan[e], Razan Altarabeen[f] and Irina Smirnova[f]

[a] *Institute of Nanotechnology, Jordan University of Science and Technology, Irbid 22110, Jordan*

[b] *Department of Pharmaceutical Sciences and Pharmaceutics, Faculty of Pharmacy Applied Science Private University, Amman, 11931, Jordan,*

[c] *Department of Pharmaceutics and Pharmaceutical Technology, Faculty of Pharmaceutical Sciences,The Hashemite University, Zarqa 13133, Jordan*

[d] *Department of Clinical Pharmacy and Therapeutics, Faculty of Pharmacy, Applied Science Private University, Amman, Jordan*

[e] *Quatro-P4 company for industrial and commercial investment, Amman, 11947, Jordan.*

[f] *Institute of Thermal Separation Processes, Hamburg University of Technology, Eissendorfer Strasse 38, 21073, Hamburg, Germany*

* email address: tkathamneh@just.edu.jo

Abstract

The development of advanced wound dressing materials with enhanced antibacterial properties is critical for improving patient outcomes and reducing infection risks. In this study, a novel bio-based aerogel composed of copper-crosslinked alginate and hyaluronic acid was prepared and evaluated for such purposes. Alginate and hyaluronic acid were selected as base polymers due to their demonstrated biocompatibility, biodegradability, and regulatory approval for medical applications. Copper ions were employed as crosslinking agents based on their dual functionality: Structural stabilization through ionic interactions with polymer carboxyl groups, and the intrinsic antimicrobial activity via multiple mechanisms including membrane disruption and reactive oxygen species generation.

The bio-based aerogel was prepared by gelation and supercritical- CO_2 drying. Different concentrations of Cu^{+2} solutions (1%, 2%, 3 %, and 4%) were used to produce Cu^{+2}/hydrogel/aerogel, with fixed concentrations of 2 % of alginate-hyaluronic acid solutions. The prepared materials were characterized using scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), BET-surface area analysis and energy-dispersive X-ray fluorescence (XRF). Moreover, the aerogel wound dressing properties were evaluated in term of fluid uptake and antibacterial activity.

The physicochemical characterization of the prepared aerogels revealed their unique structural and morphological features, which are influenced by copper ion concentration and crosslinking time.Regarding their wound dressing evaluation, both aerogel and hydrogel were found to have antibacterial properties when tested on Staphylococcus aureus with inhibition zone of (36mm, 23mm) and Escherichia coli (31.6mm, 21mm), for hydrogel and aerogel respectively. Also, excellent fluid uptake was found reach up to 743%. These findings underscore the potential of copper-crosslinked alginate-hyaluronic acid aerogels as innovative wound dressing materials that combine superior antibacterial efficacy with excellent fluid management, paving the way for improved wound healing solutions.

Acknowledgments

This work was financially supported by the deanship of scientific research at Jordan University of Science and Technology grants numbers (20220193) and The institute of thermal separation at Hamburg University of Technology.

In vivo monitorable aerogel implants for tissue engineering

Iglesias-Mejuto, A[1,2,*]; Laromaine, A[2]; Pinto Reis C[3,4]; García González, CA[1]
[1]*AerogelsLab, I+D Farma Group (GI-1645), Universidade de Santiago de Compostela, Santiago de Compostela, Spain.*
[2]*ICMAB-CSIC, Campus UAB, Bellaterra, Spain.*
[3]*iMed. ULisboa, Faculty of Pharmacy, Universidade de Lisboa, Lisboa, Portugal.*
[4]*IBEB, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, Lisboa, Portugal.*
ana.iglesias.mejuto@rai.usc.es

Abstract

Aerogels are attractive structures for biomedical applications due to their advanced physicochemical and biological performances. However, monitoring them and their degradation products through an *in vivo* bioimaging approach after implantation still represents an important challenge. The recently proposed win-win combination of 3D-printing and supercritical fluids technologies can yield aerogels loaded with upconversion nanoparticles (UCNPs), also known as the next generation of fluorophores. In this work, UCNPs-loaded aerogels were obtained by the dual processing strategy to yield traceable scaffolds by fluorescence-based bioimaging. Physicochemical and biological performances of the implants were studied by confocal, scanning and transmission electron microscopies, nitrogen adsorption-desorption analysis and different cell studies. The *in vivo* biocompatibility and the bioimaging performance of the aerogels were *in vivo* tested in a murine model. The UCNPs-loaded aerogels represent an alternative towards the development of *in vivo* long-term traceable implants.

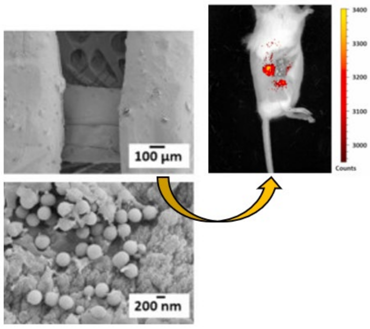


Fig 1. UCNPs-loaded aerogels and their monitoring by an in vivo bioimaging approach.

Reference

Iglesias-Mejuto A, et al. Bioact. Mater. 2024; 41:471.

Acknowledgments

This work was funded by MICIU/AEI/10.13039/501100011033 [grants PID2023-151340OB-I00, PDC2022-133526-I00 and PDC2023-145826-I00], Xunta de Galicia-GAIN [Ignicia Programme 2021, ECOBONE], ERDF/EU and European Union NextGenerationEU/PRTR. Work carried out in the framework of the ECO-AERoGELS COST Innovators' Grant (ref. IG18125) and funded by the European Commission.

3rd Aerogel Industry-Academia Forum
5th International Conference on Aerogels for Biomedical and Environmental Applications
2025, Empa, Switzerland

Title: pH-Dependent Morphology and Characteristics of Whey Protein Isolate Aerogel: Implications for Biomedical Application

U. Ashraf[1], M. Gallo[1], F. Bosco[1], B. Onida[1]
7.Department.of.Applied.Science.and.Technology?Polytechnic.of.Turin?Italy

Abstract

The batch-to-batch variability and inherent tendency of peptides to self-assembly limit the applications of naturally derived protein-based biomaterial in medical implants. In case of protein-aerogels, morphological uniformity influences the interaction of tissue and implant, as water molecules, solutes, and ions bind to the biomaterial, forming a layer that facilitates protein adsorption. Proteins from biological fluids, such as blood and interstitial fluids, adhere to this layer, enabling cells to attach by recognizing bioactive binding sites on the protein layer, rather than directly to the material [1]. Bovine Whey Protein Isolate (WPI) includes globular proteins (β-lactoglobulin, α-lactalbumin, serum albumin, immunoglobulins etc.), lipids (phospholipids), and mineral content (such as Ca, P, Fe, and K), making it a promising precursor biomaterial for biomedical purposes. In this study, we explore the WPI-aerogels potential in biomedical application focusing on aerogels as antibacterial wound dressing, as incidence of chronic wounds remains an ever-growing challenge [2] [3]. To synthesize protein-based aerogel [4], a 20% WPI suspension was stored at 4°C for over 12 h to ensure full hydration. Thermally induced hydrogels were synthesized under various gelation conditions, specifically at different pH levels (2 - 9), gelation temperatures (80 - 90°C), and gelation times (30 min). Prior to supercritical CO_2 ($ScCO_2$) drying, the hydrogel samples were immersed in absolute ethanol solutions of increasing concentrations (50%, 70%, and 99% for 24 h) to eliminate residual water. The aerogels were subsequently produced through $ScCO_2$ drying at a temperature of 40°C and a pressure of 115-120 bar. Textural and physico-chemical properties of resulting aerogels were characterized, as well as their absorption properties, as illustrated in Fig. 1.

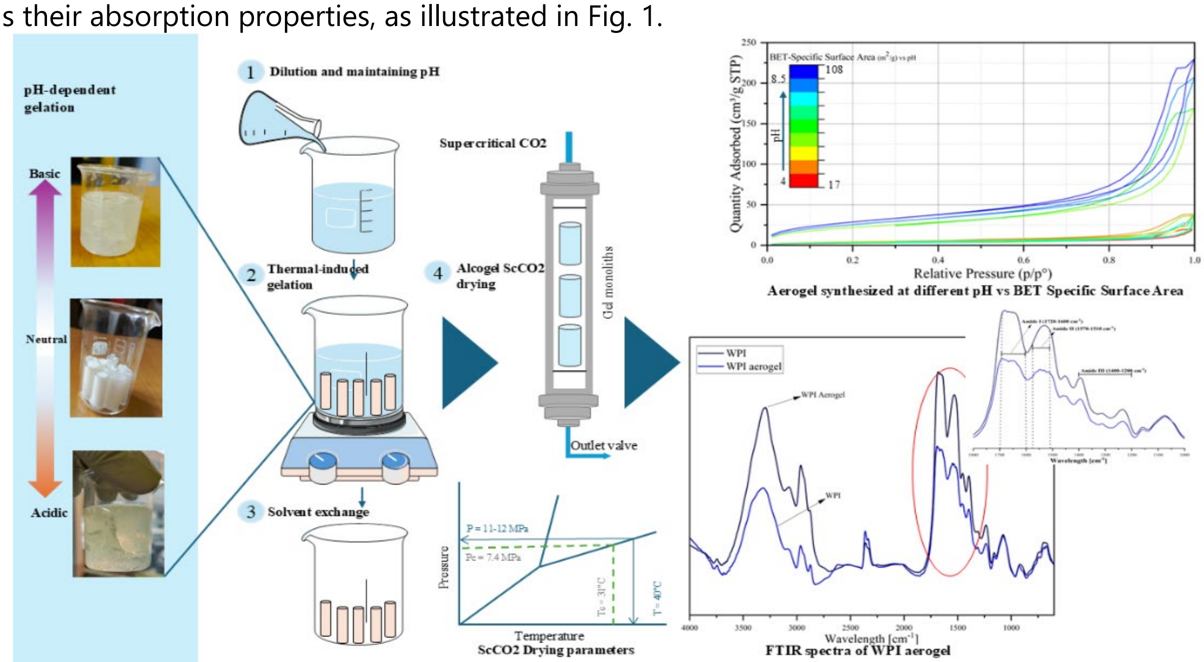


Fig. 1. Whey Protein Isolate Aerogel Synthesis

WPI's globular proteins initiate the gelation process by enhancing intramolecular interactions, leading to the aggregation of protein molecules into a gel network. The synthesis parameter e.g. pH, temperature, gelation time of hydrogels influenced the color, strength, and mesoporosity of aerogels. Following the $ScCO_2$ drying process of hydrogels synthesized at varying pH values, the aerogel produced at pH of 4.6 showed a BET-specific surface area of 17 m^2/g, whereas the aerogel synthesized at an alkaline pH 8.5 showed a significantly higher specific surface area of 108 m^2/g. As the pH increased, both the specific surface area and the percentage of shrinkage increased. A direct correlation between pH and shrinkage (volume decreased from hydrogel to aerogel), as well as surface area, was observed. The shrinkage of aerogels is affected by the pH of solution and time/temperature of gelation. Whey protein morphology changes from spherical to either granular or fibrous gel by fluctuating the pH of protein solution. At the acidic pH fibrous self-assembly initiates by hydrophobic interaction or hydrogen bond while the alkaline pH initiates the granular self-assembly by disulfide bond. Transparent hydrogels or aerogels were obtained at the pH below 4 or above 8 [5]. For the samples obtained at pH below 4, cracks appear in hydrogel during the solvent exchange and the aerogel was deformed during $ScCO_2$ drying process. The swelling ratio reached a peak increase of approximately 820% in the aerogel synthesized at pH 8.5. The swelling ratio indicates the water absorption capacity as well as high protein adsorption, which is a fundamental premise for cell infiltration and enhanced the angiogenesis. The FTIR spectra and X-ray diffraction indicated that the $ScCO_2$ drying process did not alter the WPI molecular structure.

Keywords
Aerogel, Whey Protein Isolate, drug delivery, wound treatment, tissue regeneration.

References

1. Barbosa, M. & Martins, M. C. L. *Peptides and Proteins as Biomaterials for Tissue Regeneration and Repair*. (Woodhead Publishing, 2017).
2. Yahya, E. B. *et al.* A review on revolutionary natural biopolymer-based aerogels for antibacterial delivery. *Antibiotics* 9, 1–25 (2020).
3. Eriksson, E. *et al.* Chronic wounds: Treatment consensus. *Wound Repair and Regeneration* 30, 156–171 (2022).
4. Betz, M., García-González, C., Subrahmanyam, R., Smirnova, I. & Kulozik, U. Preparation of novel whey protein-based aerogels as drug carriers for life science applications. *JOURNAL OF SUPERCRITICAL FLUIDS* 72, 111–119 (2012).
5. Kitabatake, N., Doi, E. & Kinekawa, Y. Method for preparing a transparent adjusted milk whey protein and an adjusted milk whey protein product. (1995).

Green sterilization and disinfection services for aerogels and other sensitive products

C. López-Iglesias[1,*], M. Carracedo-Pérez[1], B. Magariños[2], C.A. García-González[1]

[1] AerogelsLab, Dept. Pharmacology, Pharmacy and Pharmaceutical Technology, I+D Farma (GI-1645), Faculty of Pharmacy, iMATUS and Health Research Institute of Santiago de Compostela (IDIS), Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain

2 Departamento de Microbiología y Parasitología, Facultad de Biología-CIBUS and Aquatic One Health Research Center (iARCUS), Universidade de Santiago de Compostela, Spain

**claralopez.iglesias@usc.es*

Abstract

Aerogels are entering new markets as they gain interest from the food, health, and environmental sectors, with uses ranging from water filtration/purification to food ingredients and tissue engineering scaffolds [1]. Biopolymer-based materials are increasingly favored for both safety and sustainability. Many such applications require a disinfection or sterilization treatment of the materials to ensure a minimal microbial load, extending the shelf life of the products, or complete sterility for safe use and regulatory compliance. However, conventional methods like steam, ethylene oxide, or irradiation, may damage sensitive materials (such as biopolymers) due to heat, chemical changes, or toxic residues.

A promising alternative uses CO_2, a safe (both for the user and the operator), product-friendly, and non-toxic option [2]. In supercritical conditions, the CO_2 efficiently inactivates a broad range of microorganisms including resistant forms, leaving no residues and reducing overall processing time by avoiding aeration/drying steps. Finally, CO_2 can be reused from other industrial processes, contributing to a circular economy context.

In this startup project, we offer the processing of batches of materials under previously developed and standardized disinfection/sterilization protocols, as well as the development of new processes adapted to the needs of each client and material.

References

[1] Karamikamkar et al. Adv Sci, vol. 10, 2204681, 2023.
[2] M. Carracedo-Pérez et al. J CO2 Util, vol. 86, 102891, 2024.

Acknowledgments

Work funded by MICIU/AEI/10.13039/501100011033 [grant PID2023-151340OB-I00], Xunta de Galicia [ED431C2022/2023 and ED481D-2024-008], Aceleradora USC 2025 and ERDF/EU. Work carried out in the framework of the ECO-AERoGELS COST Innovators' Grant (ref. IG18125) and funded by the European Commission.

Metal Organic Framework Aerogel Composites (MOFACs) for CO_2 Capture

Hamed Yousefzade[1,2], Aysu Yurdusen[3], Ayça Tüter[2], Gokhan O. Aksu[2], Georges Mouchaham[2], Seda Keskin[2,4], Christian Serre[3], Can Erkey[2,4]*

[1] Department of Chemical Engineering, Yeditepe University, Atasehir, Istanbul, Türkiye

[2] Department of Chemical and Biological Engineering, Koç University, Rumelifeneri Yolu, Sariyer, Istanbul 34450, Türkiye

[3] Institut des Matériaux Poreux de Paris, ESPCI Paris, Ecole Normale Supérieure, CNRS, PSL University, Paris, France

[4] Koç University Hydrogen Technologies Center (KUHyTech), Koç University, Rumelifeneri Yolu, Sariyer, Istanbul 34450, Türkiye

Abstract

Industries such as cement, steel, and chemical manufacturing contribute significantly to global CO_2 emissions which reached an alarming value of 36 Gt. Metal Organic Framework Aerogel Composites (MOFACs) are attracting increasing attention as potential adsorbents for a wide variety of applications including CO_2 capture. In this study, composites of Ca-alginate aerogel with MOFs MIL-160(Al) and MIL-50(Al) (AlgMIL160 and AlgMIL5O) were prepared via sol/gel assisted direct mixing methods followed by supercritical drying as shown in Figure 1.

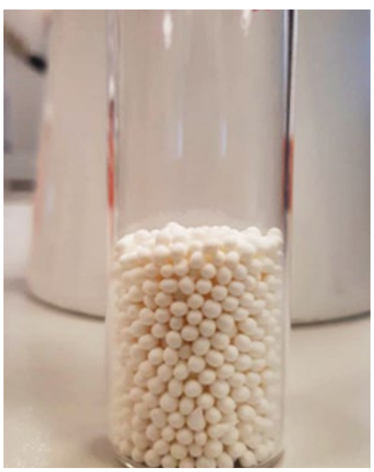


Figure 1. Composite Beads of MIL160 with Alginate Aerogel

The gas sorption, PXRD, FTIR, and SEM characterization results showed that both MIL160(Al) and MIL50(Al) were successfully incorporated into the aerogel network while their structure was preserved. The suitability of AlgMIL160 and AlgMIL50 for CO2 capture was evaluated by both static and dynamic adsorption measurements. Obtained isotherms were successfully fitted to Langmuir model using the Ideal Adsorbed Solution Theory (IAST). The single-component gas adsorption isotherms of CO_2 on AlgMIL160 and AlgMIL50 revealed CO_2 uptakes higher than that of pure MOF showing the synergistic enhancement of MIL-160(Al) and alginate aerogel. Both of the composites had higher CO_2/N_2 selectivities compared to pure MOFs at 25 °C and 1000 mbar. The dynamic adsorption performance of AlgMIL160 and AlgMIL50 were studied by using binary mixture of 15% CO_2/85% N_2 and were close to the single-component CO_2 adsorption with slightly decreased uptake showing the competitive adsorptions between CO_2 and N_2 molecules. These novel nanocomposites with remarkable CO_2 capture performance can be used in packed bed adsorbers without large pressure drops.

Acknowledgement

Financial support of Turkish Scientific and Technological Research Council (TÜBİTAK) under project no. 121N709 is acknowledged. The authors C.S., G.M., and A.Y. acknowledge Agence Nationale de la Rescherche (ANR) under the grant ANR-21-MERA-0006 (MOFAC2CAP project) for financial support.

Pushing the hydrophobicity of silica aerogels for direct air capture of CO_2

P.P. Ziemiański[1, 2, 3], M. Cherotich[1], I. Sadykov[1], C. Mansour[1], I. Lunati[2], M. Ranocchiari[3], W.J. Malfait[1], S. Galmarini[1]

1 Building Energy Materials and Components, Empa - Swiss Federal Laboratories for Materials Science and Technology, 8600 Dübendorf, Switzerland.

2 Laboratory for Computational Engineering, Empa- Swiss Federal Laboratories for Materials Science and Technology, 8600 Dübendorf, Switzerland

3 PSI Center for Energy and Environmental Sciences (CEE), 5232 Villigen PSI, Switzerland

Abstract

Silica aerogels, known for their ultrahigh porosity and tunable surface chemistry, present a compelling platform for the development of sorbents for direct air capture (DAC) of CO_2. Leveraging their large specific surface area and versatile functionalization capabilities, we explored novel strategies to overcome a major drawback in DAC applications - high water sorption under high-humidity conditions.

We developed amine-functionalized silica aerogels by sequential post-grafting of amino groups alongside long-chain aliphatic and trimethylsilyl groups. Aerogels were synthesized via a sol-gel process using pre-hydrolyzed ethyl silicate, followed by tailored surface modifications designed to balance CO_2 affinity with moisture resistance.

Our findings demonstrate that traditional amine-grafted silica gels suffer from extensive water uptake and pore blocking at high relative humidities, severely impairing their DAC viability. In contrast, hybrid-functionalized aerogels exhibited dramatically reduced water sorption (to approximately 5 wt.% at 95% RH, with respect to over 50% wt. at 95% on non-hydrophobized gel) without compromising CO_2 uptake. The co-grafting of long aliphatic chains effectively shielded hydrophilic sites, preserving pore accessibility and maintaining high CO_2/water selectivity even above 70% relative humidity.

Additionally, the materials showed robust performance even after ambient pressure drying. This work highlights the potential of chemically engineered silica aerogels as scalable, humidity-resistant sorbents for carbon dioxide capture directly from ambient air.

Acknowledgments

The authors acknowledge the financial support of the ETH Board in the framework of the Joint Initiative SCENE.

Self-Assembly of Nanoparticles into Aerogels

M. Niederberger

Laboratory for Multifunctional Materials, Department of Materials, ETH Zurich, Vladimir-Prelog-Weg 5, 8093 Zurich, Switzerland

Abstract

The self-assembly of nanoparticles across multiple scales enables the creation of macroscopic architectures with a wide range of properties from a limited number of building blocks. Three-dimensional structures like aerogels stand out for their ability to preserve the unique size-dependent properties of the nanobuilding blocks while providing extensive porosity and large surface areas - key attributes for efficient gas-phase photocatalysis. To maximize the performance of aerogels in photocatalysis, their composition, microstructure, optical transparency and geometry must be precisely matched to the specific requirements of the chemical reaction to be catalyzed and to the photoreactor used for this purpose (Fig 1).[1]

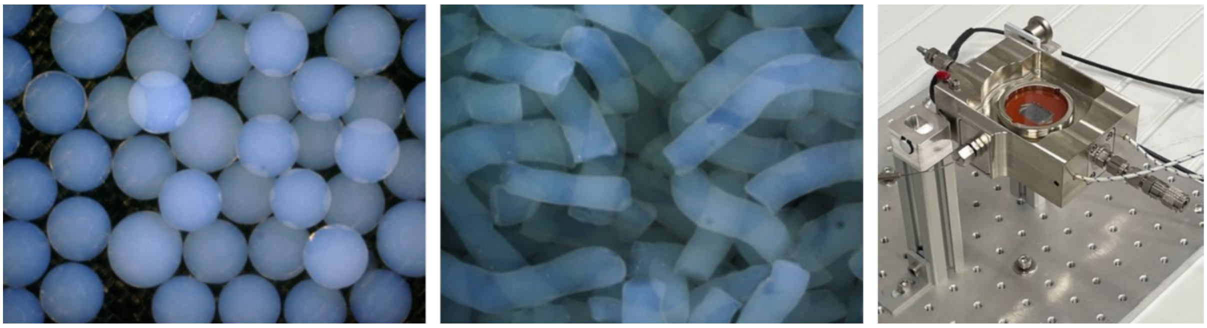


Fig 1. Pictures of titania aerogel beads, worms and photoreactor.

This talk introduces a versatile approach for synthesizing crystalline aerogels through the gelation of colloidal nanoparticle dispersions. By carefully selecting the type and concentration of the nanoparticles and fine-tuning the gelation conditions, the properties of the aerogels can be tailored for specific photocatalytic reactions. A key focus is the optimization of aerogel geometry to match reactor-specific requirements, enabling efficient gas flow and enhanced light penetration. Using photocatalytic hydrogen production from methanol as a case study, we demonstrate how these parameters collectively impact reaction efficiency.

References

[1] F. Matter, D. Kiwic, M. Bernet, E. Tervoort M. Niederberger, "*Shaping nanoparticle-based aerogels for efficient light-driven catalysis*," J. Mater. Chem. A **2025**, Advance Article

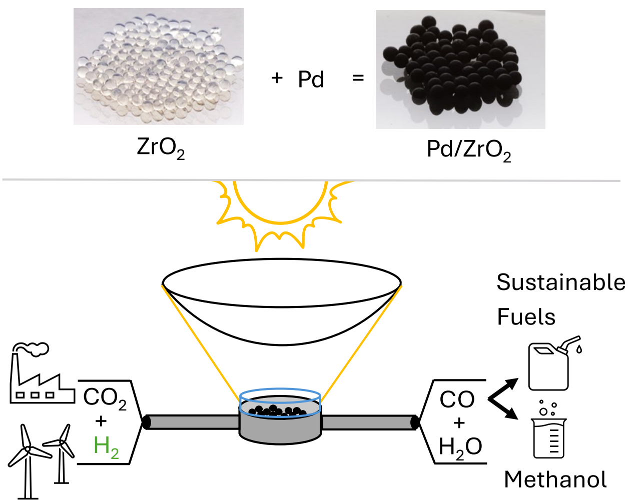
Palladium-Impregnated Aerogels for Sustainable Chemical Production

D. Kiwic[1], L. Räz[1], M. Niederberger[1]
1 Multifunctional Materials Group, ETH Zurich, Switzerland

Abstract

The chemical industry relies heavily on fossil fuels to supply the heat required for many of its processes, contributing ~1.7% of global CO_2 emissions. These emissions could be significantly reduced by using solar light to heat chemical reactions directly. In photothermal catalysis, sunlight is absorbed by the catalyst and converted into heat precisely where it is needed to drive the reaction.

Aerogel-based catalysts are especially effective for photothermal catalysis due to their efficient light absorption and excellent thermal insulation. In our work, we integrate catalytically active palladium (Pd) nanoparticles into zirconia (ZrO_2) aerogels. The Pd nanoparticles act both as photothermal nano-heaters and as active sites for many chemical reactions. When exposed to concentrated light, the aerogel catalyst reaches temperatures sufficient to drive the reaction of green H_2 with CO_2 to produce carbon monoxide (CO), an important intermediate for methanol synthesis and sustainable fuels. Our Pd/ZrO_2 catalyst shows a significantly improved CO production rate compared to standard powdered catalysts.



Our findings highlight the potential of aerogel-supported catalysts to enable light-driven chemical processes, offering a pathway toward the decarbonization of the chemical industry.

Acknowledgments

We thank ETH Zurich for the financial support.

Incorporating Environmental Burdens into the Optimization of Mesoporous Material Production Processes

I. Turhan Kara[1], E. Yapici[2,3], B. Kececi[2,3],
[1] *Istanbul Arel University, Istanbul, Türkiye*
[2] *Yildiz Technical University, Istanbul, Türkiye*
[3] *Omer Lutfu Ozgul Industrial Chemicals Import-Export & Trade Company, Istanbul, Türkiye*

Abstract

Mesoporous materials, due to their high surface area, tunable porosity, and modifiable surface chemistry, are gaining commercial attention, with their global market projected to grow by 8.4% by 2030 [1]. However, their synthesis often requires energy-intensive conditions and hazardous chemicals, raising environmental concerns and scalability limitations [2,3]. Even seemingly sustainable modifications - such as replacing hazardous solvents with biocompatible ones - can lead to increased resource consumption if process interactions are overlooked, underscoring the need for holistic design strategies [4]. Multi-objective optimization approaches that simultaneously enhance material performance and reduce environmental burdens are therefore essential for supporting sustainable scale-up [5].

In this study, recent literature on multi-objective optimization approaches that incorporate environmental criteria was critically reviewed, and a laboratory-scale production of mesoporous silica was presented as a case study integrating these insights. A Box–Behnken design with three variables—temperature, pH, and water-to-sodium silicate ratio—was employed to maximize surface area and porosity while minimizing environmental impacts, quantified through Life Cycle Assessment (LCA) in accordance with ISO 14040–44 standards.

Under optimized conditions (58 °C, pH 6.2, W:Si = 3), a material with 611 m^2/g surface area and 62% porosity was obtained, though with high environmental burdens. Adjusting the parameters to 74 °C, pH 8, and W:Si = 2.4 resulted in a 23% increase in porosity and a moderate decrease in surface area (to 477 m^2/g), while significantly reducing key environmental indicators—such as global warming potential, land use, terrestrial ecotoxicity potential, water consumption, and cumulative energy demand—by 14% to 36%. These findings underscore the potential of environmentally integrated optimization strategies to guide the sustainable scale-up of mesoporous materials.

References

[1] *Virtue Market Research, Global Mesoporous Materials Market Report 2023–2030, 2023.*
[2] *K. Bourikas, C. Kordulis, and A. Lycourghiotis, Microporous Mesoporous Mater., vol. 294, 109874, 2020.*
[3] *C. O'Driscoll, R. D. Gunning, and J. D. Holmes, ACS Sustain. Chem. Eng., vol. 11, no. 5, pp. 1832–1845, 2023.*
[4] *S. Wang et al., Agronomy, vol. 14, no. 11, 2583, 2024.*
[5] *A. K. Malviya et al., Sustainability, vol. 16, no. 15, 6425, 2024.*

Closed-loop recyclable high-performance organic aerogels

Željko Tomović

Polymer Performance Materials Group, Department of Chemical Engineering and Chemistry, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands

E-mail: z.tomovic@tue.nl

Abstract

Organic aerogels are an intriguing class of highly porous and ultralight materials which have found applications in thermal insulation, energy storage, and chemical absorption. These fully cross-linked polymeric networks, however, pose environmental concerns as they are typically made from fossil-based feedstock and the recycling back to their original monomers is virtually impossible. To overcome these obstacles and create next-generation organic aerogels, we designed and developed a set of organic aerogels containing reversible chemical bonds which can selectively be cleaved on demand. The resulting aerogels exhibit low shrinkage, high porosity, large surface area, intrinsic hydrophobicity, pronounced thermal stability as well as outstanding thermal insulating properties. More importantly, the aerogels show excellent chemical recyclability with high monomer recovery yields and purities. This approach allows to prepare fresh aerogels from the retrieved building blocks, thus demonstrating efficient closed-loop recycling. These high performance, recyclable aerogels pave the way for advanced and sustainable super-insulating materials.

References

[1] C. Wang, F. Eisenreich, Ž. Tomović, "Closed-Loop Recyclable High-Performance Polyimine Aerogels Derived from Bio-Based Resources" Adv. Mater. 2023, 35, 2209003.
[2] C. Wang, F. Eisenreich, Ž. Tomović, "Aerogel-To-Sol-To-Aerogel (ASA) Process for Recycling, Repairing, Reprogramming of High Performance Organic Aerogels", Adv. Funct. Mater. 2024, 34, 2314447.
[3] C. Pantazidis, C. Wang, Ž. Tomović, "High-Performance Organic Aerogels Tailored for Versatile Recycling Approaches: Recycling-Reforming-Upcycling", Small 2024, 20, 2403931.
[4] Y. Xiong, C. Wang, L. Dong, Ž. Tomović, "Closed-Loop Recyclable High-Performance Aerogels Derived from Polystyrene", Adv. Funct. Mater. 2025, 2420472.
[5] C. Wang, Y. Chen, F. Eisenreich, Ž. Tomović, "One-Step Synthesis of Closed-Loop Recyclable and Thermally Superinsulating Polyhexahydrotriazine Aerogels", Adv. Mater. 2025, 37, 2412502.
[6] C. Pantazidis, C. Wang, K. Saito, Y-R. Chen, Ž. Tomović, "Chemically Recyclable Polyhexahydrotriazine Aerogels Derived from PET waste", Small 2025, 21, 2502885.

Recyclable Polyimide Aerogel- Challenges and Opportunities

Mengmeng Li, Shanyu Zhao, Wim J. Malfait
Swiss Federal Laboratories for Materials Science and Technology (Empa)
(mengmeng.li@empa.ch)

Abstract

Polyimide aerogels (PI aerogels) exhibit exceptional thermal stability (>200 °C), high mechanical properties (elastic modulus exceeding 100 MPa), and ultralow thermal conductivity (<0.03 W/m·K), positioning them as promising candidates for advanced applications. Nevertheless, the inherent insolubility and non-fusibility of conventional crosslinked rigid polyimide networks pose significant limitations to material recyclability and restrict sustainable applications. Advancements have focused on molecular engineering strategies through the incorporation of flexible chain segments or sterically hindered substituents into polyimide precursors, which not only facilitate sol-gel transitions for aerogel network formation but also impart reprocessability via dynamic bond reconfiguration (Fig.1)[1]. While these developments address critical sustainability concerns, persistent challenges remain in three key domains: (1) cost-effective and scalable manufacturing utilizing environmentally benign solvents; (2) design of simplified synthetic protocols with reduced process complexity; and (3) implementation of multiscale structural engineering approaches to optimize hierarchical porosity and interfacial properties. Addressing these limitations represents a crucial frontier for translating laboratory-scale innovations into industrially viable, eco-conscious polyimide aerogel technologies.

Fig.1. Recyclable polyimide aerogel for harsh environment applications.

References

[1] Li, M., Wu, T., Zhao, Z., Li, L., Shan, T., Wu, H., Zboray, R., Bernasconi, F., Cui, Y., Hu, P., Malfait, W. J., Zhang, Q., & Zhao, S. (2025). Adv Mater, 37(5), e2411599.

Next-generation thermal superinsulation with pectin composite aerogels

E. Effraimopoulou*[1,2], P. Paraskevopoulou[3], C. Pradille[4], L. Chorro-Fernández[1,5], R. Sonnier[6], L. Ferry[6], L. Dumazert[6], P. Gle[7], C. Piegay[7], J. Jaxel[1], A. Rigacci[1], T. Budtova[2]

1 MINES Paris, PSL University, Centre for Processes, Renewable Energies and Energy Systems (PERSEE), 06904 Sophia Antipolis, France

2 MINES Paris, PSL University, Centre for Materials Forming (CEMEF), UMR CNRS 7635, 06904 Sophia Antipolis, France

3 Inorganic Chemistry Laboratory, Department of Chemistry, National and Kapodistrian University of Athens, Panepistimiopolis Zografou, 15771 Athens, Greece

4 Mat Xper, 19 Traverse du Barri, Sophia Antipolis, France

5 INSA Rouen Normandie, Normandie Université, F-76000 Rouen, France

6 PCH, IMT Mines Alès, 6 Avenue de Clavières, 30100 Alès, France

7 Cerema, Université Gustave Eiffel, UMRAE – Laboratoire de Strasbourg, 11 rue Jean Mentelin 67035 Strasbourg, France

* *eleni.effraimopoulou@minesparis.pl.eu*

Abstract

The design of advanced materials for future technologies should be coupled with environmental sustainability, and the development of high-performing bio-based materials is essential for a greener and efficient approach. The potential of bio-aerogels as insulation materials was revealed in the last decade, as several polysaccharide aerogels have lower thermal conductivity than that of air, similar to silica aerogels. For example, pectin aerogels are perfect candidates for thermal insulation applications since they exhibit very low thermal conductivity in room conditions (0.015-0.020 W m^{-1} K^{-1}).[1] As a drawback, pectin aerogels are highly hygroscopic, leading to adsorption and condensation of water vapours, collapse of the porous network, and loss of thermal insulating properties.

In this work, "composite" approach was applied to prevent material aging without altering insulation properties. Hydrophobization of pectin aerogels was achieved via deposition of polyurea on pectin fibrils. The influence of synthesis parameters on the material properties was investigated. Polyurea homogeneously coated the skeletal network of pectin aerogel, resulting in materials with high water contact angles and very low thermal conductivity (down to 0.015 W m^{-1} K^{-1}), which was stable during more than 10 months at 25°C and 80% relative humidity. Other properties related to construction materials were studied (e.g. mechanical properties, acoustic properties, fire retardancy) and revealed the potential of these materials as a new generation of high-performing insulation materials.

References

[1] S. Groult, T. Budtova, *Carbohydrate Polymers*. **2018**, 196, 73.

Acknowledgments

The work was performed in the frame of "The Transition Institute 1.5". This work was supported from the COST Action CA18125 "AERoGELS", funded by the European Commission. We thank Cargil and Covestro for providing materials and the Région Sud – Provence-Alpes-Côte d'Azur for its support in the acquisition of the MAIA 3 SEM (Research Call 2019).

Silica Aerogel in Luxury Design: The *AirSwipe* bag

I.Michaloudis[1]
1 American University of Cyprus, Larnaca, Cyprus, Europe

Abstract

After 2020's Boucheron's *"Goutte de ciel"* this *AirSwipe* bag of the Parisian fashion company Coperni is also made of NASA's nanomaterial silica aerogel, (**Error! Reference source not found.**). The luxury bag is measuring 27x16x6 cm, it is the biggest ever monolith created in silica aerogel and it is weighting only 37 grams. It had been created by the author using the hot supercritical drying method and it had been realised in his ArtSci lab/workshop, the MESL (Membranes and Materials for Environmental Separations Laboratory) and the Archaeological and Building Materials Lab of the Ceramics & Composite Materials Group in the Institute of Nanoscience and Nanomaterials (INN) of NCSR Demokritos, Greece. With the help of a CO_2 laser we created a sintering on the surface of the aerogel, a "skyprint" of Coperni's logo [1].

This bag is between something that does and something that does not exist. It too is in this in-between state, like an angelic state.

Fig 1. The Coperni's AirSwipe bag is made of silica aerogel and was first presented the 5th of March 2024, during the Paris Fashion week, © Coperni

References

[1] Michalou(di)s I, Carroll MK, Kupiec S, Cook K, Anderson AM. Facile method for surface etching of silica aerogel monoliths. J Sol-Gel Sci Technol (2018), https://doi.org/10.1007/s10971-018-4721-z

Acknowledgments

Empa Swiss Laboratories for their invitation and the American University of Cyprus, Larnaca, Cyprus, EU for the funding of this trip.

Thermal runaway in lithium-ion and post-lithium-ion batteries

R.-S. Kühnel[1], C. Battaglia[1,2,3]
1 Empa, Dübendorf, Switzerland
2 ETH Zurich, Zurich, Switzerland
3 EPFL, Lausanne, Switzerland

Abstract

Battery safety is becoming increasingly important considering the ever-growing number of battery-powered devices humans come into close contact with. Thermal runaway, which is the self-accelerating heat generation of a battery that can lead to fire or explosion, is a particularly dangerous safety hazard.[1] The first part of the presentation gives a brief introduction to the causes and stages of thermal runaway in lithium-ion batteries. In the second part, various strategies to suppress or mitigate thermal runaway will be discussed. Among these strategies are active material and separator modifications, liquid electrolytes with suppressed flammability (e.g., via flame retardants[2,3]) solid electrolytes, thermal management systems, insulation, early detection methods, etc.[4] The last part of the presentation covers the potential advantages of post-lithium-ion batteries with respect to battery safety.[5]

References

[1] X. Feng, M. Ouyang, X. Liu, L. Lu, Y. Xia, X. He, "Thermal runaway mechanism of lithium ion battery for electric vehicles: A review", Energy Storage Mater., 10, 246-267, 2018.
[2] V. Nilsson, S. Liu, C. Battaglia, R.-S. Kühnel, "Electrolytes with flame retardant pentafluoro-(phenoxy)cyclotriphosphazene for nickel-rich layered oxide/graphite cells", Electrochim. Acta, 427, 140867, 2022.
[3] S. Liu, M. Becker, Y. Huang-Joos, H. Lai, G. Homann, R. Grissa, K. Egorov, F. Fu, C. Battaglia, R.-S. Kühnel, "Multifunctional additive ethoxy(pentafluoro)cyclotriphosphazene enables safe carbonate electrolyte for SiO_x-graphite/NMC811 batteries", Batteries Supercaps, 6, e2023002202023, 2023.
[4] X. Feng, D. Ren, X. He, M. Quyang,"Mitigating thermal runaway of lithium-ion batteries", Joule, 4, 743-770, 2020.
[5] C. Qi, H. Wang, M. Li, C. Li, Y. Li, C. Shi, N. Wei, Y. Wang, H. Zhang, "Research on the thermal runaway behavior and flammability limits of sodium-ion and lithium-ion batteries", Batteries, 11, 24, 2025.

Title: IBIH Aerogels: From Commercialized Uses to Upcoming Industrial Deployments

Dr. Yunhong Wang[1]
1 IBIH Advanced Materials, China

Abstract

Aerogel materials offer outstanding thermal insulation, ultralow density, high-temperature resilience, and environmental compatibility, giving them potential across diverse industrial sectors.

Industrialized Success: IBIH's automated production of silica-based aerogel battery thermal cell pads has garnered broad market recognition. IBIH ceramic aerogel thermal cell pads not only meet—and often exceed—China's increasingly stringent "Electric Vehicles traction battery Safety Requirements "(GB38031—2025), but also provide ,robust passive thermal-runaway protection, and exceptional long-term compression durability. This presentation will showcase independent test data, key certification milestones, and real-world product examples demonstrating how leading battery manufacturers deploy IBIH's pads at the cell-, module-, and full-pack levels for comprehensive thermal management and impact protection.

Market Outlook: We will explore the tightening of safety regulations in key global markets, the evolution of performance benchmarks, and the expansion of the electric vehicle battery and energy storage markets. We will explore the significant opportunities these changes present for the aerogel industry.

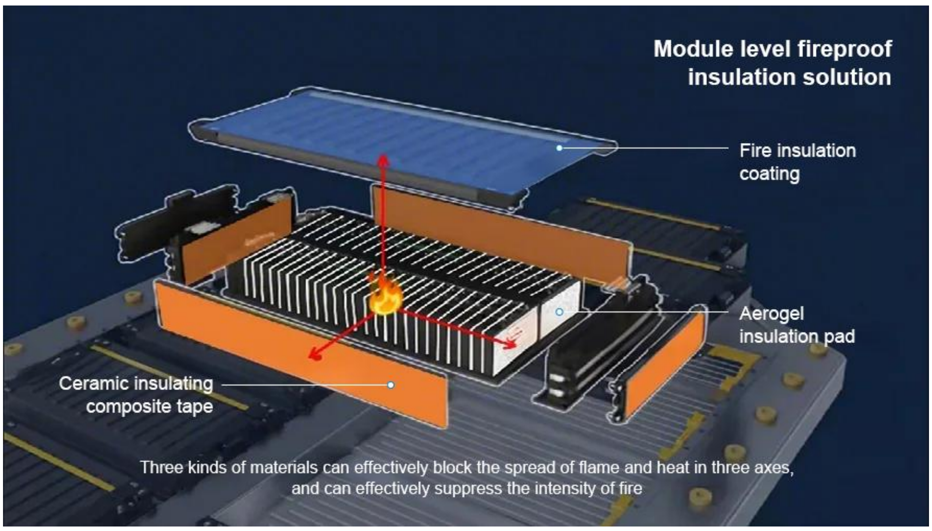


Fig 1. EV Batteries with Thermal Cell Pads

Next-Generation Aerogels

Beyond silica, IBIH and many well-known international research institutions and universities cooperate to promote the industrialization of the following cash aerogel materials:

- Polyimide (PI) Aerogels for extreme-temperature environments
- Biomass-Derived Aerogels with tailored pore structures for sustainable insulation
- Hydrophobic Aerogel Composites optimized for building and industrial insulation

For each technology, we will summarize development status, pilot-scale performance data, and projected timelines for commercial rollout.

Evolution in Inherent Vibration-Suppressive Materials

Dr S.J. Devine[1]

[1] *Graphene Composites Ltd, NETPark Incubator, Thomas Wright Way, Sedgefield, TS21 3FD, United Kingdom*

Abstract

From Aerospace through to Healthcare and Manufacturing, the need to control and/or suppress vibration across a wide range of products and markets is a critical requirement. Whether it is protecting delicate electronics from excess vibration on a satellite launch or controlling supersonic shock waves in blast/ballistic armour, the use of the right combination of materials allows this control while maintaining other properties such as mechanical strength.

This study examines the evolution of composite materials for extreme vibration suppression (ballistic events) as developed by Graphene Composites Ltd (GC). The influence of material properties, such as auxetic structured materials [1] and the addition of graphene-based additives [2] are discussed and how they influence the final material properties. The author will also discuss how this technology can be modified to transfer to utilize these materials in other market areas. Combining polymeric materials into a composite structure can wield strong, lightweight materials with excellent vibration dampening characteristics without compromising mechanical properties [3].

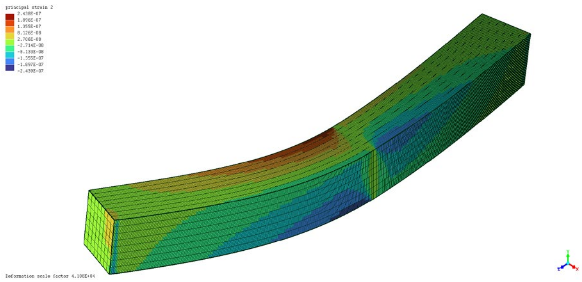


Figure 1: Simulation of strain in composite bar

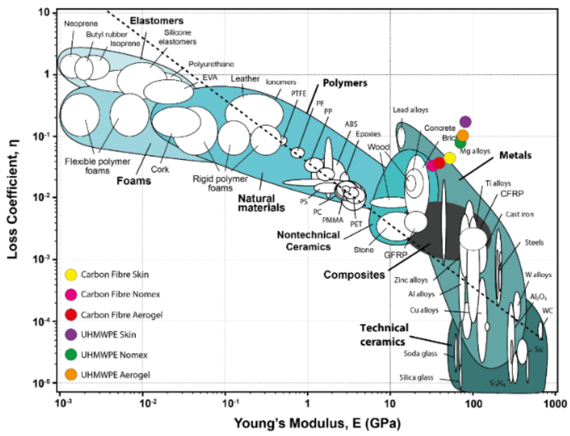


Figure 2: Ashby Chart relating to loss coefficients of GC structural materials [3]

References

[1] Liu,Y., Hu, H., Scientific Research and Essays Vol. 5 (10), pp 1052-1063, 18 May, 2010
[2] Strankowski,M., et al, Materials ***2018****, 11, 82; doi:10.3390/ ma11010082*
[3] Harland,C., B.Eng Engineering Project, University of Durham (2022)

Acknowledgments

Graphene Composites Ltd and the University of Durham Engineering Department

Aerogel Launch Factory – Feasibility Study and Next Steps

Barbara Milow, Pascal Vöpel, Bernhard Seifried

German Aerospace Center (DLR), Institute for Frontier Materials on Earth and in Space, Department of Aerogels and Aerogel Composites, Cologne, Germany

Abstract

Although numerous aerogel production processes have been developed and many possible applications for aerogels are emerging especially also in Europe, there is a need to scale-up and develop those processes further to enable industry and innovative start-ups to adopt and produce aerogels in Europe. Depending on the aerogel production process there is a lack of pilot scale aerogel production plants to enable industrial application development. The Aerogel Launch Factory (ALF) aims to bridge the gap from lab to pilot scale bringing aerogels a step closer to industrial production capacity enabling the production of sufficient quantities of aerogels, and to gain the knowledge required for industrial scale aerogel production facilities in Europe.

Especially in Europe only a few aerogel materials have found their way into industrial applications and are produced in sufficient quantities. ALF will offer at least three different processing pilot plants for aerogels to scale-up production and to produce various kinds of aerogel types for a wide range of applications. The aim is to offer aerogel pilot plants based on batch and continuous supercritical drying, atmospheric pressure freeze drying, and other processes, which will be developed in close collaboration with industry partners. With the establishment of ALF we will offer a toolbox for aerogel development with the concept that the pilot plants will be set up in the immediate vicinity of the R&D-oriented laboratories for synthesis and characterization to exploit synergies. The presentation will aim at an update on the current progress, the feasibility study and pilot plants envisioned to enable and facilitate collaboration in research, development and technology transfer. Future challenges are identified and the pragmatic approach to using the pilot plants is discussed.

Fig. 1: Visual (ChatGPT) representation of ALF filling the gap (orange box) from chemistry lab to a pilot plant of production.

Nancellulose aerogels – tailored processes for advanced properties

Gilberto Siqueira, Deeptanshu Sivaraman, Yannick Nagel, Nadia Heidari, Gustav Nyström
Empa, Dübendorf, Switzerland

Abstract

Derived from a wide variety of biomass sources (wood, annual plants, food residues), bacteria, and animals, cellulose is considered an attractive material for the fabrication of superinsulating materials, gaining interest from both the scientific and industrial communities for thermal management applications. Compared to silica, cellulose represents a promising starting source of macromolecules for aerogel production due to its inherently low thermal conductivity, renewable nature, and outstanding mechanical properties.

Using a "top-down" approach, cellulose can be converted into different types of nanocelluloses—namely, cellulose nanofibers (CNF) and cellulose nanocrystals (CNC)—through mechanical and chemical processes, respectively.

In our work, we draw inspiration from nature and apply various manufacturing approaches to combine these simple nanocellulose building blocks into structures organized across multiple hierarchical levels. Our goal is to develop materials with properties that exceed those of the original components. Among the techniques utilized by our group, additive manufacturing via 3D printing[1], densification by evaporation or compression[2], and unidirectional freezing[3] of CNC/CNF suspensions are key processes that enable the production of bio-sourced aerogels with exceptional anisotropic thermal and mechanical properties. Such nanocellulose aerogels find applications in packaging, electronics, tissue engineering, and drug delivery systems.

References

(1) Nagel, Y.; Sivaraman, D.; Neels, A.; Zimmermann, T.; Zhao, S.; Siqueira, G.; Nyström, G. Anisotropic, Strong, and Thermally Insulating 3D-Printed Nanocellulose–PNIPAAM Aerogels. *Small Structures* **2023**, *4* (12), 2300073. DOI: https://doi.org/10.1002/sstr.202300073.

(2) Sivaraman, D.; Siqueira, G.; Maurya, A. K.; Zhao, S.; Koebel, M. M.; Nyström, G.; Lattuada, M.; Malfait, W. J. Superinsulating nanocellulose aerogels: Effect of density and nanofiber alignment. *Carbohydrate Polymers* **2022**, *292*, 119675. DOI: https://doi.org/10.1016/j.carbpol.2022.119675.

(3) Heidari, N. A.; Hamdami, N.; Siqueira, G.; Nyström, G. Valorizing brewery industry waste in nanocellulose cryogel-PEG composites for cold chain packaging. *Carbohydrate Polymers* **2025**, *349*, 123031. DOI: https://doi.org/10.1016/j.carbpol.2024.123031.

Acknowledgments

All co-authors.

Recent progress in biopolymer-based aerogels: Microstructure formation

S. Takeshita[1]
1 National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan

Abstract

Biopolymers have attracted much attention as aerogel materials in this decades. In the first half of this presentation, the author introduces recent progress in chitosan [1,2] and biopolymer-polysiloxane composite [3] aerogels in the author's group mainly focusing on their microstructure formation. In the latter half, the author briefly introduces the latest data-driven literature analysis on aerogels and polymeric aerogels [4].

Supercritical drying is the standard tool for solvent removal from wet gels without changing the solid skeletal structure of the gel. Our recent studies on transparent chitosan aerogels have revealed that this is not always true [1,2]. Some crosslinked chitosan gels filled with alcohol do not have a clear solid skeleton before supercritical drying. The skeletal structure forms during the supercritical drying process, where the supercritical CO_2 acts as antisolvent to convert a molecular chitosan network into a porous solid skeleton.

Double network aerogels of biopolymer and polymethylsilsesquioxane were prepared by a two-step method [3]: sequential formation of the polysiloxane skeleton and metal-ion-induced biopolymer (alginate, pectin, carrageenan, carboxymethyl cellulose) gelation inside the skeleton. The secondary solid skeleton of the biopolymer forms during the solvent exchange with ethanol, which is antisolvent to the biopolymers, where the affinity between the biopolymers and polymethylsilsesquioxane affects the final microstructures. These results suggest that the timing of solid skeleton formation in an aerogel production process plays a significant role on the final aerogel microstructure, which is consistent with a general tendency of process–property relation of polymer aerogels based on the literature analysis [4].

References

[1] S. Takeshita, A. Sadeghpour, W. J. Malfait, A. Konishi, K. Otake, S. Yoda, "Formation of Nanofibrous Structure in Biopolymer Aerogel during Supercritical CO_2 Processing: The Case of Chitosan Aerogel", Biomacromolecules 20, 2051-2057, 2019.
[2] S. Takeshita, A. Sadeghpour, D. Sivaraman, S. Zhao, W. J. Malfait, "Solvents, CO_2 and Biopolymers: Structure Formation in Chitosan Aerogel", Carbohydr. Polym. 247, 116680, 2020.
[3] S. Takeshita, T. Ono, "Biopolymer-Polysiloxane Double Network Aerogels", Angew. Chem. Int. Ed. 62, e202306518, 2023.
[4] S. Takeshita, S. Mine, T. Ono, "Data-Driven Review on Aerogels and Polymeric Aerogels", Angew. Chem. Int. Ed. 2025, doi: 10.1002/anie.202504250.

Acknowledgments

This work is partly supported by JSPS Kakenhi Grant Numbers 19K05193, 22H01894/23K23162, and 25K01603.

Aerogels in action: What can complex three-dimensional aerogel components achieve and how are they manufactured?

B. Milow[1] M. Heyer,[1] F. Henn,[1] R. Tannert,[1] J, Seidl,[2] R. Sticher,[2] P. Voepel[1]

[1] German Aerospace Center, Institute for Frontier Materials on Earth and in Space, Linder Hoehe, 51147 Cologne, Germany

[2] Mercedes-AMG GmbH, Daimlerstraße 1, 71563 Affalterbach, Germany

Recently, interest in aerogels as efficient insulators rose significantly. Industry and users increased their interest in the direct application of aerogels and their composites. Aerogel application, e.g. in thermal insulation, promises potential energy savings based on the outstanding properties of aerogels. However, direct application of aerogels still remains challenging since dust formation might occur and scaling of the production is still an issue.

Besides construction related applications, aerogels have been applied commercially as insulting material in the automotive sector. The dust formation was described as problematic to handle that could only overcome by housing in vacuum-sealed bags. [1]

Within this work we demonstrate the application of monolithic aerogel composites as thermal insulation and protection of surrounding areas of an ICE exhaust system based on previously published synthesis protocols.[2, 3] Surface temperatures of the whole system were reduced from more than 800 °C to approx. 100 – 115 °C. In addition, temperatures of the exhaust gasses were increased which enables a more efficient. Three dimensional shapes have been realized in order to closely fit the insulation to the ICE structure. For this purpose, complex molds have been produced and the aerogels composites have been realized as depicted in figure 1.

Fig.1 top: 3D-rendering of the mold at different stages of filling and the overflow in the right depiction. Bottom: 3D model of one representative part.

1. Hartsock, D.L., et al., *Analytical and Experimental Evaluation of a Thermally Insulated Automotive Exhaust System.* SAE Transactions, 1994. **103**: p. 266-283.
2. Berkefeld, A., M. Heyer, and B. Milow, *Silica aerogel paper honeycomb composites for thermal insulations.* Journal of Sol-Gel Science and Technology, 2017. **84**(3): p. 486-495.
3. Heyer, M., et al., *Mixed Oxide Aerogels with High-Performance Insulating Properties for High-Temperature Space Application.* Advanced Engineering Materials, 2023. **25**(21): p. 10.

Characterisation Challenges in Aerogel Scale-Up: from lab to commercial scale manufacturing

Alyne Lamy[1], Stephen Parirenyatwa[1], Gurnoor Jassy[1], Sam Cryer[1], Rulande Rutgers[1].
[1] Thermulon, London, United Kingdom

Abstract

Thermulon is a deep-tech start-up based in the North-East of England and London working on the continuous production of silica aerogel materials. Created in part in response to the Grenfell Tower tragedy of 2017 [1], Thermulon is developing ways to make homes energy efficient to meet our climate goals, fire-safe, and affordable.

Aerogels are recognised for their outstanding thermal, acoustic, and lightweight properties, offering significant potential across sectors such as construction, energy, and advanced composites [2]. However, translating these materials from lab-scale innovation to industrial-scale production introduces several technical and operational challenges - particularly in characterisation and quality control during synthesis and in the final product state.

The goal of this presentation will be to focus on two key challenges encountered during the scale up development of aerogel materials. Firstly, the complexities in fully characterising the precursor system process which will allow us to monitor and ensure consistency during synthesis. Secondly, achieving representative and reproducible particle size analysis, for example, of the final dry material is both valuable and difficult. These factors directly affect process reliability and product quality control across scales.

Alongside these technical insights, we will outline our route to market, including our scale-up strategy to accelerate commercial readiness with scientific rigor. Preliminary data from end-product incorporation trials will also be presented, demonstrating compatibility with end-use applications and highlighting the commercial potential of our formulations.

References

[1] S. T. McKenna et al. "Fire behaviour of modern façade materials – Understanding the Grenfell Tower fire," J. Hazard. Mater., vol. 368, pp. 115-123, April 2019.

[2] H. Maleki, L. Durães and A. Portugal. "An overview on silica aerogels synthesis and different mechanical reinforcing strategies," J. Non-Cryst. Solids, vol. 385, pp. 55-74, February 2014.

Surface Secrets: Characterizing the Hydrophobicity of Silica Aerogel Granules

Laurens Snels[1], Ali Khodayari[1], Susana Garcia Mayo[1,2], Bjørn Petter Jelle[3], and David Seveno[1]
[1] *Department of Materials Engineering, KU Leuven, Leuven, Belgium.*
[2] *Department of Materials and Chemistry (MACH), Vrije Universiteit Brussel, Brussels, Belgium.*
[3] *Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.*

Abstract

Silica aerogels are renowned for their nanoporous microstructure, which imparts unique properties such as thermal superinsulation, high specific surface area, and optical translucency. To maintain these features in applications like glazing, self-cleaning surfaces, and thermally insulative composites, hydrophobic surface modification is typically required to prevent water intrusion [1]. However, this same hydrophobicity can hinder compatibility with water-based systems such as paints or cementitious materials, making accurate assessment of wetting behavior essential. While optical contact angle measurements (OCAM) suffice for flat monoliths, many practical applications favor aerogel granules due to their lower cost and ease of production. The irregular shapes of granules, however, complicate conventional surface characterizations. This study critically evaluates the limitations of OCAM for granular aerogels and introduces alternative techniques to improve accuracy and precision. Force-based contact angle measurements allow for precise determination of advancing and receding angles. Additionally, wetting properties are assessed using dynamic vapor sorption, X-ray computed tomography, Inverse gas chromatography (IGC), and zeta potential analysis. Results demonstrate that OCAM cannot reliably distinguish between different (super)hydrophobic aerogels. In contrast, the use of tensiometry in combination with complementary methods consistently reveals meaningful differences in surface behavior, offering a more robust framework for the characterization and optimization of aerogel materials.

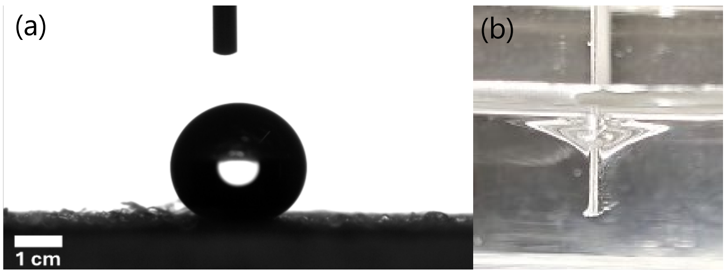


Figure 1. (a) OCAM water droplet on an aerogel powder bed and (b) vertical plate covered with silica aerogel dipped into water using a tensiometer, depicting the meniscus at the water surface.

References

[1] A. M. Anderson and M K. Carroll. (2023). ‘Hydrophobic Silica Aerogels’, in M. A. Aegerter, N. Leventis, M. Koebel, and S. A. Steiner III (ed.) *Springer Handbook of Aerogels*, p335-365.

QT-polysiloxanes – enabler technology for hybrid nano-materials and sol-gel chemistry

M. Koebel[1], D. Sivaraman[1], M. Nemec[1], G. Pagotti[1], S. Paz[1]
1 siloxene AG, Brüttisellen, Switzerland

Abstract

QT-polysiloxanes represent a new class of polymeric liquid materials invented here at Empa which are rapidly gaining significance in materials science and sol-gel chemistry due to their hybrid organic-inorganic nature. Like their name says, the are composed of non-organofunctinal Q-type units and monoorganofuntional T-type (functional silane) units. QT-polysiloxanes combine the flexibility and processability of organosiloxane polymers with the robust mechanical and thermal stability of silica networks used in standard sol-gel processing.

The QT-polysiloxane technology represents a unique and multifaceted platform for hybrid inorganic-organic building blocks with nearly unlimited possibilities to control functionality and chemical interface compatibility. Furthermore, these materials can serve as functional precursors for sol-gel chemistry, providing outstanding freedom of design for innovative multifunctional colloidal silica and polymer systems. However, their main practical relevance is likely to be found in the form of additives or modified hybrid resins for use in the manufacturing industries, particularly in paints, coatings, elastomers & sealants, adhesives and plastics processing.

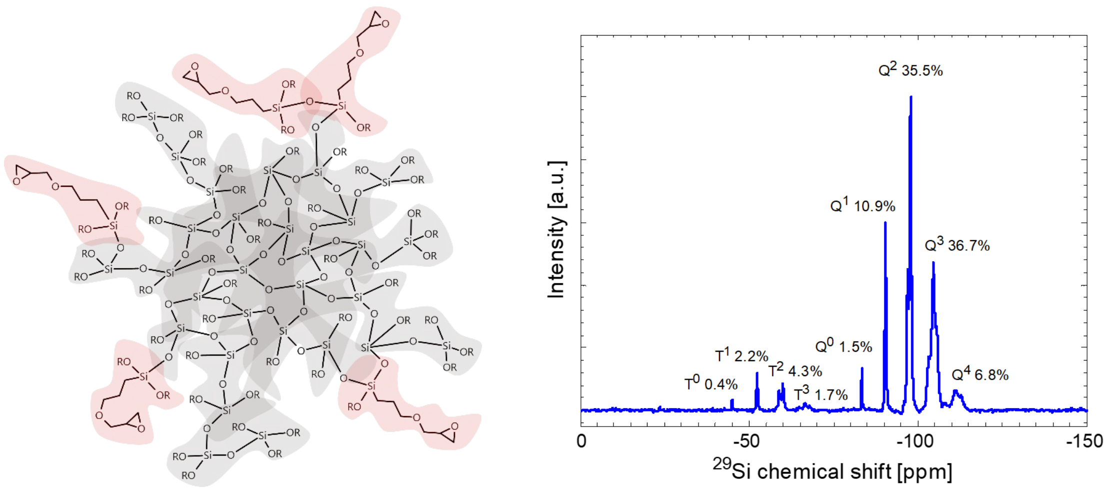


Fig 1. Representative structural formula of a glycidoxy-functional QT-polysiloxane with Q units color coded in grey and T units in red and the corresponding ^{29}Si spectrum detailing the speciation of differently bonded siloxane moieties.

In this presentation, the chemistry and practical preparation of QT-polysiloxanes will be detailed and contrasted by a handful of selected application examples. Aside from the technical aspects, the authors will briefly portray their personal journey from aerogel scientists to entrepreneurs, fueled by the passion for driving progress by means of this unique molecular toolbox.

References

[1] Nemec, M., Hauser, S. B., Rentsch, D., Pagotti João, G. M., Kuerten, L. C., Adilien, N., Huber, L., Stojanovic, A., Malfait, W. J., Koebel, M. M., " Hyperbranched, Functional Polyethoxysiloxanes: Tunable Molecular Building Blocks," ACS Appl. Polym. Mater., vol. 6, no. 12, pp. 7088–7101, June 2024.

[2] Blugan, G., Kovalska, N., Knozowski, D., Sasikumar, P.V.W., Malfait, W.J., Paz, S., Madajski, P., Leśniewski, M., Sawczak, M., Santhosh, B., Wilamowska-Zawłocka, M., Koebel, M. M. "Polymer derived SiOC/Sn nanocomposites from a low-cost single source precursor as anode materials for lithium storage applications" J. Energy Storage, vol. 89, 111676, June 2024.

Acknowledgments

The authors would like to thank the team of siloxene AG, Empa Dübendorf, in particular Lab 312, Lab 201 and of course the aerogel community for assisting them with their undying commitment to excellence, advice, technical support and personal friendship.

Aerobel: Innovative insulation materials and adhesives

S. De Pooter
Aerobel BV, Woudstraat 9, 3600 Genk, Belgium

Abstract

Aerobel is a Belgian raw materials manufacturer for adhesives and insulation materials. All materials are produced via a vertically integrated route by starting from waste streams or abundant non-edible natural resources. The product portfolio also includes hydrophobic silica aerogel, either in particle form or incorporated into fibrous battings. In order to be price-competitive, Aerobel produces its own sol precursor materials, which can be tailored to contain hydrophobic groups. A solution of silicon alkoxide precursors containing hydrophobic groups is produced via an unconventional way, which can be readily hydrolyzed and transformed into hydrophobic gels, consequently solvent exchanged and finally dried at ambient pressure. The first unit operation is far less energy-intense compared to traditional silicon alkoxide synthesis processes. In addition, hybrid silica aerogels with carbonaceous structures have been developed via a drying step during which hydrophobization and opacification occur simultaneously. This aerogel we call *Terragel* (Fig 1).

Fig 1. Terragel particles

Next to the inorganic silica-based networks, a 100% bio-based organic polymer network has been developed at Aerobel called *PolyVOX* that can serve as a replacer for polyurethane. Similar to PU/PIR, the PolyVOX can be applied as a glue, solid structure, and foam. Soft and rigid foams made out of PolyVOX have been synthesized having thermal conductivities of 32-36 mW/(m.K). Next to further optimizing the foams, also a first-of-its-kind superinsulating aerogel made out of PolyVOX is on the agenda.

Acknowledgments

The aerogel-fiber composites upscaling is funded by an EU-Life subsidy and part of the Carbip project (https://carbip.eu/).

Commercializing Aerogels is Hard. Here's Why.

Stephen A. Steiner III[1]
1 Aerogel Technologies, Boston, USA

Abstract

The past 25 years has seen a world where aerogel materials and products enhanced by them have become readily commercially available. But ongoing commercial availability of aerogels is not guaranteed, nor is the future commercial success of emerging aerogel materials. Those of us in the industry have seen plenty of booms and busts over the past three decades--efforts supported by BASF, Henkel, and Evonik to name a few, lest us forget the demise of Monsanto's Santocel in the 70s and a dozen or so failed aerogel startups thereafter in the 80s and 90s. Aspen Aerogels and Cabot Aerogel (and their government-subsidized Chinese copycats) are the closest examples of successful aerogel enterprises to date, although none can be called an unqualified commercial success. This said, both Aspen and Cabot have reached significant scale, noting both benefited from having started up in a financial environment fueled by dot-com economic momentum in which capital was plentiful and interest in industrials was still high. In contrast, capital investment in industrials in the West today is extremely low, and 95% of current venture capital funds are structured for five-year returns on investment--far shorter than McKinsey's characterization of an 11-18 year average internal rate of return for chemical and materials technologies over the course of the Twentieth Century. The result is everybody basically only wants to invest in apps and AI, because they are the only things dot-com-era venture capital investment models still work for. After all, making aerogel sounds capital-intensive, and, like, involves icky chemicals and stuff. Who wants to take that risk, especially since no one's ever really made a profit doing it?

Simultaneously, the regulatory environment in the United States and Europe has become increasingly restrictive in recent decades as governments have drifted towards a more liberal globalist world order. The evolution of ever more limiting, yet often unnecessary, fire codes and hazardous materials regulations over the past 25 years has had the net effect of severely curtailing the profitability and scalability of small chemical technology enterprises, while large chemical companies have increasingly offshored their manufacturing to avoid such regulations altogether. Indeed, the illusion that increasing regulation of manufacturers has reduced pollution and carbon dioxide emissions in the West continues to vindicate legislators, when in reality the West has simply outsourced--and magnified--its negative impacts on the environment by sending more and more of its manufacturing to coal-powered, hazardous-waste-relaxed, labor-subsidizing China, all the while surrendering energy and production self-sufficiency. This trend has thusly incentivized the creation of a highly entrenched, highly profitable regulator-consultant-insurance industry complex that feeds off the very constituency it was designed to help by choking it to death and justifiably scares off investors and entrepreneurs alike.

Over this same time period, obtaining and prosecuting intellectual property has become increasingly more expensive, slower, and less fruitful, yet somehow also more important for attracting capital. Businesses also now compete against government labs and universities who create prior art bombs that they then try--98% unsuccessfully--to license back to industry, with

which its licensees then have no ability to steer prosecution, file in foreign market-relevant jurisdictions, or create meaningful licensing partnerships. Such licenses are frequently narrowly scoped and stingy with providing exclusivity, and licensees can thus find themselves unwittingly inspiring competitors and even customers to seek their own licenses for the same technology who draft off their hard-won business model, market penetration, and goodwill once the technology been derisked and proven market-ready.

In this talk, I will highlight ten specific threats currently undermining commercialization of advanced materials like aerogels along with actionable ideas for how we can ensure such efforts stand a chance in a world increasingly full of low-cost, low-goodness products that is becoming increasingly punitive and risk-intolerant of manufacturing.

Carbon and Graphite Aerogels: Morphology, Properties, Applications

Nicholas Leventis

Aspen Aerogels, Inc.
30 Forbes Road, Bldg B
Northborough, MA 01532, U.S.A.

nleventis@aerogel.com

Abstract

Carbon aerogels are third-generation aerogels derived from pyrolysis, typically in the range of 800-1500 °C, of suitable first- and second-generation aerogels, namely, polymeric and organic/inorganic-polymer composites, respectively. Morphologically, they almost always retain the micro/nano structure of their parent aerogels. In terms of properties, they are hierarchical micro-, meso-, and macro-porous materials with generally high electrical conductivity, and they are explored for use as electrodes for batteries, capacitors, and fuel cells, as supports for catalysts, as CO_2 adsorbers, as desiccants, and, with suitable doping and pyrolysis conditions, as precursors of several metal and ceramic aerogels. Graphitic aerogels, in turn, are obtained from pyrolysis of carbon aerogels at even higher temperatures (generally over 2000 °C and more often in the range of 2400-2700 °C), or catalytically at lower temperatures (1200-1500 °C). In general, graphitic aerogels do not retain the morphology of their carbon aerogel precursors; they may include flower-like features, carbon nanorods, or even right- or left-handed helical screw-like spirals. A notable exception is graphitized aerogels from certain nanofibrous polyimide aerogels that retain the morphology of the original polymeric aerogels and display intense graphene character. In this presentation we will review the main classes of polymers that have been used as precursors for carbon and graphite aerogels, as well as the evolution of morphology and properties from carbon to graphite aerogels. Special focus will be placed on (a) the preparation of monolithic carbon aerogels from polymer-crosslinked silica xerogel powder compacts; (b) the catalytic preparation of graphite aerogels from polymer-crosslinked cobalt or iron oxide xerogel powder compacts; (c) the retention of morphology all the way to graphitization observed with polyimide aerogels; and, (d) the development of metal nanoparticle-doped carbon aerogels as reuseable catalysts prepared via galvanic trans-metalation of certain Fe-doped carbon aerogels.

PoreX: Digital Materials Development

P. Pandit[1], A. Rege[1,2]
1 German Aerospace Center, Cologne, Germany
2 University of Twente, Enschede, Netherlands

Abstract

Modern materials development demands a more intelligent way to connect synthesis, structure, and function. **PoreX** is a digital platform that enables this connection by integrating physics-based simulations with machine learning to guide the design and optimization of a broad range of materials. It allows researchers to explore reaction conditions, simulate resulting structures, and optimize target properties—all within a unified and modular system.

PoreX supports simulations at multiple scales, including particle growth, structure generation, and transport modeling, and couples these with data-driven tools such as surrogate modeling, Bayesian optimization, and active learning. The platform is designed to be material-agnostic, with initial applications ranging from porous networks and composites to structured films and hybrid materials. Users can optimize reaction conditions to achieve structural goals or, conversely, define performance targets and let the system propose pathways and candidate structures via inverse design.

This approach reduces experimental load and accelerates the discovery–deployment pipeline. By linking simulation outputs with experimental data and embedding learning algorithms that prioritize the most informative next steps, Porex enables smarter and faster iteration cycles. Our aim is for compatiblity with electronic lab notebooks and local or institutional data infrastructures, allowing seamless integration into research workflows.

Porex originates as a spinoff from the German Aerospace Center (DLR) and was recently awarded the **Helmholtz Enterprise Spin-off Grant**. The platform is currently under active development, with a company launch planned for early 2026. The team is already working with early partners on pilot applications, demonstrating the platform's value in accelerating materials innovation across domains such as filtration, energy storage, and coatings.

This talk aims to introduce PoreX and showcase some of the key technologies we have been developing under the umbrella of the German Aerospace Center (DLR). We will highlight how our integrated approach—combining simulation, machine learning, and experimental feedback—can accelerate materials discovery and design, and how PoreX is being positioned as a next-generation copilot for intelligent materials development.

Understanding and Using the EN 17956 Standard for Technical Insulation – and the Case for Mandating Energy Class C

Andreas Gürtler
European Industrial Insulation Foundation

Abstract

The European standard EN 17956 offers a structured framework for classifying industrial insulation solutions into energy efficiency classes (A–G), supporting energy savings, CO_2 reduction, and sustainability in industry. This abstract outlines how to apply the standard – selecting a performance class, defining process temperature and geometry, and using heat loss limits to design efficient insulation. EiiF's online Energy Efficiency Class Calculator supports quick, practical implementation.

A strong case also exists for mandating Energy Class C as a minimum standard across Europe. Focusing on uninsulated equipment and damaged insulation – areas with the quickest returns – could deliver immediate impact. Based on over 3.000 TIPCHECKs, annual savings across the EU 27, UK, Switzerland, and Norway could reach:

• 103 TWh of energy

• €5 billion in cost savings

• 26 million tonnes of CO_2

• €1.7 billion in carbon costs

Required investments of about €14 billion would pay back in just 2 years, boosting competitiveness. The insulation sector would grow by 9.33% annually, creating up to 15.000 new jobs in Europe.

This low-bureaucracy, high-impact proposal aligns with EU goals, focusing on immediate, proven opportunities. With 75% of TIPCHECK clients investing after audits, the potential for fast, scalable implementation is clear.

References

EiiF fact sheets, documents and studies

From Furnace to Cold Space: Aerogel Insulation System Tests in Extreme Conditions

J. Zheng[1], S. Möller[1], P. Somberg[1], D. Muresan[1], J. Dolega[2]

1 Ultima (Deutschland) GmbH, Münster, Germany

2 Armacell BeNeLux, Thimister, Belgium

Abstract

Armacell is the global leader in providing innovative, technical insulation solutions and components to conserve energy and drive energy efficiency. With its next generation of aerogel insulation, ArmaGel XG, a full re-qualification of the previously existing portfolio is currently underway. Even though certification to ASTM C1728[1], as the only recognized standard for aerogel insulation, is deemed sufficient to bring new products to market, a number of specific proof-point tests can additionally be required to prove product useability in particular application scenarios. These proof-points can be determined by i.e. local regulations, industry, market segment, client specifications, operating temperature range etc. The main challenge with proof-point testing lies within the fact that these tests usually must be performed as system tests, which requires in depth understanding of the associated components, their combination with the product, the application procedure and the execution of the test. We will present some selected tests that expose the product to extreme conditions ranging from extremely high down to cryogenic temperatures. We will provide insight into the key evaluation criteria, the challenges associated with preparing and executing the tests and some key findings.

References

[1] ASTM C1728 - 23, Standard Specification for Flexible Aerogel Insulation, ASTM International, 2023.

Breaking Down Heat Transfer Mechanisms in Aerogels and Strategies for Their Minimization

B. Merillas[1,2], C.A. García-González[3], T.E. Gómez Álvarez-Arenas[4], M.A. Rodríguez-Pérez[2]

1 Department of Chemistry, Faculty of Sciences, University of Burgos, 09001 Burgos, Spain
2 Cellular Materials Laboratory (CellMat), Condensed Matter Physics Department, Faculty of Science, University of Valladolid, 47011 Valladolid, Spain
3 AerogelsLab, I+D Farma Group (GI-1645), Department of Pharmacology, Pharmacy and Pharmaceutical Technology, iMATUS and Health Research Institute of Santiago de Compostela (IDIS), Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain
4 Dpto. Sensores y Sistemas Ultrasónicos (DSSU), ITEFI, CSIC, E28006, Madrid, Spain

Abstract

Supporting the EU transition to a more sustainable and energy-efficient future requires the development of next-generation insulating materials. Aerogels are attractive candidates thanks to their nanostructured architecture that, combined with low density, provides an outstanding thermal performance. Nevertheless, tailoring the structural features in the right direction is a complex task involving, synthetic or structural modifications, and identifying the optimal balance between the different heat transfer mechanisms.

In this work, different strategies to minimize the total thermal conductivity are explored, ranging from chemical modifications in the formulation and the addition of infrared radiation-blocking particles to a simple mechanical compression [1], [2]. The impact of these approaches is thoroughly analyzed in relation to the three main heat transfer mechanisms in these materials: conduction through the solid and gaseous phases, and radiative transfer. Tailoring densification through compression offers a simple yet effective method to engineer the porous structure of polyurethane aerogels. This approach leads to a uniform reduction in pore size while increasing density. allowing to determine the optimum compression percentage to balance all contributions. This strategy enables the design of aerogels with tunable properties, adaptable to a wide range of high-performance applications.

References

[1] B. Merillas, T. E. Gómez Álvarez-Arenas, F. Villafañe, and M. Á. Rodríguez-Pérez, Mater. Today Chem., vol. 34, no. August, 2023, doi: 10.1016/j.mtchem.2023.101789.
[2] B. Merillas, C. A. García-González, T. E. G. Álvarez-Arenas, and M. Á. Rodríguez-Pérez, Small Struct., vol. 2400120, pp. 1–12, 2024, doi: 10.1002/sstr.202400120.

Acknowledgments

Financial support from the Ministerio de Ciencia, Innovación y Universidades (Spain) (PID2021-127108OB-I00, TED2021-130965B-I00, PID2020-120010RB-I0, PDC2022-133391-I00), the Regional Government of Castilla y León and the EU-FEDER program (CLU-2019-04, VA202P20), and the European Union NextGenerationEU / PRTR (C17.I1), is gratefully acknowledged. This research is also part of JDC2023-051979-I (B. Merillas), funded by MCIU/AEI/10.13039/501100011033 and FSE+.

Title: Reinforced Carbon xerogels for high temperature insulation applications

F. Lotter[1], M. Wiener[1]
1 Center for Applied Energy Research (CAE), Magdalene-Schoch-Str. 3, 97074 Würzburg, Germany

Abstract

Carbon xerogels synthesized through the pyrolysis of porous organic precursors prepared via the sol-gel method exhibit exceptional properties for high-temperature (>1000°C) thermal insulation applications, whether in vacuum or inert gas environments. Examination of the various factors influencing thermal transport within the carbon xerogels reveals that heat transfer through the solid phase predominates thermal conductivity even under elevated temperatures. This predominance arises from the significant suppression of radiative heat transfer due to a high infrared extinction coefficient, coupled with a reduction in gaseous contribution, as the average pore diameter restricts the mean free path of gas molecules within the pores at elevated temperatures [1, 2].

While the thermal properties at high temperatures are excellent, pushing the material towards application for, e.g., thermal protection in aerospace or high temperature processing in industry offers various challenges. Specific requirements such as mechanical strength, machinability or cleanliness are tackled by reinforcing the material with fibres and surface coatings. Furthermore, by industrially upscaling the process to a pilot line level, a variety of size and geometry requirements can be met (see Fig 1).

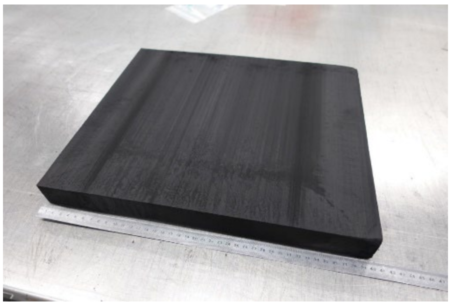


Fig 1. Fibre reinforced carbon xerogel plate for high temperature thermal protection (40 x 40 cm²).

References

[1] M. Wiener, G. Reichenauer, Microporous and Mesoporous Materials, 2015. Volume 203, p. 116-122.
[2] Wiener, M., Reichenauer, G., Braxmeier, S. et al., Int J Thermophys 2009, Volume 30, p. 1372–1385.

Aramid-reinforced silica-cork aerogels for thermoacoustic barriers

C.M.R. Almeida[1], B. Merillas[1,2], J. Rodrigues[1], L. Durães[1]

1 University of Coimbra, CERES, Department of Chemical Engineering, Rua Silvio Lima, 3030-790 Coimbra, Portugal

2 Department of Chemistry, Faculty of Sciences, University of Burgos, 09001 Burgos, Spain

Abstract

The development of multifunctional insulation materials that can be fed by raw materials from industrial wastes is an environmentally sustainable strategy and a way to contribute to energy savings and circular economy. Silica aerogels can be a cutting-edge solution in this regard, offering extremely low thermal conductivity and the possibility of chemical tailoring for improved interaction with different type of wastes [1,2]. Cork residues from cork industry activities are a renewable option to produce lower-cost, high-performance thermal and acoustic aerogel composite barriers. Cork is also lightweight, elastic, impermeable, and fire resistant, adding extra features to the final material.

Silica-cork aerogels, silylated with HMDZ and reinforced with Kevlar® pulp fibers, were optimized by design of experiments (DoE) for minimum thermal conductivity and density while keeping good mechanical resistance. Three factors were considered in the DoE, namely the silica precursor system (100%TEOS and 75%TEOS/25%VTMS), the fibers content (5 and 8 wt%) and the cork granulate size (< 0.1 and 0.5-1 mm). The first two factors were already tested in an earlier work [3]. The maximum amount of cork that could be incorporated in the system was 30 wt% and was kept constant. The optimum aerogel composites showed densities in the range 0.140-0.150 g cm^{-3} and a thermal conductivity as low as 16.6 mW $m^{-1}K^{-1}$. They also exhibited thermal stability up to 300 °C and a Young's modulus of *ca.* 500 kPa. The acoustic barrier performance was framed in an important frequency band for automotive engines sound, which can be particularly relevant for application in buildings near roads with high traffic rate.

References

[1] A. Lamy-Mendes, A.D.R. Pontinha P. Alves, P. Santos L. Durães, "Progress in silica aerogel-containing materials for buildings' thermal insulation", Constr Build Mater, vol. 286, 122815, 2021.
[2] B. Merillas, J.P. Vareda, J. Martín-de León, M.A. Rodríguez-Pérez, L. Durães, "Thermal conductivity of nanoporous materials: where is the limit?", Polymers, vol. 14, 255624, 2022.
[3] M.E. Ghica, C.M. Almeida, M. Fonseca, A. Portugal, L. Durães, "Optimization of polyamide pulp-reinforced silica aerogel composites for thermal protection systems", Polymers, vol. 12, 1278, 2020.

Acknowledgments

Work developed at CERES research unit supported by national funds from FCT - Fundação para a Ciência e a Tecnologia, I.P., and co-funded by the European Regional Development Fund (ERDF), under the projects https://doi.org/10.54499/UIDB/00102/2020 and https://doi.org/10.54499/UIDP/00102/2020. C.M.R. Almeida acknowledges FCT for the PhD grant SFRH/BD/150790/2020, funded by national funds from MCTES and co-funded by the European Commission through the European Social Fund. This research is also part of the JDC2023-051979-I contract (B. Merillas), financed by MCIU/AEI/10.13039/501100011033 and the FSE+.

Title: Scaling Monolithic Aerogel Sheets for Window Applications

Amanda Stubbs-Perry[1], Kyle Wilke[1]
1 AeroShield Materials, Inc., Waltham, MA, United States

Abstract

Losses through windows account for up to 40% of heating and cooling energy in buildings, which could be addressed with higher performance windows.[1] AeroShield has shown that by controlling density and pore/particle size of silica aerogels, we can achieve visible transmittance of >99% (Figure 1a), visible haze <1.0%, and thermal conductivity of <13 mW/(m·K) through a monolithic slab in ambient conditions. By placing only 4 mm of this material between two panes of glass to create an aerogel double-pane (Figure 1b), we can achieve a center-of-glass U-factor of 0.761 W/(K·m^2) without adverse effects on visual clarity and minimal changes to existing double-pane window design.[2] This exceeds state of the art triple-pane window performance with less weight, thickness, and embodied energy, meeting next generation energy performance targets at a lower cost. AeroShield now produces aerogel windows >1 m^2 (Figure 1c) that pass UV, fogging, thermal cycling, and slam testing. Prior to now, optically clear silica aerogel sheets have never been scaled to sizes >1 m^2, and manufacturing to produce the material at scale does not yet exist. This talk will address the technical developments required to enable scaling of our technology to larger sizes and integration of aerogels into windows.

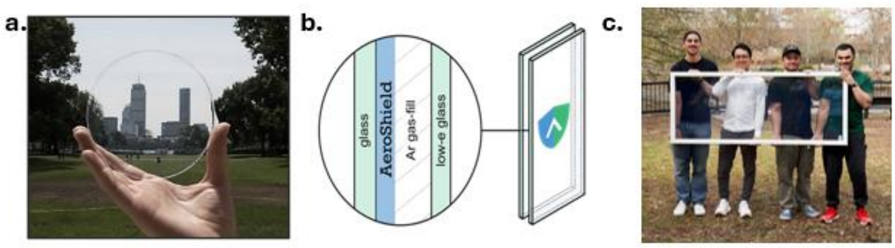


Figure 1. a) Ultra-clear aerogel sheet. b) Proposed aerogel window. c) 1 m^2 aerogel integrated into a window at AeroShield.

References

[1] J. Carmody and K. Haglund, Build. Technol. Progr. (November), 2012.

[2] E. Strobach, Strobach, E. M. (2020). Optically transparent, thermally insulating and soundproofing (OTTIS) aerogel for high-efficiency window applications. Diss. Massachusetts Institute of Technology, 2020.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 2155248. The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001920. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Aerogel: all-rounder for conservation

Beat Kämpfen

dipl. architect ETH/SIA, m.arch.UCB
kämpfen zinke + partner, Zurich, Switzerland

Abstract

In conservation of historic buildings three main themes are relevant. A modern comfort has to be guaranteed for the people living in the house and the consumption of heating energy has to be reduced. But on the same time the architectural expression of the historic building has to be maintained.

Traditional insulation materials can solve the first two themes, but have problems in keeping the aesthetic value and qualities of the old building.

1) Before renovation after renovation (application of 2 x 2cm aerogel panel)

Aerogel insulation has different advantages. The same insulation value can be reached with thinner insulation, it can be applied at the exterior or interior of a wall, it is hydrophobic and vapor barriers are not necessary. Aerogel can be applied in form of plaster for uneven surfaces, but also as insulation panels in different thickness up to 80mm.

It solves a lot of problems the architect is dealing while restoring historic buildings, but also it can help to make barrier-free problems.

References

1) Renovation Student housing Justinus, Zurich (built 1907). Architect: kämpfen zinke + partner
2) Renovation parish center Heilig Geist, Zurich (built 1973), 2. prize Aerogel competition 2022. Architect: kämpfen zinke + partner

SNUG EU project to develop sustainable insulation solutions for the building industry

Mike O'Connor

1 Keey Aerogel, Habsheim, France

Abstract

Keey Aerogel are a member of this project falling under the European Union "Built4People" initiative. This presentation will give an overview of the steps being taken by Keey Aerogel to produce a sustainable "green" aerogel. From silica sources, closed loop manufacturing, minimizing waste streams & through to logistics & the final packaging .

This sustainable aerogel will be developed into a new sustainable render system through our fellow project partner Takkenkamp.

Title: *Aerogel-Based Innovations in Residential Retrofitting: Monitoring and Material Development within the SNUG Project*

Sebastian von Stauffenberg[1], Efthymios Christodoulopoulos[1]
1 Agitec AG, Zürich, Switzerland

Abstract

AGITEC AG plays a key role in the Horizon Europe project SNUG, which aims to demonstrate scalable, sustainable retrofitting solutions to improve energy efficiency and indoor comfort in existing residential buildings. SNUG includes three real-life demonstrator sites in Switzerland, Spain, and Norway. Within this framework, AGITEC leads critical activities on both the monitoring of energy and environmental performance and the development and installation of high-performance insulation materials using aerogel technology.

Key developments include the use of blow-in insulation made from recycled production waste of PureFlex or Agitherm—two aerogel composites based on polyurethane and melamine respectively. These blow-in solutions are optimized for cavity wall retrofits in double-wall masonry buildings, providing low thermal conductivity with minimal structural intervention. To enhance circularity, AGITEC also developed a custom recycling unit that collects ultra-fine aerogel powder during the recycling process, which is being tested in new render formulations, closing the loop on material use.

Figure 1. Recycled waste blow-in material

Figure 2. Aerogel fine Powder

A full monitoring setup was installed in the Swiss SNUG demo building, including sensors for heat flux, surface and ambient temperature, humidity, CO_2 concentration, VOCs, and particulate matter. The collected data enables before-and-after comparisons of energy performance, indoor comfort, and air quality. Results feed into life cycle assessments and EPD development, supporting SNUG's broader environmental goals. AGITEC's approach demonstrates how recycled aerogel-based insulation can deliver high performance, scalability, and environmental impact in real-world retrofits.

Acknowledgments

This work is supported by the European Union's Horizon Europe program under grant agreement for the SNUG project. We thank our project partners and testing collaborators for their contributions.

Sustainable Aerogel Liners for Thermal Insulation

Harun Venkatesan[1],Sudipto Behera[1]

1 Department of Textile and Fibre Engineering,
Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India

Abstract

In this study, we have prepared hybrid aerogels using composites of polysaccharide and silica aerogels. The aerogels are cross-linked to enhance their dimensional stability and microporous structure. The addition of silica aerogel delivered a significant enhancement in insulation behavior and stability of the polysaccharide skeleton. The inherent flexibility of the fibrous matrix offers numerous benefits for aerogel integration and widens the application potential of the materials. Polysaccharide and silica aerogel composite precursors are coated onto the knitted liners to prepare flexible thermal insulation barriers. The bio-based aerogel composite fibers displayed improved warm feel and washability. The bio-composite structure prevents silica aerogels from disintegrating during washing of fabrics, which is essential for effective insulation. The findings of the study highlight the potential of polysaccharide aerogels as high-performance, sustainable materials with potential for applications in high-performance thermal insulation for textiles.

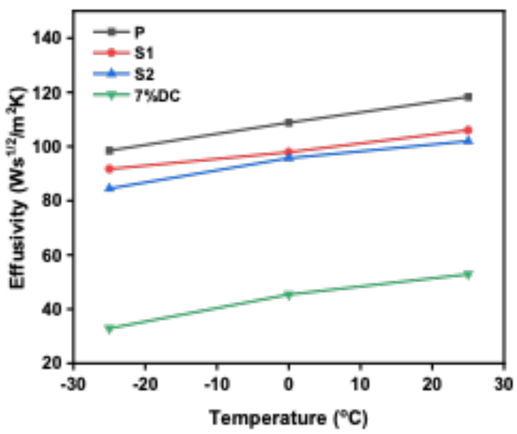


Fig. 1: Effusivity of the fabric tested at different temperatures

Acknowledgement: This work acknowledges the funding support from Science and Engineering Research Board (SERB) Start-up Research Grant (SRG/2022/001776), Anusandhan National Research Foundation (ANRF), India and National Technical Textile Mission (Project No: 2/6/2022-NTTM), Ministry of Textiles, India.

Exploring the properties of agar aerogels for potential biomedical applications

N. Atelšek Hozjan[1], G. Horvat[1], Z. Novak[1]

1 Faculty of Chemistry and Chemical Engineering, University of Maribor, 2000 Maribor, Slovenia

Abstract

Agar, a polysaccharide derived from red algae, is an abundant, renewable, and biocompatible material with exceptional gelling properties. While it is widely used in the food industry and microbiology, its potential for advanced material design, particularly as an aerogel, remains underexplored. Due to its natural origin, agar is a promising candidate for the development of sustainable bioaerogels for biomedical and environmental applications [1].

This work focuses on the development and characterisation of agar-based aerogels for potential biomedical applications. To evaluate how production processes affect final properties, the effects of polysaccharide concentration and the number and duration of ethanol-based solvent exchange steps were investigated. Additionally, aerogels were produced in various shapes to explore the impact of geometry on their performance. The resulting aerogels were analysed using a comprehensive set of techniques. N_2-physisorption analysis was used to determine the specific surface area and pore characteristics, while scanning electron microscopy (SEM) provided insights into the microstructure and morphology. Thermal properties were analysed with thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Swelling and stability were studied both in water and in simulated body fluid (SBF). The surface's wettability was measured by contact angle analysis, and the mechanical properties were tested under compressive loading. Overall, preliminary results revealed that the investigated processing conditions significantly influence the final properties of the aerogels, highlighting the potential of agar-based aerogels for a variety of applications.

References

[1] *M. Shah et al., "Advances in agar-based composites: A comprehensive review," Carbohydr Polym, vol. 346, pp. 122619, Aug. 2024.*

Acknowledgments

This work was funded by the Slovenian Research Agency (ARIS) through Research Programme P2-0046.

Direct conversion of fruit and vegetable waste into bioaerogels for the development of active food packaging solutions

A. Saitta[1], S. Plazzotta[1], L. Manzocco[1]
[1]*Department of Agri-Food, Environmental and Animal Sciences, University of Udine, Udine, Italy*

Abstract

Active packaging refers to food contact materials (FCM) able to extend shelf life of packaged food thanks to their ability to absorb unwanted substances, such as liquid serum and humidity, or release useful compounds such as antimicrobials and antioxidants. In this context, the unique open porosity of aerogels could be used to absorb huge amounts of liquids and water vapour, while hosting antimicrobial/antioxidant molecules undergoing controlled release during time. Bioaerogels produced from biopolymers bear the additional properties of biodegradability and biocompatibility, making them optimal candidates for the development of active FCMs.
Bioaerogel production conventionally involves the preparation of hydrogels from purified biopolymers, followed by water-to-ethanol solvent exchange (SE) and supercritical-CO_2-drying (SCD). Although biopolymers can be extracted from fruit and vegetable waste (FVW), this process remains suboptimal, since water- and energy-intensive, and generating extraction residues. To address these limitations, FVW tissues can be directly subjected to SE and SCD, exploiting rather than disrupting the inherent structure of plant tissues. The latter can be actually regarded as hydrogel-like materials embedding large water amounts in cellular architectures. This approach allowed turning a number of FVWs into materials with the typical physical properties of aerogels. These FVW-bioaerogels were also tasteless and colourless: highly convenient properties for FCMs which should not modify the sensory properties of the packaged food.
The aim of this study is to illustrate the potential of bioaerogels directly derived from FVWs as active food packaging devices. To this aim, discarded lettuce leaves and broccoli stems, selected as abundant FVWs, were subjected to SE and SCD. The obtained bioaerogels were characterized for physical properties (colour, bulk density, microstructure, internal surface area) and active packaging functionality (ability to absorb liquid water and water vapour). Bioaerogels showed bleached colour and aerated structure, along with high internal surface (>100 m^2/g) and porosity (>80%), and low density (<0.5 g/cm^3). One gram of FVW-bioaerogel absorbed up to 33 g water and 0.6 g water vapor.
Bioaerogels produced form FVW can be regarded as promising candidates for the development of absorbent packaging pads. These materials would address key limitations of conventional active pads, such as poor biodegradability and risk of chemical leaching. Building on these findings, future work will explore loading of FVW-bioaerogels with antimicrobials/antioxidants to develop dual-function pads.

Acknowledgments

This work was financed by the EU-NextGenerationEU projects PRIN2022 UNITED (Prot. 2022P8ZAHW); the Interreg VI-A Italia – Österreich 2021-2027 project NETTLE; the UNIUD DM-737 project UNITED.

Impact of sodium and synthesis parameters on silica aerogel from waterglass.

M. Borzova[1], F. Gauvin[1], K. Schollbach[1], H.J.H. Brouwers[1]

1 Department of the Built Environment, Eindhoven University of Technology, P. O. Box 513, 5600 MB, Eindhoven, the Netherlands

Abstract

Silica aerogels are known for their outstanding properties, such as low thermal conductivity, high specific surface area, low density, and inherent fire retardancy. Their application as building insulation would result in lower energy consumption by dwellings and increased energy efficiency. However, their large-scale use is hindered by high embedded energy and the cost of raw materials and production. Therefore, a solution is needed to improve the sustainability and upscaling feasibility of silica aerogels.

While organosilicons are popular raw materials for the sol-gel process, sodium silicate is a cheaper and more sustainable precursor. Its use comes with the need for sodium removal, as Na^+ was shown to disrupt network formation and hydrophobization of the gel [1]. Traditionally, this is done by passing the sol through ion exchange resin, which replaces the Na^+ with H^+. But this step is time-consuming and requires upkeep as resin eventually has to be recovered or replaced. Alternatively, prior research presented methodologies of using various acids as gelation agents, and the removal of Na^+ by washing or salt precipitation [2].

This work aims to optimize such a process further, incorporating sodium removal into the existing solvent exchange steps by adjusting the synthesis parameters. Effects of pH, silica concentration in sol, gelation agents, and purification approaches on the resulting aerogel quality are discussed. Preliminary results showed that a high-quality aerogel can be produced with no additional sodium removal method. Additionally, the impact of sodium on silicic acid dimerization in acidic conditions is investigated using density functional theory [3]. This computational chemistry tool is used to model the conformation and Gibbs free energy of each reaction stage. The investigation showed that sodium may interfere with hydrogen transfer and subsequent Si-O-Si bond formation, thereby hindering the condensation reaction.

References

[1] Luo, Z.; Yang, G.; Zhang, M.; Wang, Y.; Si, Z.; Mu, Y.; Liu, X. Effect of Residual Na+ on the Properties of Aerogel Prepared with Sodium Silicate via APD. J Non Cryst Solids 2022, 575, 121200.

[2] Sun, W.; Yu, L.; Su, J.; Liu, R.; Yan, X.; Su, D.; Zhang, P.; Li, X. Preparation of SiO2 Aerogel by Water Glass: Effect of Different Sodium Removal Methods on Aerogel Properties. J Solgel Sci Technol 2024, 1–11.

[3] Cheng, X.; Chen, D.; Liu, Y. Mechanisms of Silicon Alkoxide Hydrolysis–Oligomerization Reactions: A DFT Investigation. Chem Phys Chem 2012, 13 (9), 2392–2404.

Ultralight, Conductive, and Mechanically Robust $Ti_3C_2T_x$ MXene-CNTs Hybrid Aerogels for Electromagnetic Interference Shielding

Aamir Iqbal[1,2]*, *Chong Min Koo*[1], *Wim Malfait*[2], *Shanyu Zhao*[2]

1. *Materials Architecturing Research Center, Korea Institute of Science and Technology (KIST), Hwarang-ro 14-gil 5, Seongbuk-gu, Seoul 02792, Republic of Korea*
2. *Laboratory for Building Energy Materials and Components, Swiss Federal Laboratories for Materials Science and Technology, Empa, Dübendorf, Zürich 8600, Switzerland*

Corresponding author: aamir.iqbal@empa.ch

Abstract

Lightweight materials with high electrical conductivity and robust mechanical properties are highly desirable for electromagnetic interference (EMI) shielding in modern portable and highly integrated electronics. In this work, a three-dimensional (3D) porous $Ti_3C_2T_x$/carbon nanotubes (CNTs) hybrid aerogel with a long-range order of aligned lamellar architecture was fabricated via a bidirectional freeze-casting method. The synergism of the lamellar and porous structure of the MXene/CNTs hybrid aerogels contributed extensively to their high electrical conductivity (9.43 S cm^{-1}) and efficient electromagnetic shielding effectiveness (EMI SE) value of 103.9 dB at 3 mm thickness in X-band (8.2 – 12.4 GHz) frequency range. Compared to pristine MXene aerogel, the CNTs reinforcement significantly increased the compressional modulus of MXene/CNTs hybrid aerogels. These MXene/CNTs hybrid aerogels with high electrical conductivity, good mechanical strength, and superior EMI shielding performance exhibit promising potential for inhibiting EMI pollution.

Sustainable production of reprocessed starch aerogels

María Blanco-Vales[1,*], María Carracedo-Pérez[1], Ricardo Starbird[2,3], Laria F. Rodríguez-Quesada[2], Cláudia P. Passos[4], Carlos A. García-González[1], Clara López-Iglesias[1]

[1]AerogelsLab, Dept. Pharmacology, Pharmacy and Pharmaceutical Technology, I+D Farma (GI-1645), Faculty of Pharmacy, iMATUS and Health Research Institute of Santiago de Compostela (IDIS), Universidade de Santiago de Compostela, Santiago de Compostela, Spain

[2]Chemical and Microbiological Research and Services Centre (CEQIATEC), Instituto Tecnológico de Costa Rica, Cartago, Costa Rica

[3]Materials Science and Engineering Research Centre (CICIMA), Universidad de Costa Rica, Cartago, Costa Rica

[4]Organic Chemistry, Natural and Agri-food Products (QOPNA), Universidade de Aveiro, Aveiro, Portugal

*ma.blanco@usc.es

Abstract

Circular economy patterns seek waste minimization and transformation into new resources to tackle the current environmental problems. Concepts such as recycling and reprocessing should be adopted in the production of aerogels [1]. The fabrication of these materials from starch is gaining particular interest for applications in the food and pharmaceutical industries [2]. Therefore, it is important to start thinking about their end-of-life, i.e. what to do with them at the end of their lifespan.

In this work, the production of corn starch aerogels and their subsequent reprocessing to yield new aerogels has been tested. The chosen reprocessing methods together with supercritical drying were efficient, did not need toxic reagents, were not energy-intensive, and did not leave harmful residues. The reprocessed aerogels had similar or improved textural and mechanical properties with respect to the original material.

References

1. García-González, C.A.; Blanco-Vales, M.; Barros, J.; Boccia, A.C.; et al. *ACS Sustainable Chem. Eng.* In Press, doi:10.1021/acssuschemeng.4c09747.
2. Zhao, D.; Zhang, X.; Zhang, Y.; Xu, E.; Yan, S.; Xu, H.; Li, M. *Sustainable Food Technology* **2024**, *2*, 615–634, doi:10.1039/D4FB00030G.

Acknowledgments

Work funded by MICIU/AEI/10.13039/501100011033 [grants PID2023-151340OB-I00 and PDC2023-145826-I00], Xunta de Galicia [ED431C2022/2023, ED481D-2024-008], Xunta de Galicia-GAIN [Ignicia Programme 2021, ECOBONE], ERDF/EU and European Union NextGenerationEU/PRTR. Work carried out in the framework of the ECO-AERoGELS COST Innovators' Grant (ref. IG18125) and funded by the European Commission.

3D printing of aerogels

Shanyu Zhao[1,], Mengmeng Li[1], Gilberto Siqueira[2], Tingting Wu[1], Wim J. Malfait[1]*

[1] Laboratory for Building Energy Materials and Components, Empa, Swiss Federal Laboratories for Materials Science and Technology, Überlandstrasse 129, 8600 Dübendorf, Switzerland.

[2] Cellulose and Wood Materials Laboratory, Swiss Federal Laboratories for Materials Science and Technology, Empa, Dübendorf, Switzerland

Abstract

Aerogels are a unique class of porous materials known for their ultra-low density, high surface area, and exceptional thermal insulation. Despite these advantages, their inherently brittle nature and limited processability have constrained their broader applications. Additive manufacturing (AM) offers a transformative pathway to overcome these limitations by enabling the fabrication of aerogel components with customized geometries, hierarchical porosity, and localized functionalities. Our recent advances have expanded the printable aerogel portfolio beyond carbon-based systems to include inorganic, organic, and hybrid frameworks. Silica aerogels, renowned for their superinsulating performance, have traditionally been considered unprintable due to their fragility; however, emerging sol–gel strategies and rheology-modified inks now allow their direct ink writing (DIW) with high shape fidelity and functional tunability [1]. Similarly, thermally robust polyimide aerogels have been successfully printed, offering lightweight solutions for aerospace and electronics [2]. Resorcinol-formaldehyde (RF) aerogels, with their rich carbonization potential, and biopolymer-based aerogels derived from cellulose, alginate, or chitosan, provide sustainable and biodegradable alternatives with applications ranging from biomedical scaffolds to soft electronics [3]. We tried to summarize the key breakthroughs and printing strategies across these aerogel systems, highlighting ink design, gelation kinetics, and post-processing approaches that enable the retention of intrinsic aerogel properties after printing. The convergence of 3D printing with aerogel opens new frontiers for designing multifunctional, miniaturized components for thermal management, sensors, energy storage, biomedicine, and sustainable architecture.

References

[1] Zhao, S., et. Al.. Additive manufacturing of silica aerogels. Nature, 584(7821), 2020.
*[2] Wu T, et al. 3D Printed Polyimide Nanocomposite Aerogels for Electromagnetic Interference Shielding and Thermal Management. Advanced Materials Technologies **8**, 2023.*
[3] Sivaraman, D., et.al. Additive Manufacturing of Nanocellulose Aerogels with Structure-Oriented Thermal, Mechanical, and Biological Properties. Advanced Science, 11(24), 2024.

Methodologies for enhancing the performance of thermally insulating PLA aerogels

J. Lledó[1,2], J. Martín-de León[1,2], M.A. Rodríguez-Pérez[1,2], B. Merillas[3]

[1] *Cellular Materials Laboratory (CellMat), Condensed Matter Physics Department, Faculty of Science, University of Valladolid, Campus Miguel Delibes, Paseo de Belén 7, 47011 Valladolid, Spain*

[2] *BioEcoUVA Research Institute on Bioeconomy University of Valladolid, Calle Dr. Mergelina, 47011 Valladolid, Spain*

[3] *Department of Chemistry, Faculty of Sciences, University of Burgos 09001 Burgos, Spain*

Abstract

Biopolymer-based aerogels have gained significant attention in recent years due to their ease of fabrication, enhanced sustainability, and promising performance across applications such as thermal insulation, oil-water separation, or sound absorption. Among all the biopolymers, poly(lactic acid) (PLA) stands out for its excellent thermal and mechanical properties. PLA-based aerogels have already reached low thermal conductivity and high stiffness, key properties for improving insulation performance in the construction sector, while minimizing the environmental impact due to their reduced carbon footprint and biodegradability [1].

This work explores different strategies to further enhance the performance of PLA aerogels, such as the use of higher molecular weight to improve the overall mechanical performance without compromising their low thermal conductivity; or the incorporation of nanoparticles (nanoclays or graphene nanoplatelets) that can induce structural modifications. The control of the produced structures and the understanding of the structure properties-relationship enables the fabrication of PLA aerogels with tunable properties, posing environmentally friendly alternatives to some of the currently used materials.

References

[1] J. Lledó, J. Martín-de León, T. E. Gómez Álvarez-Arenas, M. A. Rodríguez-Pérez, and B. Merillas, "Unraveling the structure-properties correlation in thermal insulating and mechanically stiff PLA aerogels," J. Mater. Res. Technol., vol. 36, no. February, pp. 641–652, 2025.

Acknowledgments

Funds from the Recovery and Resilience Mechanism - Next Generation EU Funds and the Community of Castilla y León Funds. Complementary Research and Development Plans with the Autonomous Communities in R&D&I actions of the Component 17. Investment 1.
Financial support from the Science and Innovation Ministry of Spain Ministerio de Ciencia, Innovación y Universidades (RTI2018-098749-B-I00 and PID2021-127108OB-I00, TED2021-130965B-I00 and PDC2022-133391-I00) and financial assistance from the Junta of Castille and Leon of Castilla y León (VA202P20) are gratefully acknowledged. This research is also part of the JDC2023-051979-I (Beatriz Merillas), financed by MCIU/AEI/10.13039/501100011033 and the FSE+.

Development of Organic Aerogels Containing Chitosan Bio-Polymer From European Green Crab (EGC) Shells

Mr. Mitchell Barrett[1], Dr. Lukas Bichler[1], Prof. Barbara Millow[2], Dr. Marina Schwan[2], Dr. Adam Dzierbinski[2], Dr. Martin Sgraja[2], Ms. Crysta Stubbs[3], and Mr. Ryan Chamberland[3]

1 The University of British Columbia, Kelowna, British Columbia, Canada

2 German Aerospace Center, Cologne, Germany

3 Coastal Restoration Society, Port Alberni, British Columbia, Canada

Abstract

The European green crab (EGC) is recognized as one of the world's most destructive aquatic invasive species and has had a profound detrimental impact on the ecosystem of the Pacific coastline for over 20 years. The Coastal Restoration Society and the T'Sou-ke First Nations in British Columbia, Canada, have developed a large-scale trapping and control plan for EGC. This research is a part of the DLR@UBC collaboration, and focused on extracting chitin, a biopolymer naturally present in the EGC shells, and converting it to chitosan for use in organic aerogels. The carbonization and activation, along with the potential use of the organic aerogels for gas filtration applications are discussed.

Graphitization to Functionally Customize Graphene-Polyimide Hybrid Aerogels for All-in-One Electronics Design

Tingting Wu[1,2], Mingxiang Gao[3], Christopher H. Dreimol[4,1], Ekaterina Filimonova[1], Qin Li[5], Yunhong Wang[5], Dimitrios Sapalidis[1], Bruno F.B. Silva[1], Michal Ganobjak[1], Mengmeng Li[1], Yanfang Wei[1], Joshua Yip[1], Anja K. Skrivervik[3], Wim J. Malfait[1], Shanyu Zhao[1]

1 Empa, Dübendorf, Switzerland
*2 A*STAR, Singapore*
3 EPFL, Lausanne, Switzerland
4 ETH Zurich, Switzerland
5 IBIH Advanced Materials, Cangzhou, China

Abstract

Lightweight and highly porous polyimide aerogels, known for their excellent mechanical strength, low thermal conductivity and low-loss dielectric properties, are considered ideal dielectric substrates for electronics. However, for electrical devices, selective inks or materials with suitable electrical properties need to be manufactured to adhere to the polymer substrate. In this paper, by leveraging polyimide's thermally stable chemical structure, which includes imide rings and aromatic backbones, and optimizing the physically stabilized porous structure (Figure 1), a highly flexible superinsulating polyimide aerogel was manufactured. This aerogel was then patterned with a highly conductive graphene carbon layer through laser scanning (LIG). The seamless integration of the highly electrically and thermally conductive LIG pattern with the low-loss dielectric and superinsulating polyimide aerogels has been successfully achieved and demonstrated for multiple use scenarios, including smart thermal management, high-precision pressure sensors, and patch antennas operating at 5.4 GHz. An optimal polyimide aerogel structure with LIG achieves an impressive sheet resistance of 6.5 Ω/□. One example, a superlight weight aerogel patch antenna, can reach a reflection coefficient of -14 dB at 5.4 GHz and a peak gain value of 4 dBi.

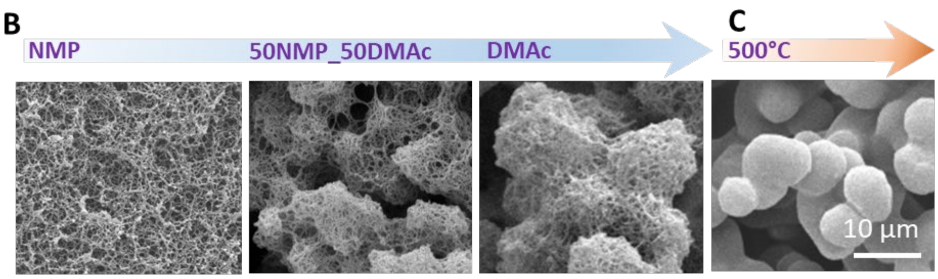


Figure 1. Evolution from homogeneous mesoporous microstructures to hierarchical pore structures with changing solvent composition. The hierarchical structure leads to improved dimensional stability at high temperature, enabling laser induced graphitization.

Comparative study on on lab-scale and continuous industrial sulfur infiltration methods for metal-sulphur batteries

Jessica Kröner, Marina Schwan, and Barbara Milow

Institute of Materials Research, German Aerospace Center, 51147 Cologne, Germany

In a metal-sulphur battery, the cathode consists of a composite of activated carbon and sulphur, which serves as an electrochemically active material. Both fusion and gas infiltration are used to fill the pores of the activated carbon with sulphur. The overall process with heating and cooling phases is very time and energy intensive. In addition, only very small quantities of sample can be processed in a batch process in the processes established to date. The cost of processing large quantities is so high that the processes are not economically feasible.

In order to optimize the production of sulphur-carbon composites, infiltration methods are required that increase the material throughput and improve the duration and energy consumption. To this end, various infiltration methods are used and their performance analyzed.

Sulphur is introduced into microporous carbon using various infiltration methods. The methods used are based on both melt and gas infiltration. Continuous industrial processes and rapid batch processes are analyzed and compared with laboratory-scale processes.

The investigated methods for sulphur infiltration were carried out with a carbon aerogel, which has a micropore volume of 0.27 to 0.45 cm^3/g. The results showed that the highest sulphur loadings could be achieved using gas, extruder and melt infiltrations, with the sulphur predominantly present in the micropores. The composites produced with gas [1] and extruder infiltrations [3] exhibit good cycle stability and high discharge capacity. In comparison, open gas infiltration, microwave infiltration and solvent infiltration showed low sulphur loading and inadequate performance in the cell. The results are summarized in our poster.

Our study shows that the following parameters should be taken into account when selecting infiltration methods:

- Properties (porosity, pore volume and pore sizes) of the carbon material

- Energy, resource and time requirements

- Transfer possibilities from laboratory cell to battery production

- Battery system (anode material, electrolyte, separator)

- Substitution and combination of process steps

Depending on the requirements for the battery, the infiltration method can be selected between complex, non-scalable with outstanding performance and economically efficient with moderate performance.

References:

1. B. Milow, M. Schwan, N. Wagner and F. Warth (2018). Elastisch verformbare Kohlenstoffaerogele als Matrixmaterial in Schwefelelektroden. DLR. Germany. **DE 10 2018 123 285.3**

2. B. Milow, M. Schwan, J. Kröner, I. Milow (2023). Verfahren zur Herstellung von Schwefel-Kohlenstoff-Kompositen, DLR. Germany. **DE 10 2023 111 810.2**