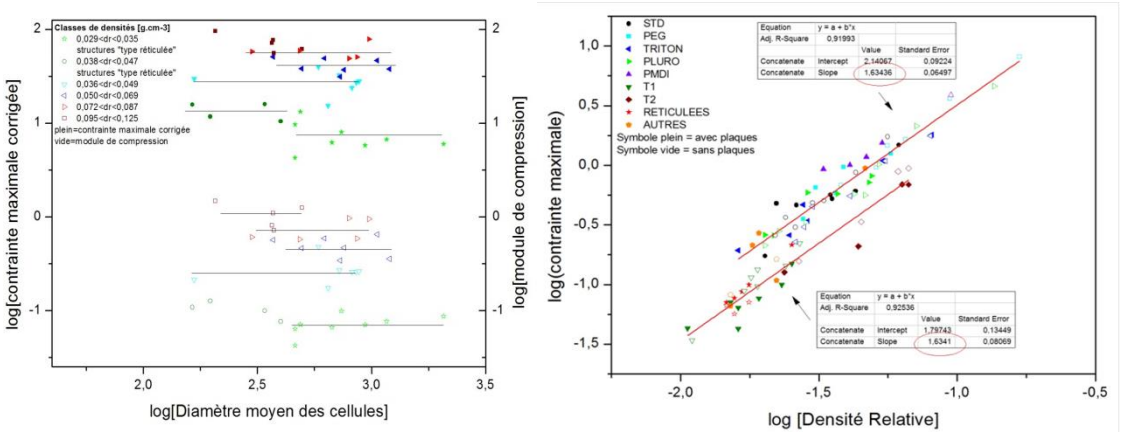
# POP-FOAMS




## Mechanical Performance Optimisation of Tannin-based Carbon Foams

*Principle investigator: Alain Celzard*

*Partners: LERMAB*

---

**Context** — The mechanical properties of vitreous carbon foams have been extremely poorly investigated despite their huge applicative potential : porous electrodes in electrochemical devices for energy conversion, scaffolds for tissue engineering, lightweight high-frequency electromagnetic shields, filters for hot or corrosive fluids, catalyst supports, high temperature insulators, precursors of cellular ceramics, etc. The synthesis techniques now available in the lab allow, for the first time, to separate density and pore size, two parameters inversely proportional to each other in conventional foams. The present flavonoid tannin-derived vitreous carbon foams were aimed at being used as model materials for understanding the mechanics of such highly porous media, and the results were expected to allow their optimisation.

**Objectives** — Optimising the mechanical performances of cellular vitreous carbons derived from vegetable resources through the preparation of samples of strictly controlled structure, the experimental measurement of their mechanical properties and the modelling of the results.

**Approach** — Cellular vitreous carbon samples were prepared and investigated thoroughly, having fixed chemical composition but structural parameters (mainly porosity and pore size) independently controlled from each other, which had never been carried out before.

**Key results** —

- Unprecedented analysis of the compressive properties of several hundreds of samples, split into 9 families of structures and 6 classes of densities
- In-depth analysis of the impact of the measurement conditions, including with and without rigid plates glued to their faces, and depending on the speed of solicitation, and determination of the relevant conditions to measure moduli and compressive strengths
- No effect of the pore size, all else equal, was noticed
- The modulus must be determined with rigid plates glued to the samples' faces, whereas the compressive strength can be determined either with or without plates
- All materials, cellular or reticulated, or even in-between, obey a same refinement of the law of Gibson & Ashby, and with the same critical exponent
- From this refined law, the fraction of solid only present in the struts of the foams could be calculated and found in good agreement with calculations based on independent measurements of thermal and acoustic properties
- The definition of a class of semi-open foams was suggested, i.e., which changes compressive stress as a function of density similar to open foam, although presenting higher values, but which modulus behaves as that of closed-cell foams

- The demonstration was done that the relative density and the fraction of solid contained in the foams' struts are the only two key parameters to be tuned for getting the desired mechanical behavior.

**Main conclusions including key points of discussion** — At the academic level, the comparison of experimental results with simulation calculations allowed to go one step further than what is usually done with rigid foams, because these truly model materials are key experimental references for understanding the effects of independent structural parameters. At the technological level, these results allow the optimisation of these materials for which each considered application requires minimal mechanical properties for being used in a given context.

**Future perspectives** — These researches open the route towards a better understanding of organic foams, whose various compositions have additional effects (enhanced elasticity, ductility) to those induced by the porous structure. Shear and flexure tests, still very hard to carry out given the intrinsically fragile nature of these materials, would be worth doing for determining the Weibull modulus of different foam structures.

**Valorisation** —

**Conference**

M. Khelifa, V. Fierro, A. Celzard, M. Letellier, C. Delgado Sánchez, FE analysis of carbon foam under multiple compressive loading, 18th International Conference on Composite Structures (ICCS18), Lisbon (Portugal) 15 – 18 Juin 2015

M. Letellier, J. Macutkevic, D. Bychanok, P. Kuzhir, C. Delgado-Sanchez, H. Naguib, S. Ghaffari Mosanenzadeh, V. Fierro, A. Celzard, Modelling the physical properties of glasslike carbon foamsm Proceedings of the International Conference Carbon 2016 Conference, State College (PA, USA). 10 – 15 Juillet 2016

M. Letellier, J. Macutkevic, D. Bychanok, P. Kuzhir, C. Delgado-Sanchez, H. Naguib, S. Ghaffari, Mosanenzadeh, V. Fierro, A. Celzard, Matériaux alvéolaires modèles en carbone vitreux pour la science des matériaux et les sciences de l'ingénieurm, Journées Scientifiques de la Société Francophone d'Etude des Carbons (SFEC 2016), Carqueirrane (Var), 20 Mai 2016

M. Letellier, C. Delgado-Sanchez, J. Macutkevic, D. Bychanok, P. Kuzhir, H. Naguib, S. Ghaffari Mosanenzadeh, V. Fierro, A. Celzard, Etude des propriétés physiques de mousses modèles en carbone vitreux, Séminaire annuel du LCTS (Laboratoire des Composites Thermo-Structuraux), Bordeaux, 11 octobre 2016.

M. Letellier, J. Macutkevic, D. Bychanok, P. Kuzhir, C. Delgado-Sanchez, H. Naguib, S. Ghaffari Mosanenzadeh, V. Fierro, A. Celzard, Physical properties of model, reticulated and cellular vitreous carbon foams, V France - Russia Conference NAMES'16 (New Achievements in Materials and Environmental Science), Nancy 7-9 Novembre 2016.

**Publications**

M. Letellier, C. Delgado-Sánchez, M. Khelifa, V. Fierro, A. Celzard. (2016), Mechanical properties of model vitreous carbon foams, Carbon 11: 562-571

M. Letellier, J. Macutkevic, D. Bychanok, P. Kuzhir, C. Delgado-Sanchez, H. Naguib, S. Ghaffari Mosanenzadeh, V. Fierro, A. Celzard, (2017), Modelling the physical properties of glasslike carbon foams, Journal of Physics Conference Series 879: 012014-1 – 012014-8

**Media**

La mousse du futur à l'étude dans les Vosges

100% Vosges, N°184, 11 octobre 2016

http://www.centpourcent-vosges.fr/actu/sengager/la-mousse-du-futur-a-letude-dans-les-vosges/