Mechanics of super-insulating silica aerogel composites: a coupled experimental and numerical approach

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Tuesday, December 7th, 2021 – 2:00 p.m.

Amphithéâtre Biologie – UFR Chimie et Biologie

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Abstract: As new regulations for energy efficiency tighten in the building sector, the thickness required for thermal insulation of buildings with conventional materials (glass wool, polymeric foams...) can become prohibitive. This is a strong driving force for the development of a new class of products, the Super-Insulation at Atmospheric Pressure (SIAP) materials, based on the use of Silica Aerogel Particles (SAP). Silica aerogels are characterized by a very high nanoporosity (~95%) responsible for their unprecedented low thermal conductivities but also for their very low mechanical properties, limiting the handling ability and the use of SIAP products in building applications. The objective of this work is to gain a better understanding of the mechanical behaviour of SIAP in order to improve their mechanical properties, mainly fracture toughness, while preserving their exceptional thermal properties (target thermal conductivity of approximately 15 mW/m/K). The materials studied here are composite panels produced using a bimodal distribution of SAP and a latex binder. Different particulate composites are processed and their microstructural, mechanical and thermal properties are characterized. An original numerical model based on the Discrete Element Method (DEM) is then developed. First, mechanical characterization (crushing) of individual silica aerogel particles is used to calibrate the material parameters of the numerical particles. The simulated failure of these digital particles is accurate enough to reproduce crack patterns similar to those observed by X-ray tomography in real silica aerogel particles. Second, large numerical particulate composites are generated using the calibrated numerical silica aerogel particles in order to simulate the fracture of composite samples and extract macroscopic mechanical properties. The influence of the SAP size distribution and fiber incorporation on the composite fracture behaviour is assessed both experimentally and numerically. Lastly, the thermal performance of composite panels without and with fibers is characterized leading to the conclusion that properly managed fiber reinforcement can

result in a significant increase in toughness (x1.5 to x2) while increasing the thermal conductivity by only 1-2 mW/m/K.