Measurement of the dynamic stiffness of porous materials taking into account their airflow resistivity

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Summary

The dynamic stiffness of a resilient material used under a floating floor is often used to predict the improvement of the impact sound pressure level, ΔL. It is also used to compare products. The measurement accuracy of this parameter is therefore essential. Unfortunately, the comparison between the predicted and the measured ΔL results shows quite high deviations which could be attributed, in part, to an incorrect estimation of the dynamic stiffness. It is now accepted by all European laboratories that the measurement procedure described in the standard ISO 9052-1 should be reviewed. This paper proposes a first step in the improvement of the measurement setup by taking into account the actual contribution of the dynamic stiffness of the air enclosed in the materials on the total dynamic stiffness. A new setup is proposed and some results are presented for products with different airflow resistivities.

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1. Introduction

The standard ISO 9052-1 [1] specifies a method to determine the dynamic stiffness, *s'*, per unit area of a resilient material used under floating floor. This parameter depends on the skeleton material stiffness, s'_s and on the stiffness of the air contained in pores, s'_a but the determination of their contributions on the global dynamic stiffness can be relatively complex. Indeed, the dynamic stiffness of air contained in the material, s'_a, plays a more or less important role depending on its compression in the material during the dynamic stress.

In the laboratory, the measurement of the dynamic stiffness of resilient materials according to the ISO 9052-1 is carried out on relatively small samples (200 mm x 200 mm). In this way, the air trapped in the open cell material can be more easily pumped in and pumped out during the local dynamic excitation than in larger samples and leads to an underestimation of the air stiffness contribution. Hence, to predict its behaviour when applied under floating floors, the measurement results have to be corrected to take into account the air contribution. An approximate correction procedure, depending on the airflow resistivity of the sample, is proposed in ISO 9052-1.

2. Measurement of the dynamic stiffness, *s'*, with large samples

To take into account the right air stiffness, a dimension of 1000 mm x 1000 mm for the sample is proposed for the measurement of the dynamic stiffness of the product.

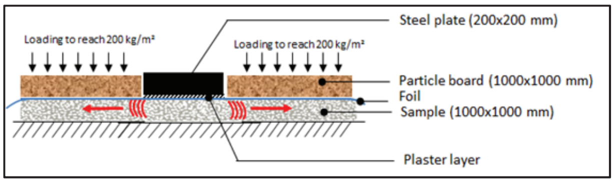


Figure 1. Diagram of the general principle

With a large sample, during the local dynamic excitation, the enclosed air under the steel plate feels the real resistance (figure 1) and the right degree of compression of air is taken into account in the measurement [2].

A static-load of 200 kg/m² has to be applied on the top of it in order to ensure the right airflow resistivity. For the experimental test, a particle board loaded with sand bags is used (figure 2). At its centre, a cut of 200 mm x 200 mm is done in order to introduce the steel plate needed for the measurement of s_t'.

Figure 2. New test bench for the dynamic stiffness measurement

In all cases, the dynamic stiffness, *s'*, is:

$$s' \cong s_t' \cong s_s' + s_a' \quad (1)$$

Where,

s_t' is the apparent dynamic stiffness of the sample (1000 x 1000 mm²) in MN/m³;

s_a' is the dynamic stiffness of air contained in the material in MN/m³;

s_s' is the dynamic stiffness of the skeleton in MN/m³.

The determination of the airflow resistivity is no longer needed overcoming its complex measurement. The second source of possible error concerning the experimental determination of the porosity of the material is also eliminated.

Several tests have been carried out to compare the measurement results of s_t' for different common products. Apart from the particular measurement setup (figure 3), the sample preparation and measurement method described in ISO 9052-1 is followed as closely as possible. The dynamic force is applied by a hammer hit and the acceleration is measured on top of the steel plate. A plastic foil is placed on the sample to avoid the expulsion of air through the gap around the steel plate between it and the particle board. A thin plaster layer is applied between the steel plate and the sample in order to ensure a good bonding between both. The samples are laid on a heavy concrete foundation.

- ✓ Test 1: This setup illustrates the new configuration (figure 3-1). A 1000x1000 mm² sample is used and covered by a loaded particle board (ca. 200 kg/m2);
- ✓ Test 2: For this setup (figure 3-2), the sample is cut off to a 600x600 mm² sample and covered by a loaded particle board (ca. 200 kg/m^2);
- ✓ Test 3: This setup is performed always with the same sample but with the adjustment to the standardised size i.e. 200x200 mm² without any lateral cover of petroleum jelly (figure 3-3). This setup corresponds to the standard setup for open-cell materials in ISO 9052-1. In this case, the enclosed air can easily be expelled. The contribution s_a' is the lowest for open cell materials.
- ✓ Test 4: The size of the sample is still 200x200 mm² but in this case, the lateral edges of the sample are covered with petroleum jelly *on the entire thickness* (figure 3-4). The enclosed air cannot escape and the contribution of s_a' is the highest. For open cell materials, the results of this setup should approach the results of Test 3 corrected with s_a' .

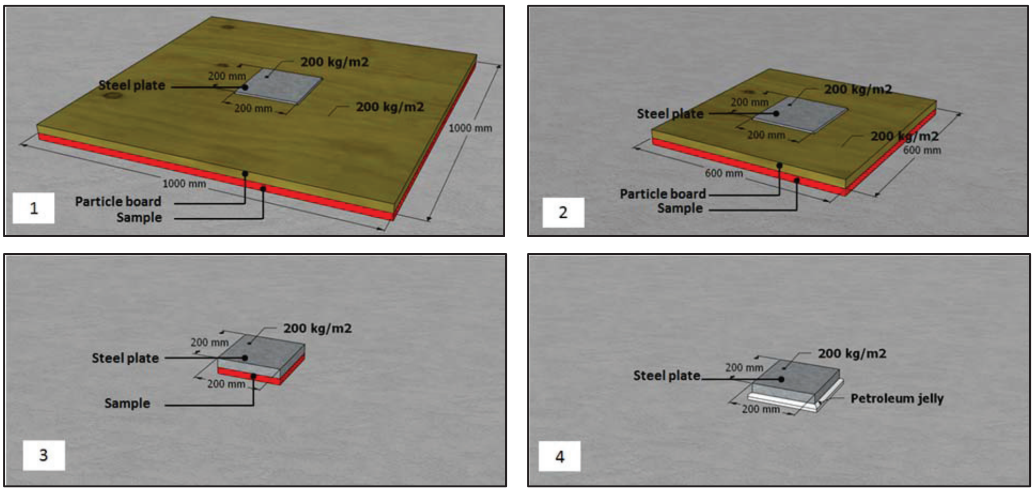


Figure 3. Sketch of four test configurations tested at BBRI laboratory

$$s'_{t,test\ 4} \cong s'_{t,test\ 3} + s'_a \qquad (2)$$

The airflow resistivity of each sample was measured by the CSTB acoustics laboratory.

3. Test results

Six different open cell resilient materials have been tested in the four test configurations described above. Three samples for each product's type were tested (except for products 1 and 6) and five measurements were carried out for each sample. The graphs below present the average value of these five measurements for each sample and the standard deviation.

1.1. Product 1

Material: Open cell polyurethane sprayed foam
Thickness: 25 mm
Density: 55-65 kg/m³
Airflow resistivity: ≥ 100 kPa.s/m²

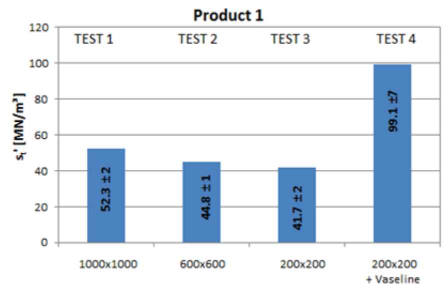
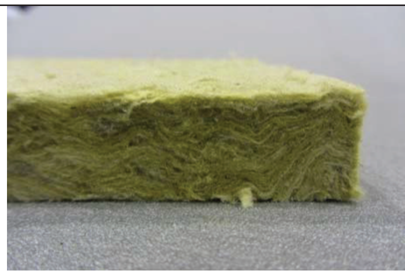


Figure 4. The average apparent dynamic stiffness for the open cell polyurethane sprayed foam for one sample and according to the four test procedures. The average and the standard variation are calculated on five measurements.

According the standard ISO 9052-1, the results from all the tests should be similar since the air is considered as trapped in all cases but Test 4 gives surprisingly an increase of 138%. This can be attributed to the fact that the airflow resistivity, in the transverse direction, is probably lower than the measurement result carried out in the vertical direction.

1.2. Product 2

As with product 1, the airflow resistivity is bigger than 100 kPa.s/m² and all results should be similar since the air is considered as trapped but Test 4 shows an increase of 92%. As product 1, the airflow resistivity, in the transverse direction could be lower than the measurement result carried out in the vertical direction.



Material : Mineral wool
Thickness:20 mm
Density: 90 kg/m³
Airflow resistivity:119.4 ±19 kPa.s/m²

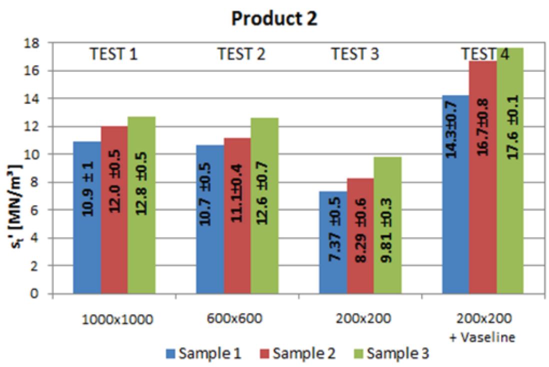


Figure 5 – The average apparent dynamic stiffness for the mineral wool for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.

1.3. Product 3

If we the ISO 9052-1 approximation to estimate the dynamic stiffness of the air, we obtain:

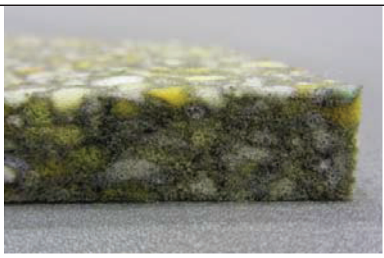
$$s'_a \approx 11\text{MN/m}^3$$

This leads to an overestimation of $s'_{t,test\ 4}$ since

$$s'_{t,test\ 4,\text{estimated}} \cong s'_{t,test\ 3} + s'_a \approx 5.75+11 \approx 17\ \text{MN/m}^3$$

And,

$$s'_{t,test\ 4,\text{measured}} \cong 9\ \text{MN/m}^3$$



Material : PU foam
Thickness:10 mm
Density: 100kg/m³
Airflow resistivity: 46.5 ±7 kPa.s/m²

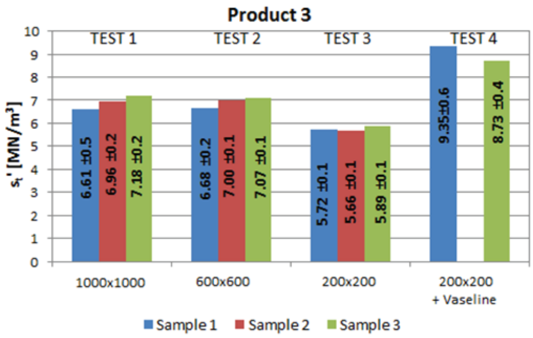
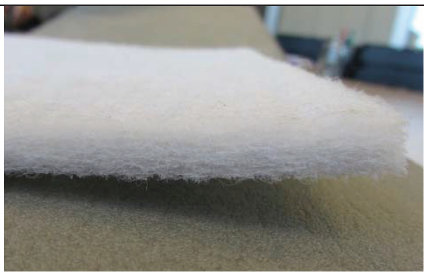


Figure 6. The average apparent dynamic stiffness for the PU foam for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.

1.4. Product 4



Material : Low density felt
Thickness:10 mm
Density: ± 40kg/m³
Airflow resistivity: 40.2 ±6 kPa.s/m²

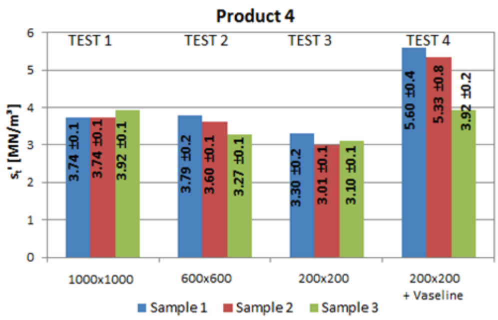


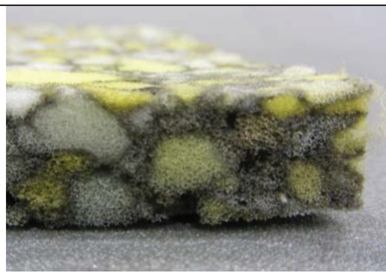
Figure 7. The average apparent dynamic stiffness for the low density felt for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.

After the loading, this sample has lost 3 mm of its thickness. *d* is then equal to 7 mm and we have:

$$s'_{t,test\ 3} + s'_a \approx 3.14+16 \approx 19 \text{ MN/m}^3$$

This result also shows a high overestimation of $s'_{t,test\ 4}$: 19 MN/m³ instead of 4.95 MN/m³.

1.5. Product 5



Material : PU foam
Thickness:10 mm
Density: 80 kg/m³
Airflow resistivity:38.6±6 kPa.s/m²

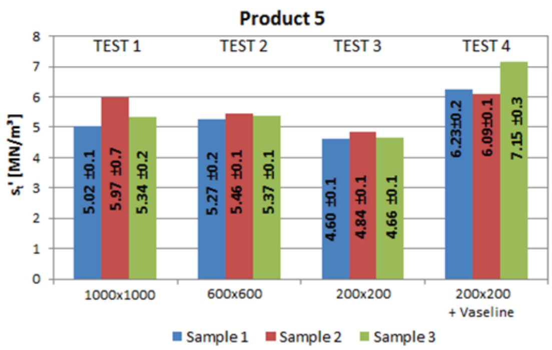


Figure 8. The average apparent dynamic stiffness for the PU foam for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.

For this case, we have:

$$s'_{t,test\ 3} + s'_a \approx 4.7+11 \approx 16 \text{ MN/m}^3$$

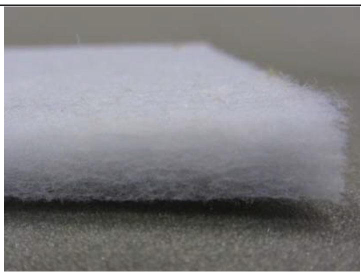
This result also shows a high overestimation of $s'_{t,test\ 4}$: 16 MN/m³ instead of 6.5 MN/m³.

1.6. Product 6

It is a very low density felt. It is always applied with another resilient layer. The airflow resistivity is very low (assumed lower than 10 kPa.s/m²) and the dynamic stiffness of the air doesn't play a role both for the small sample and for the larger samples. We are in the case where:

$$s' \cong s'_t \cong s'_s \qquad (3)$$

However a slight increase is still observed between Test 3 and Test 1 (+12%). As expected, the increase of s'_t is higher for Test 4 (an increase of 41%). This is due to the air trapped in the sample.



Material: Low density felt

Thickness: 9 mm

Density: ±20 kg/m³

Airflow resistivity: r < 10 kPa.s/m²

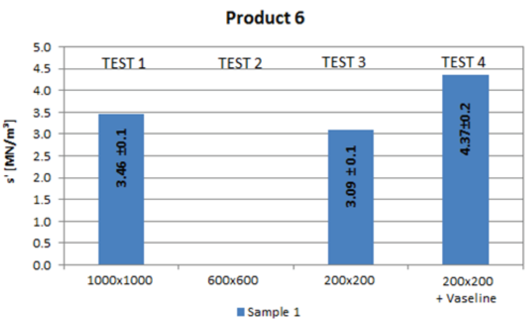


Figure 9. The average apparent dynamic stiffness for the Low density felt for one sample and according to three test procedures. The average and the standard variation are calculated on five measurements.

4. Summary and Conclusion

For materials with a medium airflow resistivity (between 10 kPa.s/m² and 100 kPa.s/m²) the standard ISO 9052-1 proposes to add the dynamic stiffness of air contained in the material to the apparent dynamic stiffness measured on a sample of 200 x200 mm² to take into account the trapped air which occurs in large sample. The results presented in this article showed that this proposition leads to large overestimations.

The tests carried out with the standardized size but with the lateral borders completely sealed with Petroleum jelly (200x200 mm² + Petroleum jelly, test 4) also show an overestimation of the real dynamic stiffness of the products but to a lesser extent. This is due to the fact that, in this case, the compression of the air in the sample during the local excitation is higher than in the reality where the air can be expelled.

The tests done with the new test bench (i.e. with samples of 1000x1000 mm²) give more consistent results. With this new setup, the effect of the air enclosed in the sample is properly taken into account and reflects the on-site conditions.

During the local dynamic excitation, the stressed air under the steel plate feels the real resistance and the right air compression is taken into account in the measurement. The determination of the airflow resistivity is no longer needed overcoming its complex measurement.

Different products have been tested and the results are summarized in table 1. This table gives the average absolute difference and the average relative difference of s'_t compared to the standardised results.

Table 1: The average absolute difference $\Delta s'_t$ and, in brackets, the average relative difference of s'_t in percentage compared to the standardised results of the standard ISO 9052-1 for each test procedure.

	$\Delta s'_t$ [MN/m³] 1000x1000 mm²	$\Delta s'_t$ [MN/m³] 600x600 mm²	$\Delta s'_t$ [MN/m³] 200x200 mm²	$\Delta s'_t$ [MN/m³] 200x200 mm² +Vaseline
Polyurethane sprayed foam, 25 mm, (55-65 kg/m³), r≥ 100 kPa.s/m²	10.6 (+25%)	3.13 (+7%)	0	57.4 (+138%)
Mineral wool, 20 mm (90 kg/m³), r=119.4 kPa.s/m²	3.40 (+41%)	2.99 (+36%)	0	7.71 (+92%)
PU foam, 10 mm (100 kg/m³), r=46.5 kPa.s/m²	1.17 (+20%)	1.16 (+20%)	0	3.24 (+56%)
Low density felt, 10 mm (40 kg/m³), r=40.2 kPa.s/m²	0.66 (+21%)	0.42 (+13%)	0	1.81 (+58%)
PU foam, 10 mm (80 kg/m³), r=38.6 kPa.s/m²	0.74 (+16%)	0.67 (+14%)	0	1.79 (+38%)
Low density felt, 9 mm (20 kg/m³), r < 10 kPa.s/m²	0.37 (+12%)	-	0	1.28 (+41%)

Figure 10 presents the relative differences of tests 1, 2 and 4 versus test 3 in function of the airflow resistivity.

The blue and red curves show the trend expected i.e. a low relative difference of s'_t for samples with a high airflow resistivity ($r \geq 100$ kPa.s/m²) and with a low airflow resistivity ($r < 10$ kPa.s/m²). The results for the mineral wool, with an airflow resistivity equals to 119.4 kPa.s/m², show however a high relative difference which leads us to believe that the limits between medium and high airflow resistivity products (100 kPa.s/m²) proposed in the standard ISO 9052 should be increased.

For the products with medium airflow resistivities, the blue and red curves give similar results which confirm that a sample of 1000x1000 mm² is enough to take into account the right airflow resistance in the products.

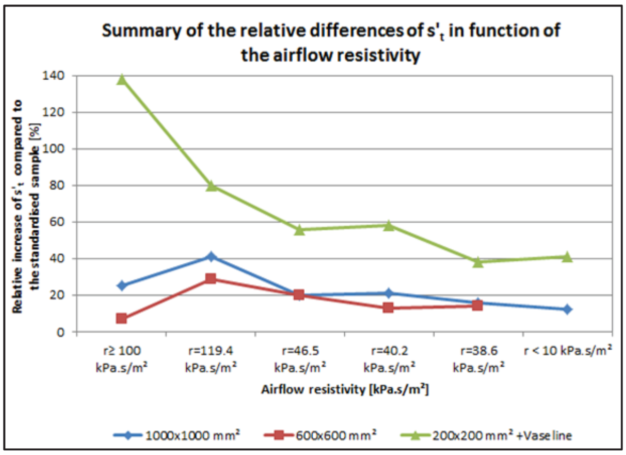


Figure 10. The average relative difference of s_t' in percentage compared to the standardised results of the standard ISO 9052-1 in function of the airflow resistivity.(In blue, the results for the 1000x1000 mm² samples, in red, the results for the 600x600 mm² samples and in green the results for the 200x200 mm² samples with Petroleum jelly).

Acknowledgement

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References

[1] ISO 9052-1, Acoustics - Determination of dynamic stiffness – Part 1: Materials used under floating floors in dwellings (1989);

[2] Crispin C., Mertens C., Medved Juraj- Measurement of the dynamic stiffness of porous materials taking into account their airflow resistivity, Journal of Building Acoustics, Vol. 21, n° 3 (2014), pp 221-233.