Experimental evaluation of a ductile aerogel as damping layers in gypsum wallboards for increased sound transmission loss

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Abstract

Low-density, highly porous solid monolithic macroscopic objects consisting of hierarchical mesoporous three-dimensional assemblies of nanoparticles (aerogels) are pursued mainly for their low thermal conductivity. Unlike classical aerogels of the most common kind based on silica which are fragile materials, structural fragility issue has been addressed successfully with materials referred to as polymer-crosslinked (or X-) aerogels and organic aerogels. Organic aerogels are low-density materials, yet they have significantly enhanced mechanical strengths and ductility compared with silica aerogels. This work explores ductile organic aerogels for potential use as constrained damping layers integrated into gypsum wallboards. Due to their ductility and mechanical strength, lightweight organic aerogel panels of less than 1 cm in thickness can be conveniently integrated into gypsum wallboards. The objective of this work is to develop integrated wallboards to achieve significantly increased sound transmission loss without significantly increasing thickness and weight of the integrated wallboard system. This paper discusses preliminary test results carried out in chamber-based diffuse sound field measurements, and potentials of combining their excellent thermal and sound insulation into an integrated wallboard system.

Background

This work reports results from preliminary investigations (based on ISO 10140-2 and ASTM E90 [1-2]) of aerogel panels with nanostructures (nanoparticles and/or nanofibrous as shown in Fig. 1) arranged in a sandwich-structure between 2 thin layers of gypsum wallboards. The most common kind of aerogels is based on silica (amorphous SiO_2), but in spite of their very attractive attributes (e.g., very low thermal conductivity and mesoporosity that can host functional guests with useful chemical, electrical, magnetic or optical properties) [3], applications have been mainly confined to space exploration [4]. The reason is that silica aerogels are very fragile materials, and also the high manufecture cost is prohibitive for wide practical applications. The fragility issue has been overcome successfully by nanoencapsulation of the entire skeletal framework with a thin layer of a conformal polymer layer [5-6]. In addition, recent advances in all-polymer aerogels have also resolved fragility issues rendering them viable alternatives to silica-based aerogels [7-10]. In particular, polyurea aerogels (Fig. 1), can be synthesized in a single, environmentally-friendly step from inexpensive triisocyanates and water over a wide range of densities. Reasoning that the nanoporous characteristics of organic aerogels could be accompanied by high, structure-dependent acoustic attenuation [11] and dynamic properties (Young's modulus, damping constant, etc.), we think that the random multiscale heterogeneous structural elements and hierarchical porosities provide highly tortuous paths, and resisstance to air flow that result in synergistic dynamic mechanisms yielding broadband acoustic attenuation, and intriging dynamic properties.

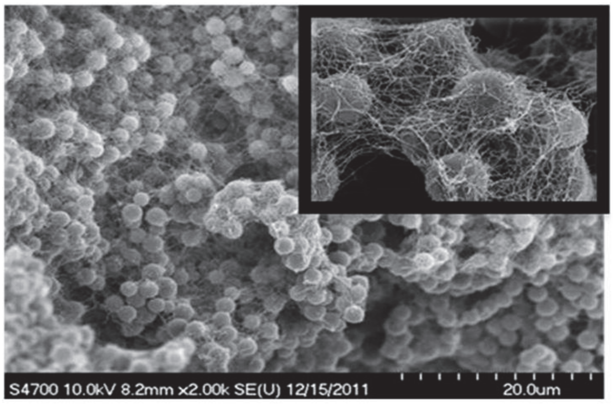

Figure 1: Fractal nanostructure of polyurea aerogel samples containing nanoparticles and nanofibours.

Nonascale modeling

As the first step towards understanding the drastic acoustic wave attenuation effect through porous nanostructures, we conducted a preliminary study using a simplified one-dimensional monoatomic model, whereas 60 beads of the same mass, representing the 2-μm solid polyurea particles in Fig. 1, were connected with springs, representing the cons-training nanofibers. Two situations were simulated: (a) with constant spring constants; (b) with spring constants varying randomly by ±50% around the average value used in (a). A longitudinal excitation was introduced from one end, and the amplitude of the wave arriving at the other end of the assembly was calculated. The constant spring constant arrangement showed no attenuation (Fig. 2). The random arrangement induced acoustic impedance mismatch, and vibration localization that led to significant attenuation at both low as well as high frequencies. To evaluate the role of damping, a damping coefficient, ξ, was introduced in the model. As indicated by the data in Fig. 2, damping does provide some additional attenuation, however, the overall curve follows the top envelop of the original curve (without damping), thus signifying that most of the attenuation is provided by the structure, rather than by damping effects of the skeletal structures.

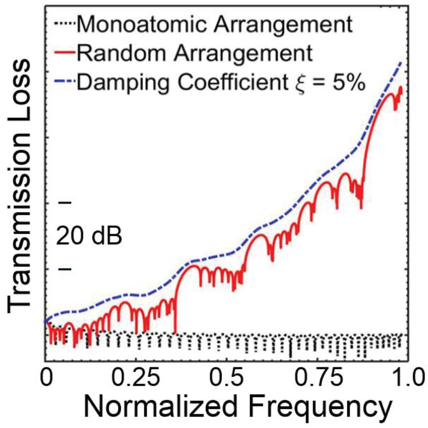

Figure 2: Simulated sound transmission loss of nano-structure of polyurea aerogels based on one-dimensional (compressional wave) model with random-spring constants of nanofibours. Also plotted are simulation results of monoatomic arrangment of nanofibours with constant spring constants.

This finding supports our hypothesis that even under the simplest situations. On the down side, however, this simulation did not furnish the experimental broadband attenuation, or sound transmission loss, particularly in random incidence situations. For this reason, preliminary investigations on wallboards in sandwiched structures have been conducted based on experimental testing method widely accepted by building acoustics practice. In the furtue, the computational simulation work will be expanded into two and three dimensions in various random structures based on experimental materials. Ultimately, simulations will include interactions between the pore-filling air and the deformable solid framework based on theory similar to, or in compliance with Biot theory [12], and thus will capture attenuation of sound waves travelling both through the pores and through the solid. Also in addition to compressional waves, shear- (or bending-) waves will be invoveld in the simulations /calculations.

Table I: Density and thickness of the aerogel panels as consrained damping layers and gypsum boards.

Variations	Thickness (mm)	Density (g/cm^3)
Gypsum boards (2)	10 mm/each	0.9-1.0
Aerogel layer 1	5 mm	0.15
Aerogel layer 2	5 mm	0.25

Transmission-Loss Experiments

This work reports on preliminary investigations (in compliance with ISO 10140-2 [1], similar to ASTM E90) of organic aerogel panels inserted between the gypsum wallbards in sandwich structures; namely polyurea aerogel boards are inserted between two gypsum boards. Each gypsum board has a thickness of 10 mm, giving a total thickness of 20 mm for the two gypsum boards. As constrained damping layers, the organic aerogel panels with two different densities (corresponding to different nano-morphologies) are bonded together, the sandwich structure consists of one identical gypsum board on each side of the bonded aerogel board (total thickness is 10 mm), Table I lists the thicknesses and densities of these boards.

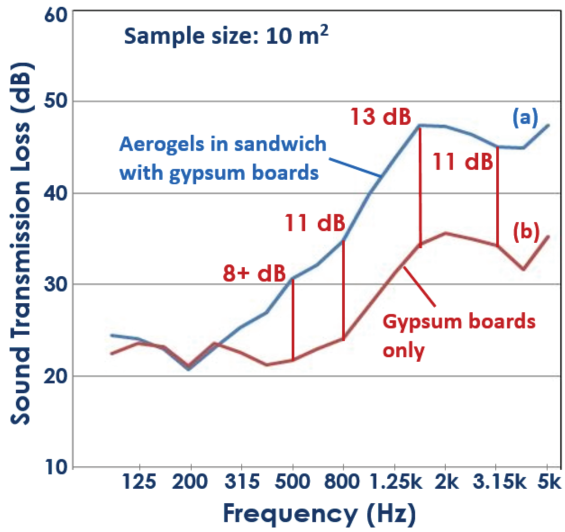

Figure 3: Comparison between sound transmission losses of two wallboard-structures. a) Aerogel panels (densities 0.15 g/cm^3 and 0.25 g/cm^3) are glued in between two gypsum boards of same thickness / density. b) Two gypsum boards of same thickness / density bonded together. Measurements were conducted in transmission-loss test chambers with sample size of 10 m^2 (in compliance with ISO 10140, similar to ASTM E-90).

The experimental investigations were conducted in test chambers for sound transmission loss which are in compliance with ISO 10140-2 [1]. The primary goal of these investigations is to explore the possiblity of increased sound transmission loss, thus the comparison is made with two types of wall constructions: the two sheets of gypsum boards with and without the aerogel boards inserted between the gypsum boards. The difference in the two constructions is in the 10 mm thick organic aerogel plate. Results from the two bonded gymsum boards represent the baseline data. As listed in Table I, with the two sheets of aerogel panels inserted as constrained damping layers between the gypsum boards, thickness of the entire wall structure under test increases only 10 mm from the baseline structure of 20 mm, while the weight of the entire wall strcutrue increases by only 10.0% in comparison with only two gypsum boards glued together. Figure 3 illusrates the experimentally measured results of two wall structures for direct comparison. The wall samples are 10 m^2 in size (in compliance with ISO 10140). With the aerogel panels inserted as the constrained damping laers, the sound transmission loss increases signifantly over the frequency range higher than 400 Hz. An incresement of sound tranmission loss over 10 dB clearly breaks the 'mass law'.

Another set of measurements was also conducted, employing wall samples of the same structrure (with same thicknesses, respectively for constructions with and without aerogel panel), yet with smaller size, 1 m^2, in order to confirm the effect of the constrained damping layers. Figure 4 illustrates the sound transmission loss results. Again a significant increase in sound transmission loss has been achieved in a simiar manner; the difference is due to different sizes of the test samples.

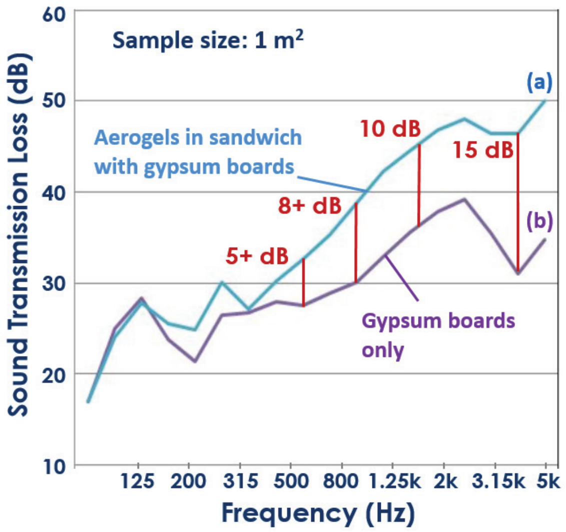

Figure 4: Comparison between sound transmission losses of two wallboard-structures. a) Aerogel panels are glued inbetween two gypsum boards of same thickness/density. b) Two gypsum boards of same thickness/density clued together. Measurements were conducted in transmission-loss test chambers with sample size of 1 m^2.

Concluding Remarks

These two sets of experimental results demonstrate consistently a significant increase of sound transmission loss when aerogel pannels are inserted as constrained damping layers into gypsum wallbord in sandwich structures.

The aerogel papnels can be machined to even thinner panels. Ongoing research effort is to experimentally evaluate thinner panels as the constrained damping layers. In the near future, dynamic properties of the employed aerogel materials, such as compressional, and shear wave speed, Young's and shear modules, and dymamic density will be experimentally characterized, to facilitate the modeling effort to predict the sound transmission loss in a well-controled manner. Due to their extremely low thermal conductivity, low-cost and ease of moding and machining of this type of organic aerogel materials, we envision that they will find wide applications in buidling acoustics practice.

Acknowledgment

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