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TRANSMISSION LOSS VARIATION OF MASS CONSTANT SANDWICH PLATES USING GEOMETRIC HONEYCOMB CORE VARIATION

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Pollutant emissions like CO2 or NOX increased in the last decades. One reason is the increased average distance covered by each person which has grown in a similar proportion. This again leads to the use of vehicles with combustion process more frequently. In order to counteract this trend, the government restricts the pollutant emission of new vehicles. One approach for efficient vehicles is the reduction of the transported mass. Lightweight structures such as sandwich composites offer the possibility of mass reduction with similar stiffness. Unfortunately, this leads to an increased sound radiation at lower frequencies. Therefore, insulating elements are necessary to reduce the sound transmission in the vehicle cabin, but this increases the mass and counteract the benefit of the lightweight structures.

The example of sandwich plates will be used to show that the geometrical variation of a honeycomb core can increase the transmission loss. The core mass stays constant during this variation. The cell diameter of these cores varies between 5 cm and 13 cm, while commercially available cores have often diameters in millimeter range. The core variation is done with finite element analysis in the frequency range up to 2000 Hz. The transmission loss of selected sandwich plates is measured in order to confirm the simulation results. If the cell diameter size increases, the transmission loss increase can be shifted to lower frequencies. With a cell diameter of 13 cm the averaged increase of the transmission loss is by 3 dB and it starts by approximately 500 Hz. Thus, the design of a mass constant core improves the acoustic properties of a sandwich and it can address critical frequencies. Such acoustically adapted lightweight structures will reduce the number of insulating elements in vehicles. This design approach can contribute to lower the pollutant emissions of future vehicles.

Keywords: transmission loss, sandwich, honeycomb core

1. Introduction

In the last decades the covered distance of people increases year by year. As an example Ausubel et al. showed for the U.S. in the 20th that the covered distance per person increase 2.7% per year [1]. The major transportation vehicles are cars, busses and also aircrafts. All of them are using combustion process, which lead to an increased CO_2 and NO_X pollution. Politics counteract these pollution with higher restrictions and with research programs like the Flightpath 2050 vision of the European Commission for future aircrafts [2]. One key part in these research programs is the improvement of structures for a lightweight design. This means very often a reduction in mass while the stiffness remains similar. The result from an acoustical point of view is that these lightweight structures radiate the sound efficiently already at low frequencies. Hence, an insulation is required, which lowers the mass benefit of the lightweight structure. Other ideas for insulating can be found in the patent of Ayle and in the patent of Newton et al. [3, 4]. These two examples focus on sandwich structures with a honeycomb core. The hollow core and a perforated face sheet are used to create Helmholtz resonators. The design within the core allows different volumes, which results in a bandwidth absorption. A disadvantage is the perforated face sheet, because it reduces the bending stiffness of the sandwich. Another approach can be found in the patent of Thomas and Wandel [5]. The face sheets of this sandwich design are solid and the core geometry varies. Due to the variation the transmission loss can be adapted and coincidences can be avoided. The patent predicts a general plate behaviour in low frequencies and a double wall effect at high frequencies due to hollow honeycomb core. The transition between these two effects depends on the core geometry. The influence of a core variation was already studied by Kurtze and Watters as well as by Ford and Walker [6, 7]. These studies show that a core variation can shift the coincidence of sandwich structures. A core variation without changing the mass offers an adaption of the transmission loss and keep the lightweight idea. The studies of Griese et al. and Galgalikar et al. provide a parametric approach of honeycomb cores with constant mass [8, 9]. This approach was used and extended in previous study to show the influence of a geometric core variation on the transmission loss for numerical analyses [10]. This study is an experimental follow up of the numerical analyses. The first part describes the selected core geometries, which were evaluated experimentally. The second part describes the experiment to measure the transmission loss of sandwich plates. This part also includes a mass measurement of the core in order to evaluate manufacturing tolerances compared to the simulation models.

2. Variation of honeycomb core for sandwich plates

The generation of a mass constant honeycomb core follows the work of Griese et al. and Galagikar et al. [8, 9]. An extension of this approach can be found in previous study in order to achieve a more accurate mass consistency regarding the manufacturing [10]. The approach uses 9 dependent parameters of the core. These parameters are the length L_{pl}, the width B_{pl} and the height H_{pl} of the core, the number of cells in vertical direction n_v as well as the number in horizontal direction n_h, the cell angle α, the thickness of the core walls d, the target core mass m_{tar} and the density of the core material ρ_{core}.

Figure **1** shows the area of the honeycomb core with the length L_{pl} and width B_{pl} as well as a single honeycomb cell with the angle α and the wall thickness d. The dashed lines in

Figure **1** indicate the numbers of cells, which is 5 for the horizontal direction n_h and 2 for the vertical direction n_v. These numbers will be varied, which lead to the core notation 5x2. This will be used for the whole study.

Other parameters like the overall dimensions of the core, the target core mass, the core material and the cell angle remain constant. All constant parameters are listed in Table 1. The constant parameters in the table and the number of cells lead finally to a wall thickness d in order to achieve a mass constant core.

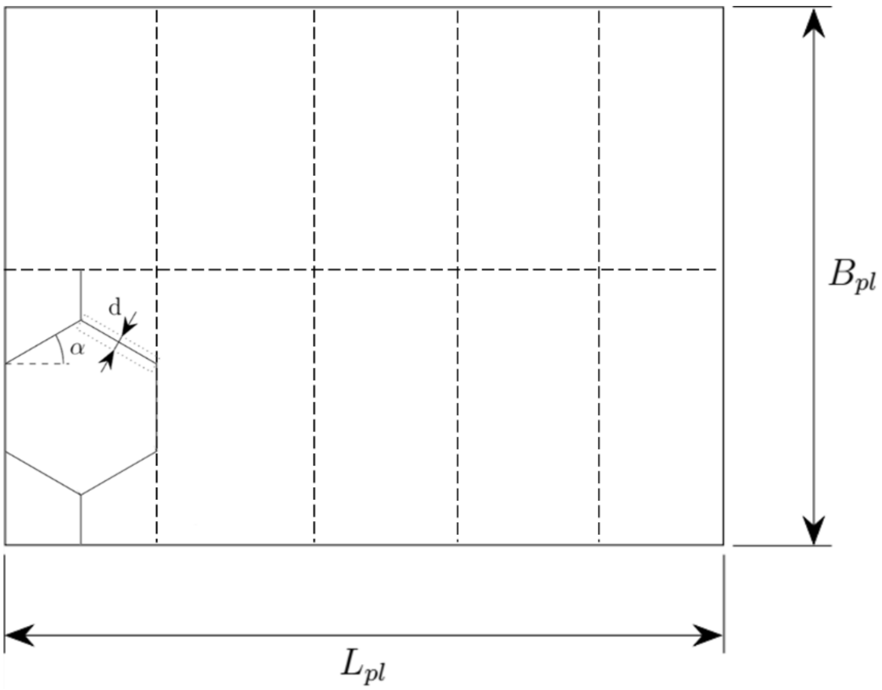

Figure 1: Area of honeycomb core with cell division and one honeycomb cell

Table 1: Constant core parameters for experimental investigation

Parameter	
L_{pl} in mm	800
B_{pl} in mm	600
H_{pl} in mm	20
m_{tar} in g	768
ρ_{core} in kg/m³	1230
α in °	30

The variation in this study focus on the scaling of honeycomb cells. The aspect ratio of each single cell is constant. Figure 2 shows four different core geometries with the notations 6x3, 8x4, 10x5 and 16x8. The cell diameter of these honeycomb cores varies approximately between 5 cm for the core 16x8 and 13 cm for the core 6x3. All honeycomb cores are not commercially available. Therefore, an additive layer manufacturing process was chosen to get single samples of these four cores. Due to the selected process the material also differs from commercially honeycomb cores, which are often out of aluminium or aramid fiber with impregnated epoxy resin [11, 12]. The material of the printed core samples is called SL-Tool® New White [13]. It is a mix of synthetic polyol, acrylate monomers and epoxy resin and can be processed within a stereolithography printing process.

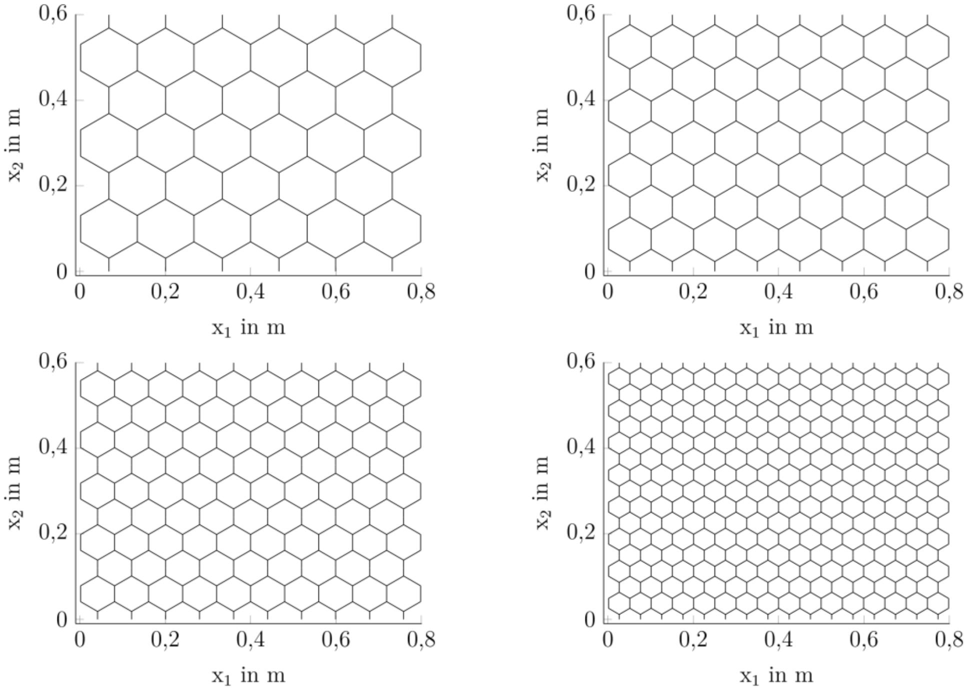

Figure 2: Selected core geometries with the notations 6x3 (upper left), 8x4 (upper right), 10x5 (lower left) and 16x8(lower right)

3. Transmission loss measurement of sandwich plates

The experimental measurement of the transmission loss is divided in three parts. At first, the mass of the manufactured honeycomb cores is determined in order to get manufacturing tolerances. The second part describes the sandwich assembly with glass fibre reinforced plastic plates as face sheets, the honeycomb core and a wooden frame. The last part describes the transmission loss measurement of these sandwich plates.

3.1 Mass measurement

The honeycomb core models have a given mass of 768 g, which is a result out of the overall dimensions of the core and a density of 80 kg/m³. This density is related to commercially available honeycomb cores in order to allow a mass constant comparison in future investigations [11]. The measurement of the core masses allows an estimation of the manufacturing error. Each core was measured 10 times and the mean values of the core masses are listed in Table **2**. Also, the relative mass errors between model and manufactured core are listed in this table.

The relative mass error is less than 9% for all cores and also the error is less than 2 % for three of four cores. One reason for the higher error of core 16x8 can be a manufacturing requirement. The wall thickness has to be greater than 1 mm for the manufacturing process. The CAD model of core 16x8 has a wall thickness of 1.5 mm, which is close to the minimum required thickness. The core 10x5 has already a wall thickness of 2.4 mm in the model. The proximity between the wall thickness of core 16x8 and the manufacturing requirement can cause a higher mass deviation. The assumption of the mass deviation is that the core mass will have no major influence to the transmission loss of the sandwich plates, because the overall mass of the sandwich plate is approximately 2.5kg. This mass includes the core and the two face sheets. A mass core variation of 9% is equal to a mass variation of 3% of the sandwich plate.

Table 2: Mass of core geometries and relative error between model and manufactured core

Core notation	m_c in g	err in %
6x3	755.63	1.6
8x4	779.98	1.6
10x5	765.10	0.4
16x8	830.72	8.2

3.2 Sandwich sample preparation

The sandwich plates are assembled after the measurement of the core masses. The face sheets are commercially available glass fiber reinforced plastic plates, which are standardized. The designation of the plates is EP GC 202 and the properties can be found in the technical data sheet [14]. The face sheets have the dimensions of 1090 mm x 740 mm x 1mm. The two largest dimensions of the plates are greater than the dimensions of the core due to the boundary condition in the experiment. The sandwich plate is clamped with two steel frames along the edges of the sandwich plates. Figure **3** shows a glass fiber face sheet in black with the honeycomb core in white and the wooden frame on top of the face sheet. The wooden frame indicates the position of the steel frames, which are clamping the sandwich plates from both sides. The 2-component epoxy adhesive LOCTITE® EA 9466 from the Henkel Corporation joins the glass fiber plates with the core and the wooden frame. The wooden frame is not glued to the core at the contact points. The second face sheet is glued on top of core and wooden frame, which is not shown in Figure **3**.

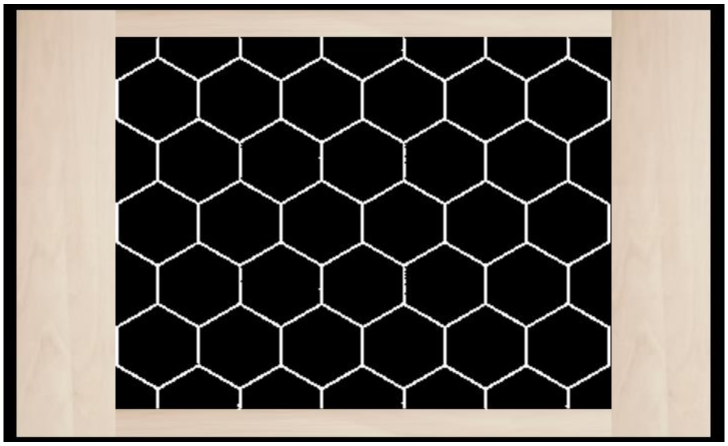

Figure 3: Sketch of sandwich sample without the top layer face sheet

3.3 Experimental setup for transmission loss

Figure 4 shows the setup for the transmission loss experiment. A transmission opening with an installed sandwich plate connects an anechoic room and a reverberation room. The plates are excited with a diffuse sound field, which is generated in the reverberation room with the source from Bruel and Kjaer type 4292 [15]. The excitation signal is a white noise, which is generated by the amplifier of the source. The white noise has a bandwidth between 100Hz – 3150 Hz. The diffuse field in the reverberation is measured with the Bruel and Kjaer diffuse-field microphone type 4942 on a rotating microphone boom [16]. In the anechoic room the Bruel and Kjaer intensity probes type 3599 measures directly the radiated sound intensity I_{rad} [17]. The spacer for the intensity probe has a length of 12 mm in order to address the frequency range of 100 Hz – 2000 Hz.

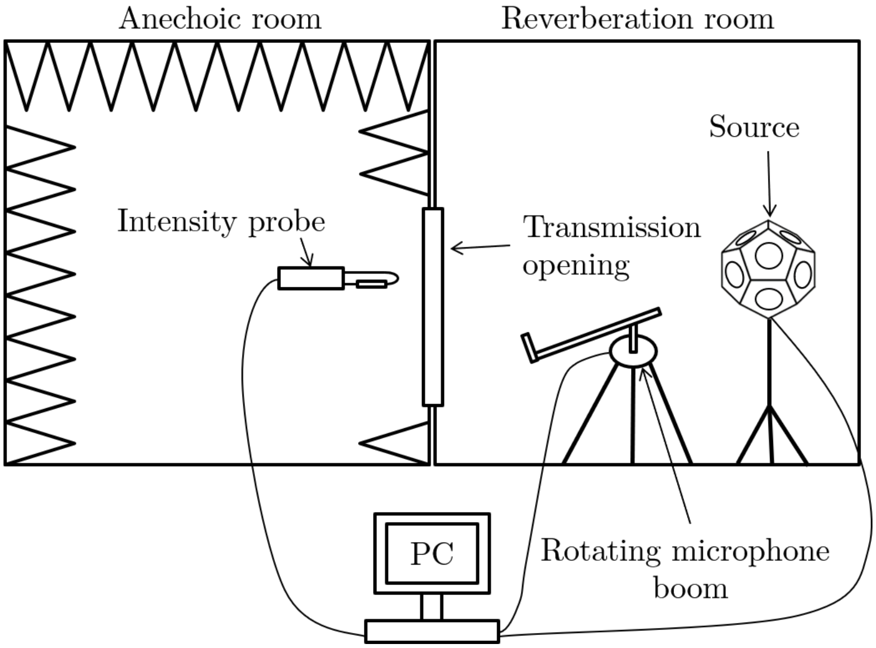

Figure 4: Setup of transmission loss with anechoic room and reverberation room.

Figure 5 shows a section cut of the transmission opening with the sandwich plate. The sandwich plate is clamped between two rectangular steel frames along the edges. The inner dimension of the steel frames is 800 mm x 600 mm, which is equal to the size of the cores. The second steel frame is connected to a plywood construction within the transmission opening in order to reduce the opening size. The two steel frames are connected with 30 M10 screws where each screw is tightened with 25 Nm. This realizes a fixed bearing of the sandwich plate along the sandwich edges in the transmission opening.

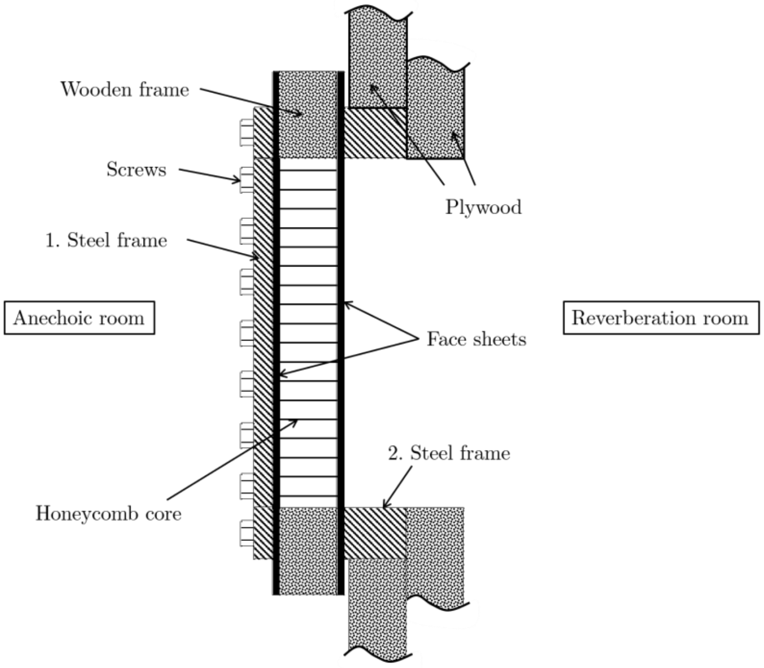

Figure 5: Section cut of transmission opening with sandwich plate

The RMS value of the measured pressure p̃ in the reverberation room can be used in eq. (1) in order to get the incident sound intensity I_{in} [18].

$$\boldsymbol{P_{in} = \frac{\tilde{p}*S}{4*\rho*c} = I_{in} * S} \tag{1}$$

This equation requires the speed of sound c, the density of air ρ and the surface S of the sandwich plate. The ratio of the incident intensity and the radiated intensity results in the transmission loss TL [19].

$$\boldsymbol{TL = 10 * log_{10}\left(\frac{I_{in}}{I_{rad}}\right)} \tag{2}$$

3.4 Experimental results

Figure 6 shows the moving average of the transmission loss of the four sandwich plates. The moving average improves the visibility of the curve progression and the identification of local minima and maxima. The moving average covers 30 values for a single frequency. The frequency steps are 0.625 Hz. The transmission loss value at 1 kHz is an average value with a bandwidth of 990.625 Hz – 1009.375 Hz.

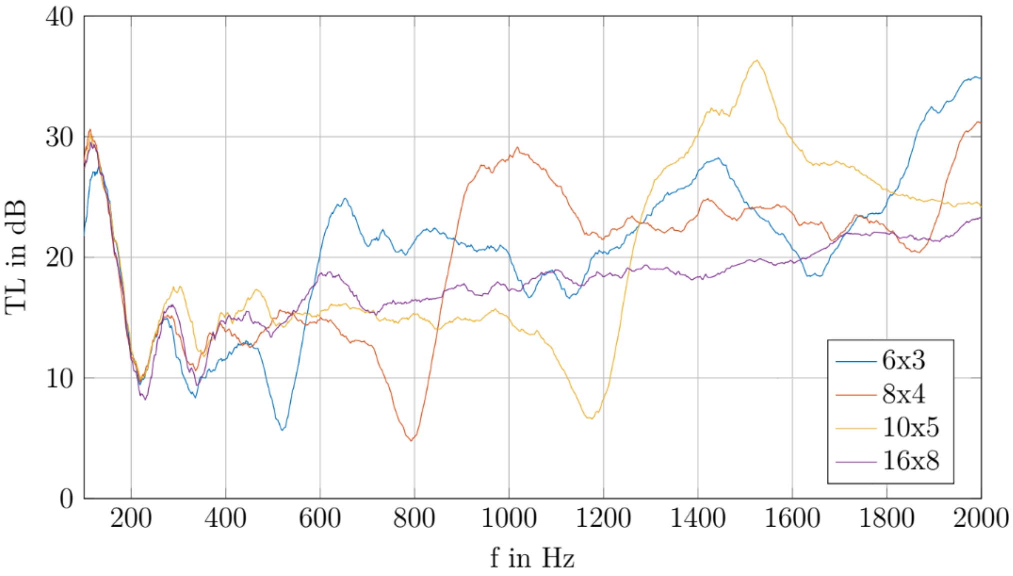

Figure 6: Transmission loss of the four sandwich plates with moving average

The sandwich plates show in the frequency range up to 400 Hz a similar behaviour. A significant difference of the transmission loss curves can be observed in the frequencies above 400 Hz. The sandwich plate with the core 6x3 has a local minimum at 521 Hz, the plate with the core 8x4 has a local minimum at 792 Hz and the plate with 10x5 has a local minimum at 1171 Hz. The plate with the core 16x8 has not such a minimum in the frequency range up to 2000 Hz. The transmission loss also increases in the frequency above the respective minimum. The mean value of the transmission loss increase is by approximately 3dB for the cores 6x3 compared to the core 16x8 in the frequency bandwidth between 700 Hz and 2000 Hz. A similar behaviour can be observed between 8x4 and 16x8 in the frequency range of 900 Hz – 2000 Hz as well as between 10x5 and 16x8 in the range of 1300 Hz – 2000 Hz. A greater cell sizes decreases the frequency where the transmission loss increases.

4. Conclusion

The geometry variation of a honeycomb core can be used to increase the transmission loss of a sandwich plate. The cell size defines the frequency where the transmission loss increases. This was shown in an experiment with sandwich plates where the cell size varies between 5cm and 13cm. The cores were designed with a constant mass. The manufactured cores had a mass deviation with less than 9% compared to the CAD model. This influences the mass of the sandwich plates less than 3%. One result of the transmission loss experiment is that a greater cell size decreases the frequency where the transmission loss of the sandwich plate increases. This increase in transmission loss can be used advantageous in sandwich structures, because the mass of the sandwich was not increased significantly. A disadvantage of the core variation was an additional local minimum in the transmission loss, which has to be avoided in the application. The core variation allows a new design method for lightweight structures without a mass increase.

REFERENCES

1. Ausubel, J.H., Marchetti, C., Meyer, P.S.: Toward green mobility: the evolution of transport. European Review **6**(2), 137–156 (1998). doi: 10.1017/S1062798700003185
2. European Commission: Flightpath 2050. Europe's vision for aviation; maintaining global leadership and serving society's needs; report of the High-Level Group on Aviation Research. Policy / European Commission. Publ. Off. of the Europ. Union, Luxembourg (2011)
3. Ayle, E.: Acoustic Strucutre with Increased Bandwidth Suppression. USA Patent US 8,651,233 B2, 18. February
4. Newton, J.F., Martin, T.D., Westre, W.N., Carbery, D.J., Ikegami, R.: Lightweight Honeycomb Panel Structure. USA Patent 5,445,861, 29. August
5. Thomas, C., Wandel, M.: Sandwich Structure with Frequency-Selective Double Wall Behavior. USA Patent 7,631,727B2, 15. Dezember
6. Kurtze, G., Watters, B.G.: New Wall Design for High Transmission Loss or High Damping. The Journal of the Acoustical Society of America **31**(6), 739–748 (1959). doi: 10.1121/1.1907780
7. Ford, R.D., Lord, P., Walker, A.W.: Sound transmission through sandwich constructions. Journal of Sound and Vibration **5**(1), 9–21 (1967). doi: 10.1016/0022-460X(67)90173-3
8. Griese, D., Summers, J.D., Thompson, L.: The Effect of Honeycomb Core Geometry on the Sound Transmission Performance of Sandwich Panels. J. Vib. Acoust (2014). doi: 10.1115/1.4029043
9. Galgalikar, R., Thompson, L.L.: Design Optimization of Honeycomb Core Sandwich Panels for Maximum Sound Transmission Loss. J. Vib. Acoust **138**(5), 51005 (2016). doi: 10.1115/1.4033459
10. Radestock, M., Haase, T., Monner, H.P.: Transmission loss adaption of sandwich panels with honeycomb core variation. In: Impact of noise control engineering. 47th International Congress and Exposition on Noise Control Engineering (INTERNOISE 2018) : Chicago, Illinois, USA, 26-29 August 2018. Curran Associates Inc, Red Hook, NY (2018)
11. EURO-COMPOSITES: Mechanische Eigenschaften für Waben aus Aluminium, Industriegüte. https://www.euro-composites.com/wp-content/uploads/2014/07/EC537-10e.pdf. Accessed 1 August 2017
12. EURO-COMPOSITES: Mechanische Eigenschaften für Waben aus Nomex, Industriegüte. https://www.euro-composites.com/wp-content/uploads/EC536-68e.pdf. Accessed 1 August 2017
13. Robotmech Stösl GmbH: Datasheet SL-TOOL(R) NewWhite. https://www.robotmech.com/fileadmin/media/downloads/Datasheets/Stereolithografie/robotmech-SL-TOOL-NewWhite_EN.pdf (2019). Accessed 14 January 2019
14. Erhard Hippe KG: Datasheet EP GC 202 HFD. https://www.hippe.de/wp-content/uploads/datasheets/qs_97_english/sheets/EPOXY/Product_Data_Sheet_EP_GC_202_HFD.pdf (2014). Accessed 2 April 2019
15. Bruel and Kjaer: Datasheet Omnisource(TM) Type 4292. https://www.bksv.com/-/media/literature/Product-Data/bp1733.ashx (2019). Accessed 23 April 2019
16. Bruel and Kjaer: Datasheet Diffuse-field Microphone Type 4942. https://www.bksv.com/-/media/literature/Product-Data/bp1878.ashx (2019). Accessed 23 April 2019
17. Bruel and Kjaer: Datasheet Sound Intensity Probe Kit Type 3599. https://www.bksv.com/-/media/literature/Product-Data/bp1880.ashx (2019). Accessed 23 April 2019
18. Möser, M.: Technische Akustik, 10th edn. VDI. Springer Vieweg, Wiesbaden (2015)
19. Raichel, D.R.: The Science and Applications of Acoustics. Springer Science+Business Media Inc, New York, NY (2006)