On the uncertainty of dynamic stiffness measurements

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Introduction

Facades sound insulation is influenced by used method of façade elements anchoring (light weight facades) but mainly by the composition of façades. To achieve accurate façade sound insulation prediction, appropriate is to know except of construction geometry data, façade layers physical properties and characteristics of their connections. Nowadays already unneglectable part is the thermal insulation layer. In external thermal insulation composite system (ETICS) case, the thermal insulation layer can interact as the attenuator of sound waves propagated in the construction. Airborne sound insulation can be affected by the elastic properties of used layers. It is matter of design if thermal insulation would improve significantly or on the other hand decrease sound insulation properties of construction. Compared to the original acoustic insulation spectrum of the bare wall, the insulation spectrum after application of ETICS shows a dip around the mass-spring-mass (m-s-m) resonance frequency of the two ETICS layers, due to the thin solid layer acting as a responding mass, and the thermal insulation layer as spring [2-14]. ETICS the spring mechanical properties can be characterized by dynamic stiffness s (MN.m^{-3}) (ratio of the dynamic force to the dynamic displacement). One of the approaches is using the same measurement technique as for floating floors case EN 29052-1 [1]. The research published in [15-17] proved already that, there are significant differences (up to 300%) in measurement results obtained in accordance to EN 29052-1 in different laboratories.

This paper presents partial results of extensive dynamic stiffness measurement campaign (39 different samples) with the goal to point on the deviation in results by comparison two measurement approaches. In next chapter the round robin test (RRT) between three laboratories is presented.

The measurement setup

The method of the standard EN 29052-1 determines the dynamic stiffness by measuring the resonance frequency f_r of the fundamental vertical vibration of mass-spring system where the mass is a steel plate. The excitation of the load plate technique was performed in presented campaign (Figure 1). The excitation by modal hammer hit with force sensor combined with accelerometer mounted on the steel plate on the one side and white noise signal excitation by shaker connected with impedance head on the other side was compared. Based on the mass and resonance frequency the apparent dynamic stiffness was determined s'_t (MN.m-^{3}).

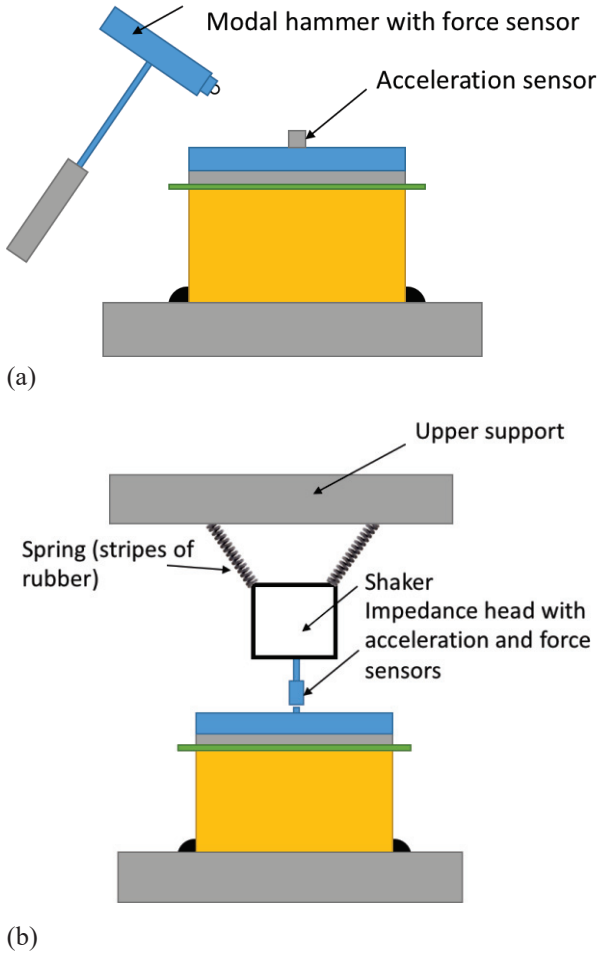

Figure 1: Illustration of the a) pulse excitation and b) white noise excitation measurement setup.

Samples

The apparent dynamic stiffness of 39 different samples was measured. The package of samples consisted of closed cells materials (white and grey expanded polystyrene (EPS) included also hollowed EPS–and rigid foam of thickness and density in range of 0.02 – 0.22 m and 13.6 – 16.8 kg/m^3) and open cell materials (mineral and glass wool of thickness, density and flow resistivity in range of 0.1 – 0.22 m, 53 – 112 kg/m^3 and 14.8 – 22.1 kNs/m^4). Four special samples consisted of 30mm layer of mineral wool coupled with grey polystyrene were present in the package as well (in results marked as “combi” Figures 2-4).

Figure 2: Closed cells sample (EPS- 160mm)

Figure 3: Open cells (Mineral wool- 160mm)

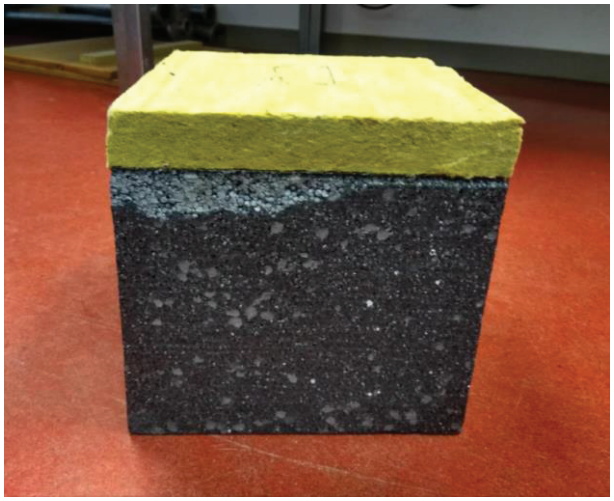

Figure 4: Combi (Mineral wool 30mm +EPS 165mm)

Partial results

Based on obtained measurement data, the analysis of results deviation based on used excitation signal was evaluated (Figure 2). The deviation of open cells material measurement results was up to 8.5 % and of combi samples 35%. Interestingly, the resulting data of open cells materials excited by impulse signal were lower in comparison to the white noise signal. On the other hand "combi" samples results showed higher dynamic stiffness in case of white noise excitation signal. Closed cell materials showed deviation below 1% what is acceptable difference. The sample marked by black dot was considered as measurement with error data and was removed from the analysis (open cell material- mineral wool of 100mm ρ=80.975 kg/m^3). The influence of ratio of density and sample thickness on the s'_t was evaluated (Figure 6 and 7).

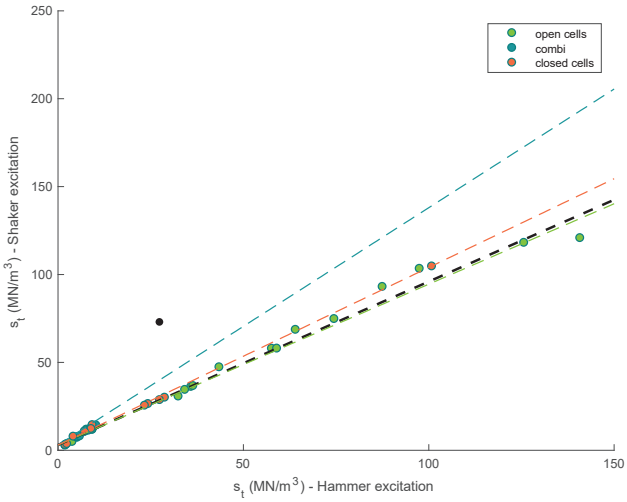

Figure 5: Relation between used sample excitation. Black dashed line- the mean linear fitting of all results (factor -7%); green dashed- open cells (factor -8.5%); blue dashed line- combi material (factor +35%); red dashed- closed cells (factor +1%). The black point shows the result out of the tendency of relation.

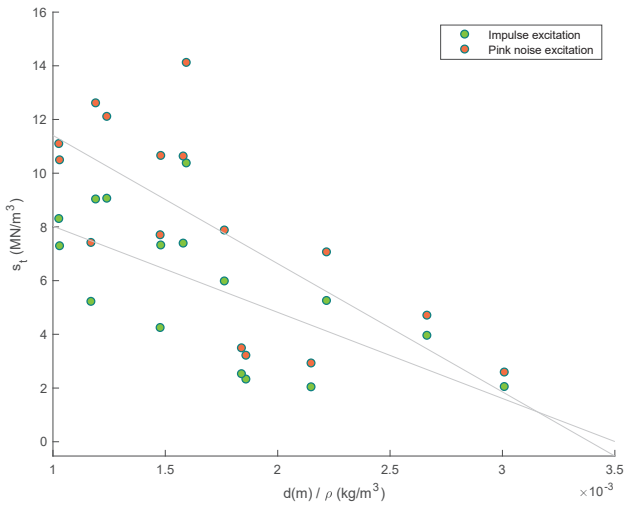

Figure 6: The relation between s'_t and d/ρ of open cell specimens (s'_t =-(3,2 to 4,8)e^3.(d/ρ)+(11 to 16)).

Results shows us, the dynamic stiffness of the closed cell, stiff material gives neglectable difference depend on the used excitation source. Based on that, closed cell material samples were chosen for inter-laboratory comparison test.

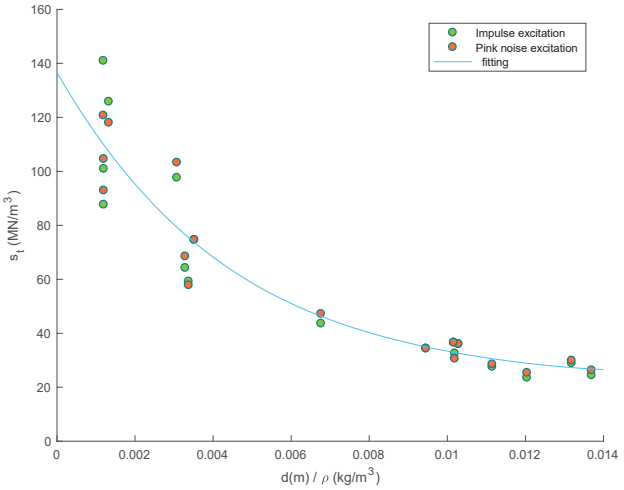

Figure 7: The relation between s'_t and d/ρ of closed cell specimens ($s'_t = 2{,}6e^9.(d/\rho)^4 - 1{,}2e^8.(d/\rho)^3 + 2{,}5e^6.(d/\rho)^2 - 2{,}5e^4.(d/\rho) + 1{,}4e^2$).

Inter-laboratory comparative test

The closed cell samples from EPS (ρ=20 kg.m^{-3}) with thicknesses of 20, 50 and 140 mm were chosen for measurements. "Vibration of the load plate only" measurement method as one of the most frequently used method was used. Three different excitation ways were used (excitation by pulse signal, white noise and sine signal). Laboratories invited in this test were:

- Laboratory of Acoustics (KU Leuven, Leuven, Belgium)
- Laboratory of Acoustics (A&Z Acoustics s.r.o., Bratislava, Slovakia)
- Laboratory of Acoustics (TGM, Wien, Austria)

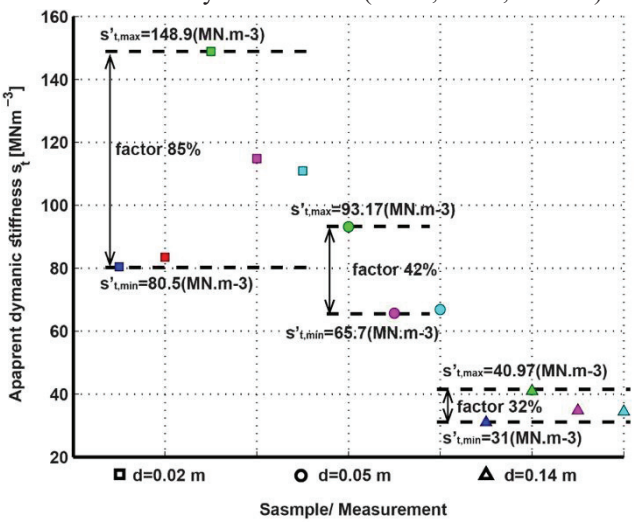

Figure 8: The comparison of mean resulting values of s'_t [17]. dark blue – Lab.1(pulse excitation); red- Lab.1(sine signal excitation); green- Lab.2 (white noise excitation); magenta- Lab.3(pulse excitation); cyan- Lab.3 (white noise excitation)

Some deviation in laboratory results was expected in advance. Measurement results can be strongly influenced by the boundary conditions of measured samples. The precision of plaster layer and sealant material application can influence the measurements.

Unneglectable difference between different laboratory measurement results was obtained. The resonance peak is dependent on the force applied on the specimen. Force amplitude applied in case of pulse excitation is higher in comparison to shaker excitation case. Shaker excitation resonance frequencies are moreover extrapolated to the theoretical Force F=0N. This procedure is not done in case of hammer excitation. Also nonlinearities in dynamic response of specimen occurs in case of hammer excitation. All of that could cause the differences between shaker and hammer excitation results. In respect to mentioned above, one would recommend to don't compare hammer and shaker based excitation. However the difference between labs also in case of comparison just the shaker based excitation is more than 85% (20mm thick EPS sample).

Conclusions

In this paper the summary overview of dynamic stiffness results achieved in accordance to standard EN 29052-1 was presented. There was 39 different samples (closed cells, open cells, combi) measured. Generally speaking, two excitation methods were compared (white noise excitation and pulse excitation). Measured apparent dynamic stiffness was in range up to 150 MN/m^3. The significant deviation in results achieved based on different way of sample excitation was measured. However, this difference occurs just in case of open cell materials presence (difference in results up to 8.5 - 35%). One of possible reasons could be presence of nonlinearities in dynamic response of soft specimens. Subsequently, the interlaboratory comparative test was performed. Measurements were focused on testing closed cell material samples (in respect to neglectable deviation of result based on different excitation approaches in previous tests). Generally three excitation approaches (pulse- hammer hit; white noise- shaker and sine signal- shaker excitation) were used. The significant differences in measurement results were obtained. Both the measurement results between the laboratories differed, as well as between measurement approaches used. It appeared that the differences between the laboratories are more significant as compared to the differences between measurement approaches (e.g. hammer versus shaker excitation). The differences in the measurement results between the laboratories can probably best be explained by the way the specimen was fixed (the plaster and sealant). The (less significant) differences between the measurement approaches can be explained by an uncontrolled force amplitude of hammer excitation and nonlinearities in the dynamic response of specimen in case of hammer excitation.

In further work the nonlinearity analysis and potential elimination of its influence should be investigated.

ACKNOWLEDGEMENTS

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