Aerogels as innovative insulation materials – a range of acoustic properties

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Introduction

Aerogels are highly porous nanostructured solids with quite low densities. Due to their branched structure with open pores in a range from nanometers to micrometers they have large internal surfaces compared to their small volume [1]. Low sound velocities lead to good sound absorption properties. Moreover, they show very low thermal conductivities. This makes them a promising basis for materials with a diverse and consistently high level of insulation.

Aerogels are manufactured in a sol-gel process. The main ingredients are alcohol, water, catalysts and alcoxide which will form the structure of the porous material. In the first step, the sol is created by mixing of all liquid compounds. Afterwards, the formation of the structural network occurs. This state is called the gel. In the last step, the solvent needs to be removed from the pores. This can be done by drying. For the aerogels discussed here the drying can be done at room temperature [1].
The parameters of the aerogel like the pore sizes can be influenced by changes in the synthesis process. For example, a change can be the temperature or pH value of the solution. Another possibility is to change the ratio of the ingredients. In the following, two materials with different amount of alcoxide but the same amount of the other compounds will be discussed.

Aerogel samples

The aerogels discussed in the following are both based on methyltrimethoxysilane and dimethyldiethoxysilane. They were produced by DLR (Institute of Materials Research, Aerogels) based on [2].
The first material will be named *Basic* in the following as it was the basic recipe. It has a density of 110 kg/m^3. A reduction of around 20 % of the amount of alcoxide leads to the second material, in the following called *Diluted*. It has a density of only 70 kg/m^3. They look quite similar but due to the reduced amount of the structural network, the *Diluted* material is a little more fragile. For both materials samples with 9 mm thickness were produced. A picture of both samples is shown in figure 1.

Figure 1: Two flexible aerogels based on methyltrimethoxysilane and dimethyldiethoxysilane. Top: material "*Basic*" with a density of 110 kg/^{3} and a thickness of 9 mm. Bottom: material "*Diluted*" with a density of 70 kg/m^3 and a thickness of 18 mm.

Absorption coefficient

For the characterisation of the acoustic properties the absorption coefficient was determined. First, impedance tube measurements were done. The absorption was determined with the two-microphone method [3]. Measurements with one layer (see figure 1 top) and two layers (see figure 1 bottom) of each material were done.

The results are shown in the straight lines in figure 3. As one would expect, the absorption of two layers is higher than for one layer due to the higher mass. But for the *Basic* material the difference at higher frequencies is quite low. Comparing *Diluted* with *Basic* the absorption for one layer is lower at all frequencies. But two layers of the *Diluted* material show a different behaviour in the higher frequency range than the *Basic* material. Here, two layers show a large increase in the absorption coefficient compared to one layer.
This leads to the assumption that the acoustic properties of these materials are different. Parameters that influence the acoustic behaviour for example the pore size are difficult to determine because typical measurement methods do not work in the range of the pore size of these aerogels. Therefore, the method of inverse char-

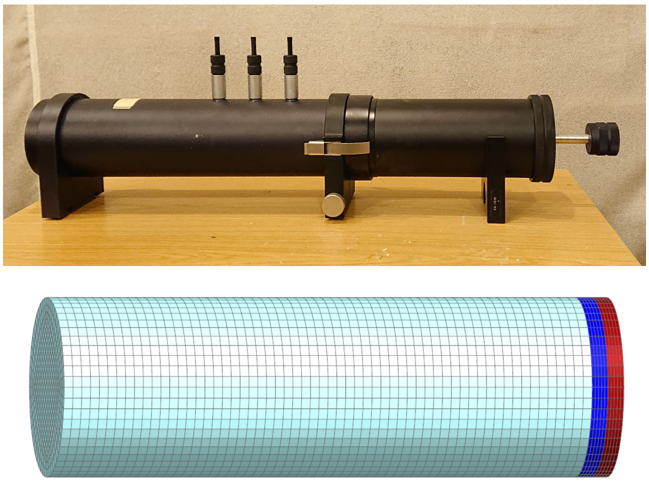

Figure 2: Setup for the determination of the absoprtion coefficient. Top: impedance tube measurement with two-microphone method. Bottom: simulation with 3D FEM. The porous material is described by the Johnson-Champoux-Allard model.

acterisation with a comparison of a simulation to the measurement results was used. In the simulation the impedance tube measurements with both one and two layers are represented with a 3D FEM model. It includes the air inside the impedance tube, the aerogel samples and the microphone positions (figure 2 bottom). The excitation is represented by a normal velocity.

The results are shown in the dashed lines in figure 3. They match quite well with the measurements. Therefore, the simulation can be used to identify some of the acoustic parameters of the materials.

The porous material is described by the semi-phenomenological Johnson-Champoux-Allard model [4, 5]. This model uses the Biot-Parameter flow resistivity, viscous and thermal length, porosity and tortuosity. The values for these aerogels are shown in table 1.
The main difference between *Basic* and *Diluted* is the flow resistivity. With the lower density *Diluted* has a flow resistivity only half the size as *Basic*. This is the parameter with the largest influence on the measured absorption coefficient. Another important parameter is the viscous length which is the size of the connection of two pores. The viscous length of the *Diluted* material is a little bit larger than for the *Basic* material. This makes sense as for the same volume of the liquids, less structure was available to form the network and the resulting pores need to be larger. The thermal length, which is the diameter of the pores, porosity and tortuosity have only a small influence on the absorption coefficient. The thermal length is a little bit larger for *Diluted* than for *Basic* due to the same reason as for the viscous length. The porosity of *Diluted* is a little bit higher due to the lower density.

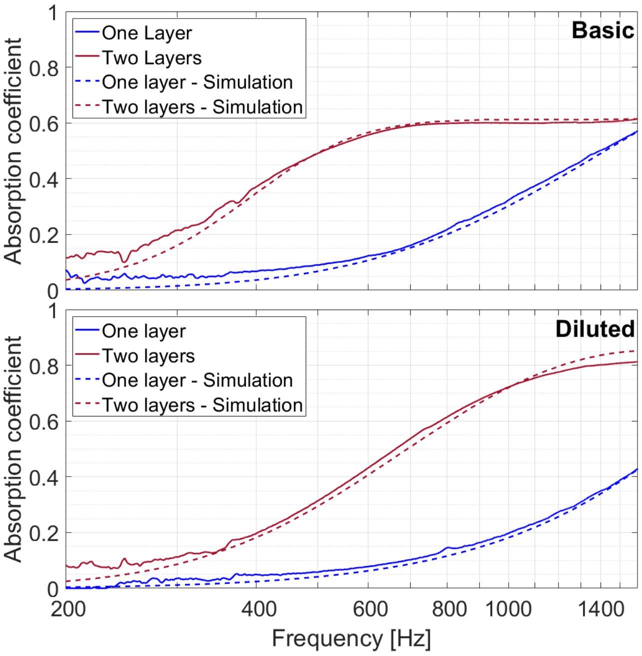

Figure 3: Absorption coefficient determined by measurement and simulation for one layer (9 mm thickness) and two layers (18 mm thickness) for *Basic* (top) and *Diluted* (bottom) material.

Table 1: Biot-Parameter of *Basic* and *Diluted*. Abbreviations: ρ - Density, r_f - Flow resistivity, Λ' - Viscous length, Λ - Thermal length, ϕ - Porosity and α - Tortuosity

	Basic	**Diluted**
ρ [kg/m^3]	110	70
r_s [kNs/m^4]	250	120
Λ' [μm]	40	60
Λ [μm]	40	60
ϕ [-]	0.95	0.97
α [-]	4	4

Combined materials

In the next step both materials were combined. The same setup with the impedance tube was used. One layer of each material was combined with one layer of the other material and the layout was changed so that both materials are once placed front in regard to the incoming sound. The results of the simulation are shown in figure 4 and compared with two layers of each material. The measurements show the same behaviour and are not discussed for compactness. The absorption coefficient for two layers of *Basic* and for one layer of *Basic* in front with one layer of *Diluted* behind is nearly the same although the mass of the combined layout is lower. The same behaviour is visible if one layer of *Diluted* is placed before one layer of *Basic*. This resulting absorption coefficient is nearly similar as for two layers of *Diluted*.

It appears that the front material is the main reason for the resulting absorption coefficient. This shows the potential of aerogels for tailoring isolation materials with

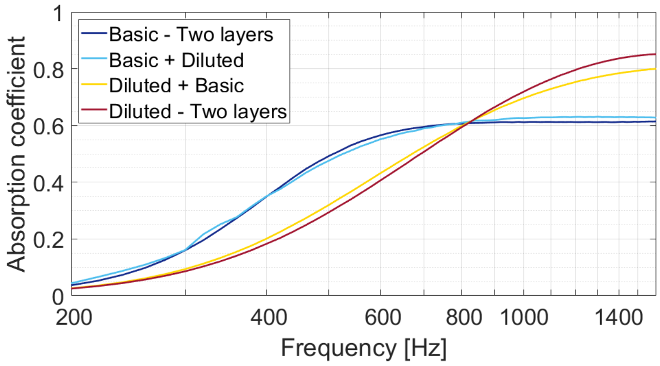

Figure 4: Absorption coefficient of two layers of each material and combinations of both materials. The results are determined with the simulation. Measurements show the same behaviour.

properties of interest. Focussing on the lower frequency range, one can use *Basic* and *Diluted* instead of two *Basic* layers. This reduces the mass without reducing the absorption coefficient. Regarding the higher frequency range one can get a material that is less fragile through a combination of *Diluted* and *Basic* instead of only *Diluted*.

It is important to keep in mind that this setup has normal sound incidence. Therefore, a simulation with a diffuse field excitation was set up.

Diffuse field excitation

The chosen application for the diffuse field application is the sound transmission through an airplane fuselage. It is a part of an A340 with a dimension of around 1 m x 1.2 m. The model includes an isolation material of 0.1 m thickness. A sketch of the model is shown in figure 5. The same material combinations as before were investigated which are 2 x *Basic*, 2 x *Diluted* and the combination of both with once *Basic* and once *Diluted* as front material. For all material combinations the transmission loss is calculated.

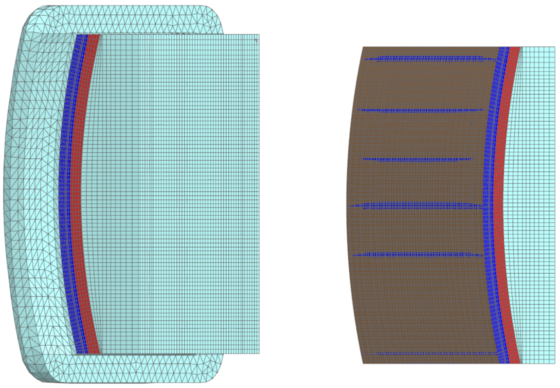

Figure 5: Simulation setup for a transmission loss calculation through an A340 fuselage with diffuse field excitation.

The resulting transmission loss is shown in figure 6. First, the transmission loss of the structure (dashed black) was compared to the results with *Diluted* (red) as isolation material. The transmission loss with isolation is of course higher due to the higher mass. Therefore, the mass of the isolation was added to the structure by changing the density of the structure. The resulting transmission loss (straight black) only shows a constant offset through the whole frequency range whereas the aerogel yields a higher transmission loss especially at higher frequencies. These results show that the aerogels not only have good acoustic properties due to their mass but due to their porous properties.

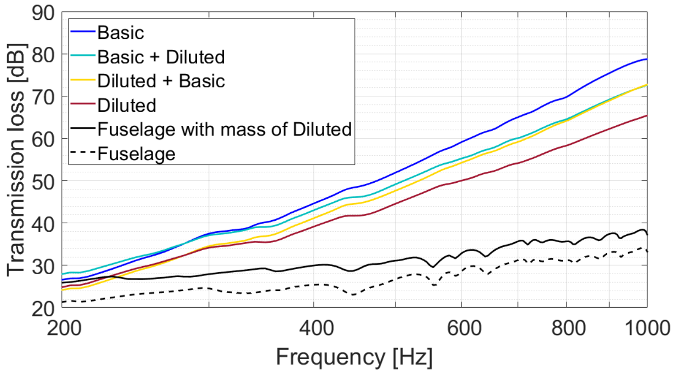

Figure 6: Transmission loss through an airplane fuselage with a dimension of 1 m x 1.2 m. The thickness of the isolation material is 0.1 m.

In the lower frequency range up to 350 Hz the same behaviour as for the normal sound incidence is visible. The combination of *Basic* + *Diluted* yields the same transmission loss as 2 x *Basic* and also *Diluted* + *Basic* yields the same transmission loss as 2 x *Diluted*. One can also see that in the higher frequencies the mass of the material has the largest influence on the transmission loss. At 1000 Hz the transmission loss of both combined materials is the same and between the pure *Basic* and *Diluted* materials. This leads to the conclusion that the layout of aerogels can influence the acoustic behaviour also with diffuse field excitation.

Summary

In summary, aerogels can be good acoustic absorbers. Small changes in the synthesis can strongly influence their acoustic properties like the pore size and the flow resistivity. It is shown that combinations of two different materials can yield the acoustic behaviour comparable to only one material of the same thickness. Here, the layout of the materials has a large influence on the resulting acoustic behaviour. Combinations of different materials might be a possibility to reduce mass or increase mechanical stability in some applications without reducing the absorption properties.

Acknowledgement

This work was done within the project MULTIKABIN. We would like to thank the Federal Ministry of Transport and Digital Infrastructure for their financial support and the project partners from DLR Cologne for the preparation of the samples and their support for this contribution.

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