Sound Insulation of Structured Double Walls

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Introduction

Structured sheet metal has embossed bumps that increase its bending stiffness compared to flat sheet metal. Thus, it offers great potential in lightweight construction especially for vehicles, because of either having a higher bending stiffness with the same sheet metal thickness or having a similar bending stiffness with a lower thickness and mass. However, both have an adverse effect on the sound insulation that could be already demonstrated for single wall constructions made of structured sheet metal [1]. One option to increase the sound insulation of lightweight and stiff structures is to use double wall constructions.
In this contribution, the effect of using structured sheet metals for double walls is analyzed. To this end, practical measurements and numerical simulations using the Finite Element Method (FEM) of the sound insulation of various double wall configurations made of both flat and structured sheet metal are performed. The results are compared and validated for a wide frequency range.
As an outcome a good accordance of the transmission loss values of the measurement and calculation results both of the flat and structured sheet metal is obtained. Furthermore the single and double wall configurations made of structured sheet metal have decreased sound insulation in a high frequency range. It is shown that it is possible to predict the transmission loss behavior by means of numerical simulation and that the double wall constructions are one possibility to apply structured sheet metal when high sound insulation is required.

Structured double wall

The regarded structured sheet metal consists of hexagonal bumps in a regular arrangement with a small bridge of 2 mm between the bumps. It is manufactured by means of hydroforming from flat sheet metal [2, 3]. There are several parameters describing double wall configurations consisting of structured sheet metal which can be varied, the most important can be seen in Table 1. In addition to these constructions with two walls separated by a cavity, the structured double wall investigations include four different configurations of each two structured sheet metal, jointed at every bump using spot-welding and bonding and jointed at every second bump using bonding and two different adhesives.
While flat sheet metal can be considered as an isotropic plate, a single wall structured sheet metal has orthotropic characteristics. Thus its bending stiffness is not the same in all directions. Isotropic plates have one coincidence frequency, in this range the transmission loss is decreased. Due to the varying bending stiffness the orthotropic plates have an extended frequency range with reduced

Parameter	shell 1	cavity	shell 2
surface	flat, structured		flat, structured
bump diameter	33 mm		33 mm
dimension	587×587 mm		587×587 mm
thickness	0.5 mm	40 mm, 60 mm	0.5 mm, 0.7 mm, 1.0 mm
material	steel	air, foam	steel

Table 1: Double wall parameters used

sound insulation. For a single wall this effect was already investigated in measurements [4] and numerical simulations [1, 5]. Pursuing the sound insulation behavior of structured double walls is investigated.

Measurement

The transmission loss of several double wall configurations was measured in a window test chamber at TU Berlin based on DIN standard [6]. The sheet metals were fixed within a wooden frame and the spacing between the two shells was also realized using wooden plates with an opening as can be seen in Figure 1. The cavity was either filled with air or additionally damped with foam material.
The measurement results are all shown in third-octave

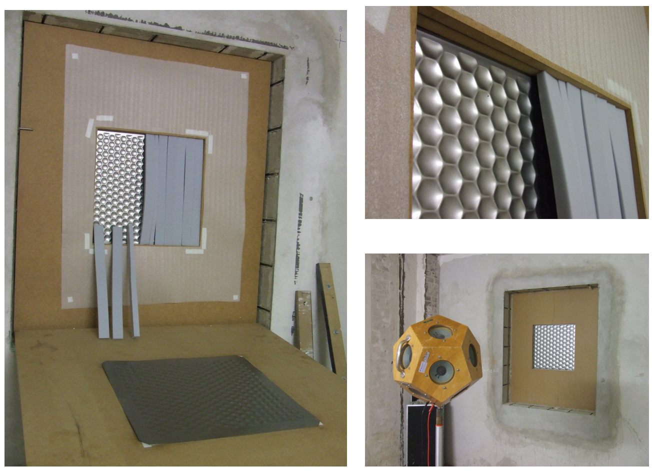

Figure 1: Fixing and assembling of a structured double wall in a window test chamber by means of a wooden frame, cavity half-filled with damping material

bands. Figure 2 shows the transmission loss results of the measurements of flat and structured double walls.

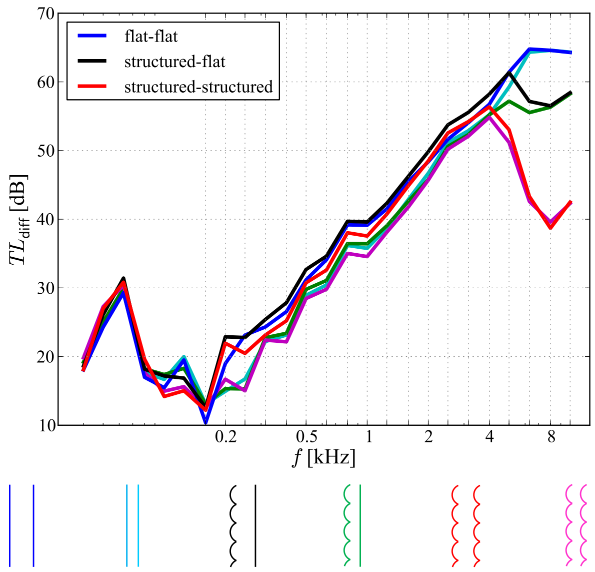

Figure 2: Measured transmission loss TL_{diff}, shell thickness each 0.5 mm, cavity width 40 mm and 60 mm (see pictogram), cavity undamped

Every single sheet metal has the thickness 0.5 mm, the distance between the two plates is set to 40 mm and 60 mm, respectively. The cavity is filled with air and contains no foam material.
The double wall resonance frequency induces the transmission loss decrease in the 160 Hz band for a cavity width of 60 mm or in the 200 Hz to 250 Hz bands for a cavity width of 40 mm for both flat and structured sheet metal. The double wall resonance frequency f_r is calculated by

$$f_r = 60\sqrt{\frac{M_1 + M_2}{M_1 M_2 d'}} \qquad \text{[Hz]}, \qquad (1)$$

where M_1 and M_2 is the mass per area of each plate and d' is the cavity width [7]. In this way one obtains a double wall resonance frequency of 174.9 Hz or 214.1 Hz for each 60 mm and 40 mm cavity width. With increasing frequency the transmission loss increases with slightly less than 12 dB per octave, as is expected regarding the theoretical characteristics. Above the frequency range of 4 kHz the double wall consisting of two structured plates shows a decrease in transmission loss. In contrast to the flat double wall transmission loss, which continues its increase, the structured double wall transmission loss is 25 dB lower for the 8 kHz band. At higher frequencies it increases again. The combination of each one flat and one structured sheet metal shows a transmission loss located in between the one of the two other configurations as this double wall includes only one structured sheet metal. There is less difference between the two cavity widths and only the width of 60 mm will be regarded consecutively. Regarding the influence of cavity damping, Figure 3 shows that foam or other damping material can reduce the adverse effect of the structured sheet metal on the sound insulation. The effect is much higher for the structured double wall than for the structured–flat combination and the flat one. Thus the cavity damped structured–flat combination nearly reaches the transmission loss values of the flat one. For better distinguishing and examining the structured sheet metal influence, hereafter results for undamped cavities are used.
Furthermore the jointed structured sheet metal are compared to double wall configurations and a single flat sheet metal with the same mass per area or shell thickness of 1.0 mm (see Figure 4). Generally the jointed plates

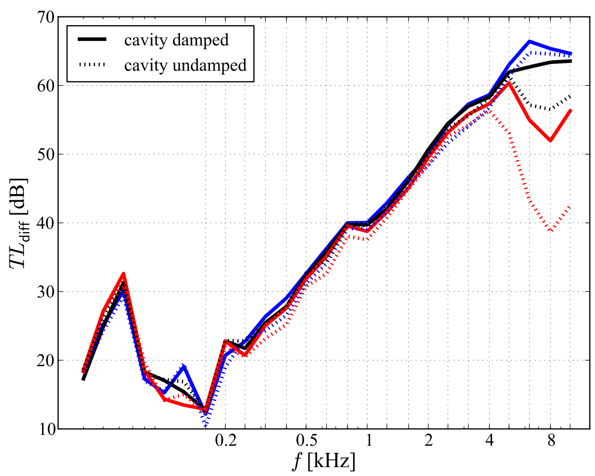

Figure 3: Cavity damping influence on measured transmission loss, shell thickness each 0.5 mm, cavity width 60 mm, flat–flat, structured–flat, structured–structured

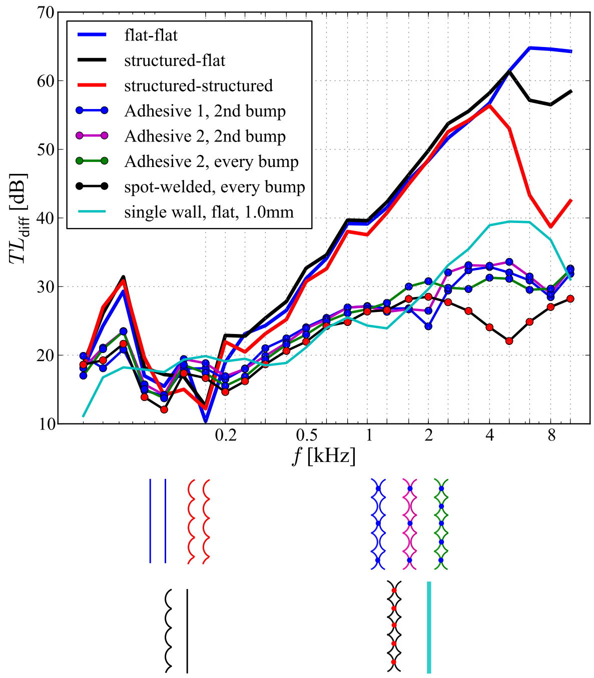

Figure 4: Comparison of measured transmission loss of double wall configurations with cavity width 60 mm (see left pictogram) and jointed configurations (see right pictogram), shell thickness each 0.5 mm, cavity undamped, and single wall flat sheet metal, shell thickness 1 mm

have a transmission loss much lower than that of the double wall constructions almost for the whole frequency range. Above 200 Hz the transmission loss increases with 6 dB per octave according to the mass law for a single wall. The curve progression is similar to that of a flat single sheet metal with the same mass per area. Below a frequency of 2 kHz the jointed plates have slightly higher values, beginning at a frequency of 2.5 kHz the transmission loss is lower than that of the single plate. There is neither a difference between the two adhesives used nor between the bonding of every second bump and the bonding of every bump. The spot-welded plates, which are the stiffest joint, have the lowest transmission loss around a frequency of 5 kHz. Hence the jointed plates can not be seen as double wall constructions regarding the transmission loss but as single walls with the same mass per area.

Numerical simulation

The numerical calculation of the transmission loss was performed using commercial FEM software. CAD models of the plates, as can be seen in Figure 5, were discretized using linear 2D triangular shell elements. The cavity was discretized using linear 3D hexagonal elements. As the calculated frequencies ranged up to 10 kHz the mesh size was chosen satisfying an element ratio of 6 elements per wavelength and up to 169,000 elements were used in the model. The transmission loss was derived from the ratio of the incident and the radiated sound power. Therefore on the incident surface of the double wall a diffuse sound field was generated by the sampling of 30 plane waves that originate from a hemisphere. The transmitted power radiated from the surface of the other plate was derived using a Rayleigh integral (Figure 5). The calculation was performed using the material properties of steel and air and setting low material and cavity damping. The calculation was performed fully coupled. A simply supported boundary condition was simulated.
In Figure 6 the calculated transmission loss results are

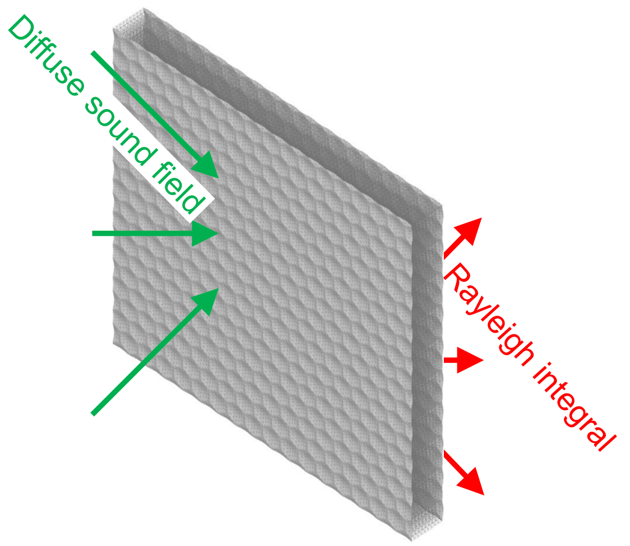

Figure 5: Meshed CAD model of a double wall made of structured sheet metal used for numerical simulation with incident and radiated sound power

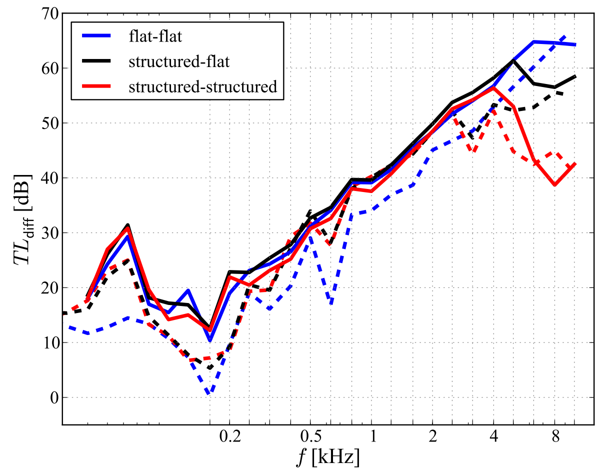

Figure 6: Comparison of measured (solid) and calculated (dashed) transmission loss, shell thickness each 0.5 mm, cavity width 60 mm, cavity undamped

added as dashed lines to those of the measurements with undamped cavity. The thickness of the single plates is 0.5 mm and the cavity width is 60 mm. The transmission loss results of the double walls including at least one structured sheet metal match well, also the results in frequency ranges where minima and maxima of the transmission loss occurs is reproduced well by the calculation. The calculated results for the flat–flat double wall are about 6 dB lower than the measured one.
Carrying on the simulation the transmission loss of two

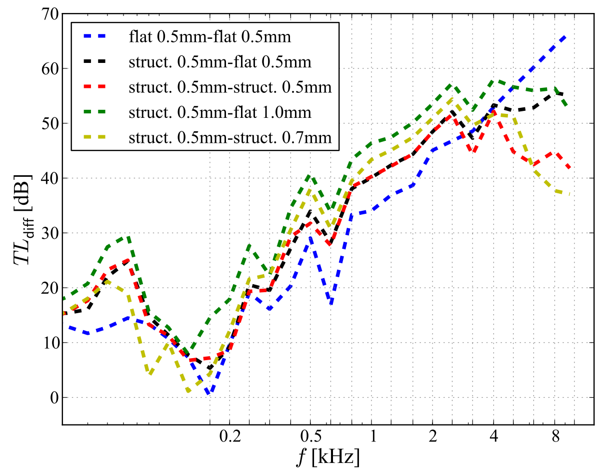

Figure 7: Calculated transmission loss, varying shell thickness, cavity width 60 mm, cavity undamped

varying double wall configurations was calculated as can be seen in Figure 7. The calculation results above are extended with a structured–flat and a structured–structured double wall combination. The radiating plate has a thickness of 1.0 mm or 0.7 mm respectively. As expected the transmission loss of the each varied wall is generally higher corresponding to the higher mass per area. The double wall resonance frequency of the combination represented by the green curve is shifted in a lower third-octave band. The characteristic reduction of the sound insulation of the double walls including at least one structured sheet metal in the frequency range above 4 kHz can be seen clearly. Hence the simulation is suitable for fast and variable calculations of the transmission loss of structured sheet metal.

Conclusion

In the present paper, the transmission loss of double walls made of flat and structured sheet metal was measured in a window test chamber and compared to numerical simulations.
It is known that single walls consisting of structured sheet metal have a reduced transmission loss in high frequencies above 4 kHz. This effect can also be seen for high frequencies when structured sheet metals are installed as double wall constructions. If the cavity between the two plates is damped using foam materials, this adverse effect is reduced. Constructions consisting of jointed structured sheet metal using spot-welding or bonding have a transmission loss similar to that of single sheet metal with the same mass per area. The curve progression of the double wall transmission loss is simulated successfully, the calculation results deviate maximum about 5 dB.

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