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Preliminary Acoustic tests on resilient materials: comparison between common layers and nano-structured layers

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ABSTRACT

Nowadays, efficient thermal insulation is a principal requirement for buildings and, accordingly, huge amounts of insulators are applied in the constructions, particularly for external walls, radiant floor, roofs, etc. Acoustic insulation is another of the most stringent parameters to be taken into account both in the construction of new buildings or their rejuvenation in order to obtain good internal comfort. Notwithstanding these needs, only few materials are marketed which feature reasonably good both thermal and acoustic insulation properties. More often, materials with good sound insulation proprieties show poor thermal efficiency and vice versa. Further, most of materials which have good both acoustic and thermal properties are thicker than either acoustic or thermals insulators which creates technical difficulties in their use, particularly in the buildings' renovation. Nano-structured materials such as, for example, microporous or aerogel materials, are characterised by highly efficient thermal insulation power, in spite of their reduced thickness compared to conventional systems.

INTRODUCTION

The aim of this work is to compare properties of conventional and unconventional materials that could combine both acoustic and thermal insulation properties

The new unconventional material is a nano-structured layer which is characterized by good thermal insulation capacity in spite of its reduced thickness. This makes it particularly advantageous for the engagement in building partitions. Appropriated acoustic test were conduced in order to determine if this material is able to offer also good resilient properties and efficiency in the reduction of impact sound level in floating floors. Further, a comparison between the resilient properties of different insulating material was performed.

CHARACTERISTICS OF MATERIALS USED UNDER FLOATING FLOOR

Dynamic stiffness

The dynamic stiffness for unit area of materials used under floating floors in dwellings is the principal parameter to use in order to determine the attenuation of impact sound pressure level achievable by floating floors. A dynamic stiffness low value material that can reduce the level of impact sound insulation more than a material with high dynamic stiffness value (i.e. inelastic).

Standard ISO 9052-1 [1] introduces the test arrangement and the measurement method for the calculation of the following quantities: dynamic stiffness per unit area of enclosed gas, s'_a; apparent dynamic stiffness per unit area of test specimen, s'_t; dynamic stiffness per unit area of the installed material, s'.

The apparent dynamic stiffness per unit area of test specimen s'_t is related to the extrapolated resonant frequency f_r of the fundamental vertical vibration of the resilient material under test and load plate system, as given by the equation:

$$s'_t = 4\pi^2 m'_t (f_r)^2 \qquad \text{(Eq. 1)}$$

where m'_t is the total mass per unit area used during the test (a still load plate size 20x20 cm and weight of 8±0.5 kg).

For porous materials, if the lateral airflow resistivity, measured in accordance with ISO 9053 [2], is included in the range: $100\ kPa \cdot s/m^2 > r \geq 10\ kPa \cdot s/m^2$ then the dynamic stiffness per unit area of the enclosed gas has to be determined with the equation:

$$s'_a = \frac{p_0}{d\varepsilon} \qquad \text{(Eq. 2)}$$

where p_0 is the atmospheric pressure, d is the thickness of the test specimen under the applied static load and ε is the porosity of the test specimen.

In this case, the enclosed gas could be considered as a further spring, connected in parallel with the spring due to the material itself. The dynamic stiffness per unit area of the resilient material can be determined with the equation:

$$s' = s'_t + s'_a \qquad \text{(Eq. 3)}$$

In case of high airflow resistivity the s'_a contribution could be considered not influential.

The results shall be the mean value of the respective measurements made on minimum three test specimens, rounded to 1 MN/m^3.

For the determination of resonance frequency, the acoustic laboratory tests of the Department of Materials and Natural Resources at University of Trieste uses pulse signal technique, as described in ISO 7626-5 standard [2]. The measurement set-up consists of (Figure 1): impact hammer PCB Piezoeletronics® Mod. 086C03, N. 26753; accelerometer Dytran® Mod. 3023M2 Triaxial; hardware National Instruments® mod. NI 9234; software LabVIEW® Sound and Vibration Toolkit for signal acquisition.

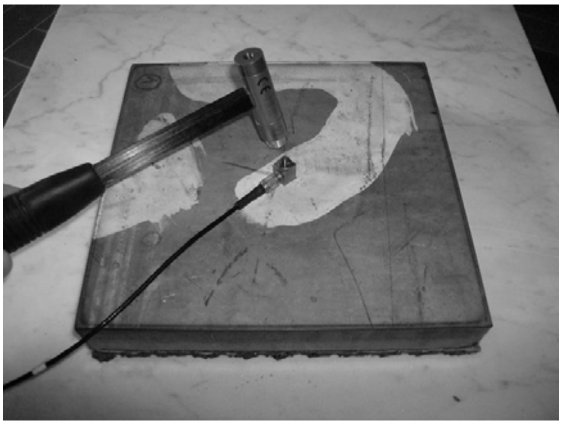

Figure 1. Measurement set-up for apparent dynamic stiffness

Thickness for floating floor insulating products

If a floating floor is subjected to an instantaneous compression due to a significant load, the elasticity of resilient material is influenced by the extent of the crushing. If after the overload action the resilient material is able to recover all the lost thickness, it will continue to behave like a spring. Otherwise it remains partially crushed, losing its initial resilient propriety.

The standard EN 12431 [3] specifies the equipment and procedures for determining the thickness of thermal insulating products for impact sound insulation in floating floor applications. The thickness is determined as the distance measured between a rigid flat base plate on which the test specimen is placed and a rigid flat pressure plate exerting different specified pressures on the top surface of the test specimen. The following quantities have to be determined: d_L: thickness of the product under a load of 250 Pa; d_F: thickness of the product under a load of 2 kPa; d_B: thickness of the product under a load of 2 kPa after application of a short time additional load (48 kPa). Ten test specimens shall be used. The results for each thickness shall be the mean value of the respective measurements made on all test specimens, rounded to the nearest 0.1 mm.

In order to determine the capacity of the resilient material to recuperate the thickness lost due to overloaded the following quantities is introduced:

$$c = d_L - d_B \qquad \text{(Eq. 4)}$$

where *c* represents the compressibility of the material (that is the faculties to recover the lost thickness due to the overload).

A resilient material that has a low value of compressibility can offer performance almost constant in terms of reduction of impact noise level.

The measurement set-up for the determination of thickness for floating floor insulating products at the acoustic laboratory tests of the Department is composed by: reference steel plate size 200x200 mm; steel load plate size 200x200 mm and weight about 1 kg; steel load plate size 200x200 mm and weight approximately 8 kg; hydraulic press Paul Weber Types PW 40 that exerts pressure on the test required by rule; analogical dial gauges (Figure 2).

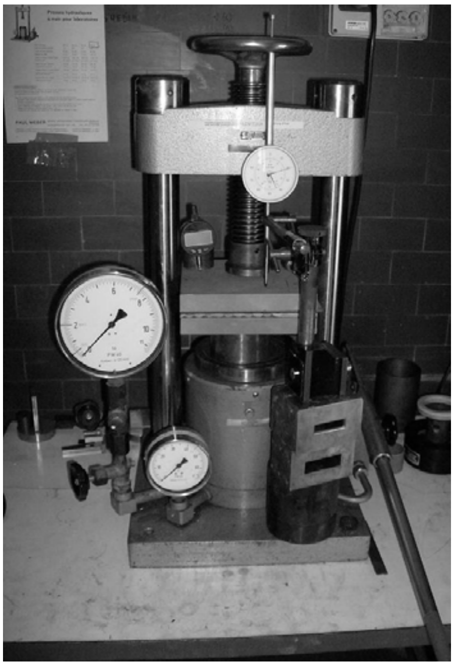

Figure 2. Measurement set-up for thickness under different static load values

Determination of compressive creep

The standard EN 1606 [4] is applicable to thermal insulating products and specifies the equipment and procedures for determining the compressive creep of test specimens under various conditions of stress. The compressive creep is determined by measuring the increase of deformation of a test specimen under a constant compressive stress and specified conditions of temperature, humidity and time. The test is carried out at three or more different stresses. In order to compare the creep results with those obtained by dynamic stiffness and compressibility tests a load of 8 kg on a surface size 200x200 mm has been chosen. The compressive creep X_{ct} represents the increase of the deformation X_t (reduction in thickness) of the test specimen under a constant stress with time. The relative deformation ε represents the ratio of the deformation X_t of the test specimen and its thickness d_S measured in the direction of the load. The deformation X_t has to be determined at precise time intervals after application of the load (equidistant increments in a logarithmic time scale) over a period of at least 90 days in order to apply Findley equation calculation method and extrapolate the compressive creep for the tested material with a maximum extrapolation up to 30 times of the testing time.

The results were evaluated as the mean value of the respective measurements made on minimum three test specimens.

A low creep material is able to provide nearly constant performance in time in terms of reduction of impact noise level.

The measurement set-up for the determination of compressive creep at the acoustic laboratory tests of the Department is composed by: steel base plate; steel load plates, size 200x200 mm and load of 200 kg/m^2; digital micron gauge (Figure 3). For all specimens, each deformation was rated as average of at least two positions on the load plate.

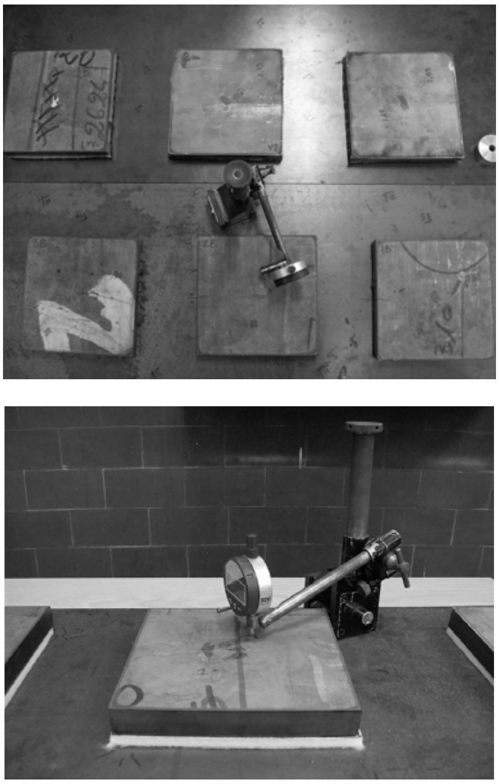

Figure 3. Measurement set-up for compressive creep

CHARACTERISTICS OF COMMON THERMAL INSULATION MATERIALS

Materials employed for thermal insulation are typically characterized by low density and large amounts of air embedded within small sphere, fibres or cells.

This leads to a bad acoustic behaviour. For vibration, nevertheless, resilient material can bring useful help to the building structure.

Resilient materials can behave both as thermal insulators and “vibration dimmers”.

Thermal conductivity (λ), which is an intrinsic the property of a material to transmit heat, is determined by laboratory tests with thermofluximeter or hot plate technique.

For an insulating layer, the correlation between λ and thermal insulation is given by the Eq. 5

$$q = -\lambda \cdot \frac{dT_s}{dx} \qquad \text{(Eq. 5)}$$

Where q is the specific heat flow between the faces of the flat plate, λ is the thermal conductivity, $dT_s = T_2 - T_1$ is the temperature difference between the two walls of the layer to be measured and *dx* is its thickness. Good thermal insulator have obviously low λ. As shown in Eq.5, this property is independent from the thickness. λ of some representative materials are reported in table 1

The data show significant differences between the construction and insulation materials: despite its low thermal conductivity, a layer thick more then 10-15 cm made of expanded polystyrene is needed in order to achieve an external wall insulation required by current regulations in Central Europe.

Table 1. Some common thermal insulator

material	*Heat conductivity [W/m K]*
Reinforced concrete	2.4
General brick	0.8
Mineral wool	0.039
Expanded polystyrene	0.035
Polyurethane foam	0.024

Another use of thermal insulation is in radiant floors. Generally, a thickness of 3 or 4 cm of the thermal insulator is needed to minimise direct heat transfer to the upper side of the floor. However, this thermal insulator will not have any particular acoustic properties. So usually a coupling of the acoustic and thermal material is employed. The acoustic part often doesn’t feature good thermal insulation capability (because of its composition and low thickness) as shown in table 2

Table 2. some common acoustic resilient materials ($10 < s' < 80$)

material	*Heat conductivity [W/m K]*	*Required Average thickness [mm]*
Synthetic mineral or natural fibres	0.045	8
Closed cells Polyethylene	0.037	7
Recycled rubber	0.15	10
Elastic expanded polystyrene	0.035	300

DESCRIPTION OF THE NEW NANO-STRUCTURED LAYER

The use of nanostructured layers containing microporous aerogel–type of materials has received a considerable interest in the last years. Aerogel are highly porous materials - typically more than 80% of their volume consists of pores filled with air - which accordingly feature good thermal insulation properties. Generally speaking, the pore distribution in these microporous materials is critical for their efficiency as insulators due to the fact that the heat transferred through a porous material (λ'_t) can be considered as the sum of the heat transferred through the solid phase (λ'_s) and through the gaseous phase (λ'_g), whereas other factors can generally be ignored at ambient temperature [5] .

Regarding the transfer in the aerogel phase, this is described by the relationship:

$$\lambda'_s = \lambda_s^0 \times V_s \times \left({}^{v_p}\!/_{v_d} \right) \qquad \text{(Eq. 6)}$$

Where λ_s^0 is the intrinsic conductivity of the solid that makes up the aerogel, ${}^{v_p}\!/_{v_d}$ is the ratio of the sound velocities in porous and dense bodies, *Vs* is the volume fraction of the solid, and *Vg* is the volume fraction of the voids or fractional porosity: *(1 - Vs)*. Pore size, i.e. pore diameter (*Dp*) , strongly influences conductivity of the gaseous phase. For a *Dp*>140nm this is found to be:

$$\lambda'_g \approx 2.5 \times 10^{-2} \times V_g \qquad \text{(Eq. 7)}$$

Conversely, for materials having pores of *Dp* < 140 nm, conductivity is given by the expression:

$$\lambda_g \approx 1.7 \times 10^{-5} \times V_g \times D_p \qquad \text{(Eq. 8)}$$

A reduction of three orders of magnitude in the gas conductivity value is noted when considering materials with pores of D_p < 140 nm. Accordingly, the use of microporous aerogel-type materials is highly promising in comparison to conventional materials as shown in Figure 4 which compares typical thermal insulation properties of a number of common insulation materials [6].

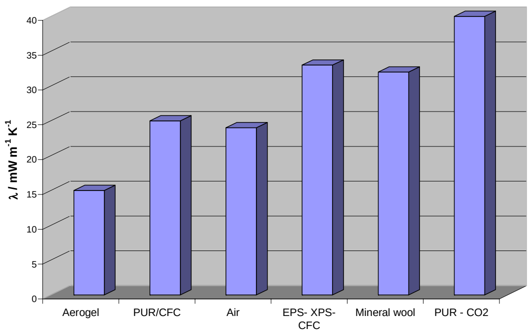

Figure 4. Comparison of the thermal insulation properties of some common insulating materials with those of the aerogel. PUR: polyurethane foam, CFC: chlorofluorohydrocarbons; EPS, XPS: expanded and extruded Polystyrene. Adapted from [6]

It is also worth of noting that the aerogel microporous structure can affect the acoustic properties of a solid material, by modifying the speed of sound propagation. For instance, sound velocities of 100÷300 m/s were found for SiO_2 aerogels compared to the sound velocities of 5000 m/s measured in quartz (SiO_2) glass [6].

Accordingly, here we investigate the acoustic properties of a series of inorganic resilient materials containing an inorganic aerogel-like material. As shown in Figure 5, in view of the above considerations on the importance of the pore distribution, an aerogel-like material, featuring a singular pore distribution where most of the pores are located at a pore diameter smaller that 140 nm, was used here.

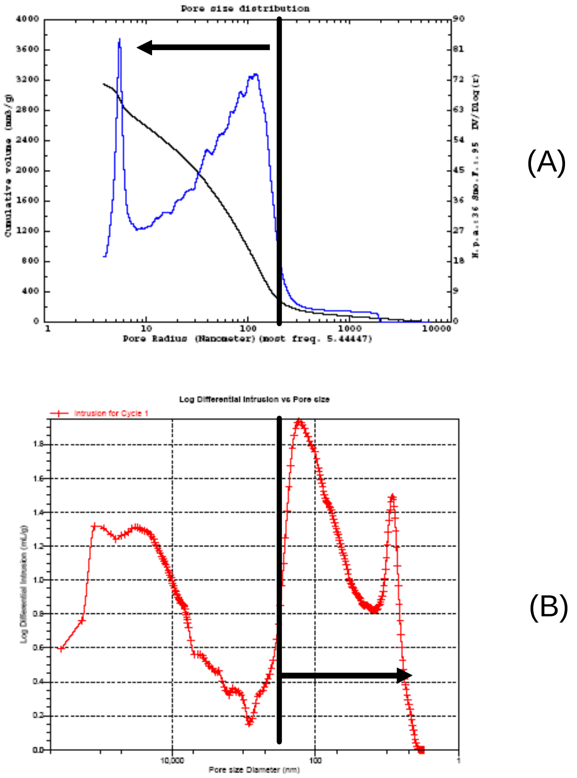

Figure 5. Comparison of the pore distribution of (a) the aerogel-like microporous material used in this study and (b) that of a conventional aerogel-like material.

The nano-structured materials were prepared according to WO2008/077876. Pore distribution were measured on Micromeritics porosimeters, using both N_2 and mercury adsorption techniques. Thermal conductivity was measured as reported in WO2008/077876.

COMPARISON BETWEEN COMMON LAYERS AND NANO-STRUCTURED LAYERS

We compare different material typologies in terms of:

- thickness
- dynamic stiffness
- compressibility
- compressive creep

The obtained results are shown in table 3. For the dynamic stiffness behaviour the comparative quantity is the apparent dynamic stiffness *s'*$_t$, determined without use of plaster covering in order to minimize the measurement errors [7], with a variable pre-load time depending on the stabilized value of s'_t and analysing the resonant frequency dependence by excitation force amplitude [8]. The indicated values are obtained as mean value of six test specimens for each material.

For the compressibility behaviour, the selected pause before measuring the thickness d_B was 120 s for each material. The indicated values are obtained as mean value of ten test specimens for each material.

For the creep behaviour the test was carried out using a stress value σ_c=200 kg/m^2 in order to compare the results with that obtained with dynamic stiffness and compressibility test. The test is continued for 90 days for each material. The indicated values are obtained as mean value of three test specimens for each material.

Table 3. values of thickness, dynamic stiffness, compressibility and creep for different material typologies

material	*thick. [mm]*	*s'_t [MN/m^3]*	*C [mm]*	*X_{ct} [mm]*
PE smooth surface	7.66	18	0.43	2.06
PE bubble surface	8	9.8	1.58	1.8
Fiber-low density	13.4	11	5.4	3.32
Fiber-high density	10.8	8.5	3.79	2.91
Rubber lattex	10	22.8	1.29	0.89
Mineral wool	24.7	11.51	3.3	3.11
Recycled rubber	5.72	55.4	0.51	4.46
Nano-structured layers	8	22	6.71	--

The behaviour of nano structured layer show good dynamic stiffness property, comparable with other very good resilient materials.

Conversely, the compressibility test did not exhibited good properties indicating a need for improvement of this property. We must stress that the present preparation of specimens are preliminary and were not specifically designed for floor applications. In order to increase this particular parameter a new polymer matrix is being investigated.

The compressibility value for the nano-stuctured material is pretty high, comparable to the values obtained for fibre and mineral wool. We can verify this behaviour for fibrous materials and high porosity materials. The *final thickness dB* results from "load history"; it is the application and removal of the maximum load of 50000 Pa. This excessive stress can be detrimental for fibrous materials such as rock, glass or ceramic wool, wood fibre because it could cause irreversible rupture.

Figure 6. End of compressibility test for nano-composite layer. We can notice disgregation of the material

In the case of high porosity materials, the overload can produce the release of most of the air captured within the material, but the air can't return the same amount after the crushing of the pores. For the nano-structured layer the obtained results suggest the occurrence of both issues during the test.

The compressibility tests show how different kind of materials have different behaviours as shown in figures 7 and 8.

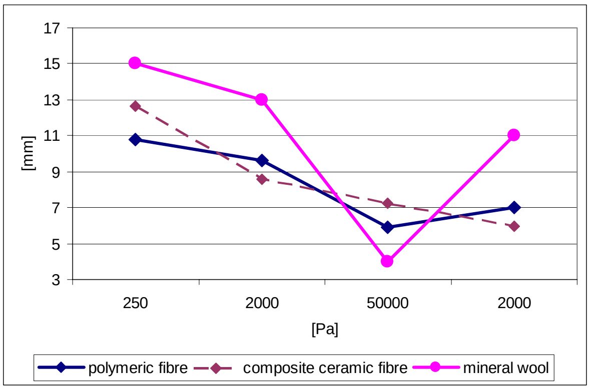

Figure 7. Comparison between different kinds of resilient fibrous materials under compressibility tests.

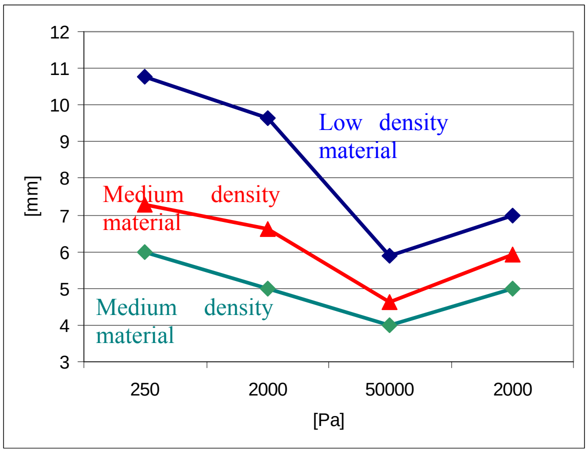

Figure 8. Comparison between different kinds of resilient polymeric materials on compressibility tests.

The results show that under 50000 Pa pressure, fibrous materials do not behave as good resilient materials: in fact, ceramic fibres presumably break up and exhibit no “spring-like” properties that could restore the specimen thickness after the heavy loads.
In particular, ceramic fibres do not show resiliency after the heavy load application.
For polymeric fibres, the original material has resilient properties; this material can “re-organize” under loads, so its behaviour is better than the ceramic ones.
Finally, under 50000 Pa pressure, polymeric materials do behave as good resilient materials. The original material indeed has resilient properties; this material can then “re-organize” under loads, so their behaviour is better than the ceramic ones.

Compressive creep results show that this property may depend on original material and don’t depend on the shape of the specimen.
We tested, as an example, closed-cells reticulated polyethylene. Different shapes were tested with the three method described.
Compressive creep shows almost the same behaviour for different shape (spheroidal contact, areal contact, etc).

A great change in shape occurred after three month load test as shown in figure 9.

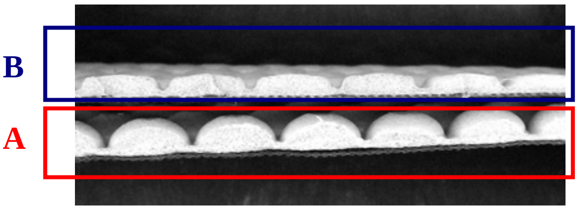

Figure 9. Comparison between original material (a) and end of compressive creep test material (b) for particular shaped polyethylene.

Other polymeric materials like chemical reticulated or physically reticulated ones, despite of particular shapes like punctual contact, line contact, alternate line or cross-line contact, show the same compressive creep behaviour, as shown in figure 10.

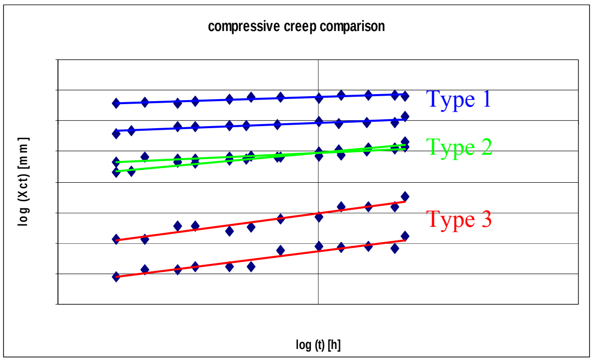

Figure 10. Comparison between different kinds of resilient materials under compressive creep tests: Type 1= rubber latex; Type 2= polyethylene ; Type 3=fibres

The compressive creep represents a more realistic load condition for material used under floating floor in common dwelling. The compressive creep of nano-structured layer is on-going and what we expect, on the basis of some shorter tests, is that the application of a selected static load will not lead to negatively results as observed in the compressibility test since they are related to the inorganic resilient matrix of the layer rather than to its aerogel-like nature.

FINAL REMARKS

Preliminary investigation was carried out on a nano-structured layer, characterised by highly efficient thermal insulation power, in spite of their reduced thickness compared to conventional systems.

The acoustic laboratory tests have demonstrated that the behaviour of nano structured layer shows good dynamic stiffness property, comparable with other very good resilient materials. Compressibility test showed inadequate properties which was associated with the preliminary preparations of these specimens. The application of a very high stress has caused irreversible rupture of layer, as it is often observed for materials for fibre and high porosity matrixes. To improve this specific parameter a new polymer matrix will be considered.

The comparison in terms of compressive creep for nano-structured layer will be reported in a future development of this work.

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