

Wheel liner design for improved sound and structural performances

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Abstract. Vehicle noise is composed mainly of wheel-road noise and noise from the power unit. At low speeds power unit noise dominates while at high speeds wheel-road noise dominates as wheel-road noise level increases approximately logarithmically with speed. The wheel liner is designed as a component of the vehicle that has a multiple role. It has to prevent the dirt or water from the road surface that are engaged by the wheel to access the engine/front bay. Same time it has the important role to reduce perceived noised in the passenger's compartment that comes from the wheel-road interaction. Progress in plastic injection moulding technology allowed for new structures to be developed – nonwoven materials in combination with a PP based carrier structure which benefits from a cell structure caused by MuCell injection moulding. The results are light parts with increased sound absorption performances. An adapted combination of materials and production processes can provide the solution for stiff yet soundproofing structures valued for modern vehicles. Sound absorption characteristics of materials used for wheel liners applications were reported in this study. Different polypropylene and polyester fibre-based thermally bonded nonwovens varying in weight and thickness were investigated. Having as a background the performances of the nonwoven material the microcellular structure was part of the analysis. Acoustical absorptive behaviour was explained by analysing the results obtained using the impedance tube and correlating with the knowledge of materials structure.

1. Introduction.

Noise refers to the irregular and chaotic sound. With rapid development of modern industry and transportation, noise pollution has become increasingly prominent [1]. When it comes to transportation sector, the vehicle noise is composed mainly of wheel-road noise and noise from the power unit. At low speeds power unit noise dominates while at high speeds wheel-road noise dominates as wheel-road noise level increases approximately logarithmically with speed. Designed as a multi role barrier [2] the wheel liner is an important component of the vehicle. Initially designed to prevent the dirt or water from the road surface that are engaged by the wheel to access the engine/front bay now days the focus is on the important role to reduce perceived noised in the passenger's compartment that comes from the wheel-road interaction.

Progress in plastic injection moulding technology [3] allowed for new structures to be developed – nonwoven materials in combination with a PP based carrier structure which benefits from a cell structure caused by MuCell injection moulding.

In 2001, Trexel successfully developed a microcellular injection moulding process (MuCell) as an innovative process aimed to assist injection moulding [4]. By that time there have been developed studies on process, material, and technical developments. The process is still undergoing studies in



order to materialize the full process potential [5–9]. Microcellular injection moulding [10] offers a number of advantages such as cost savings, weight reduction, ease in processing due to low viscosity, and dimensional accuracy [11]. Due to these advantages, the microcellular injection moulding process is used in many industries such as automotive, electrical goods, and home appliances. The process can be also applied to a wide range of thermoplastics [12].

Figure 1 presents a cross-sectional view of SEM micrograph of foamed specimens, allowing the skin layer and foam core layer to be identified.

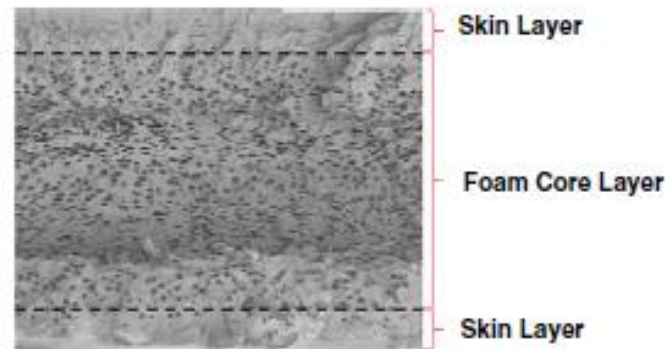


Figure 1. SEM micrograph of foamed specimens [13].

As it can be identified in Figure 1 the material has a multiple structure as a rigid skin layer and a porous core that may be addresses also as a sound absorbing material.

2. Experimental study

A number of specimens were investigated as components of existing solutions for vehicle wheel liners. Using specialized equipment the sound absorption performances were investigated.

Transmission loss is the number of sound decibels that are stopped by a structure at a given frequency or the accumulated decrease in acoustic intensity as an acoustic pressure wave propagates outwards from a source. As the acoustic wave propagates outwards from the source the intensity of the signal is reduced with increasing range due to spreading and attenuation.

A second parameter that is investigated is the Sound Absorption Coefficient that refers to the process by which a material, structure, or object takes in sound energy when sound waves are encountered. The measuring principles using the impedance tube are presented in Figure 2.

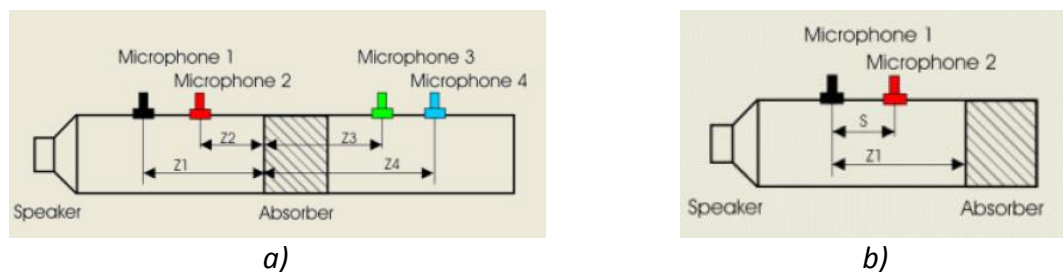


Figure 2. The measuring method.

a) method for Sound Absorption performance; b) method for Transmission Loss performance.

The layout of the measuring equipment comprising in the sound impedance tube, microphones and data acquisition system are presented in Figure 3.



Figure 3. Measuring equipment.

The samples collection is presented in Figure 4. It consists in four specimens of PP (polypropylene) based structures, four non-woven thermoformed parts and a specialized sound absorption material.

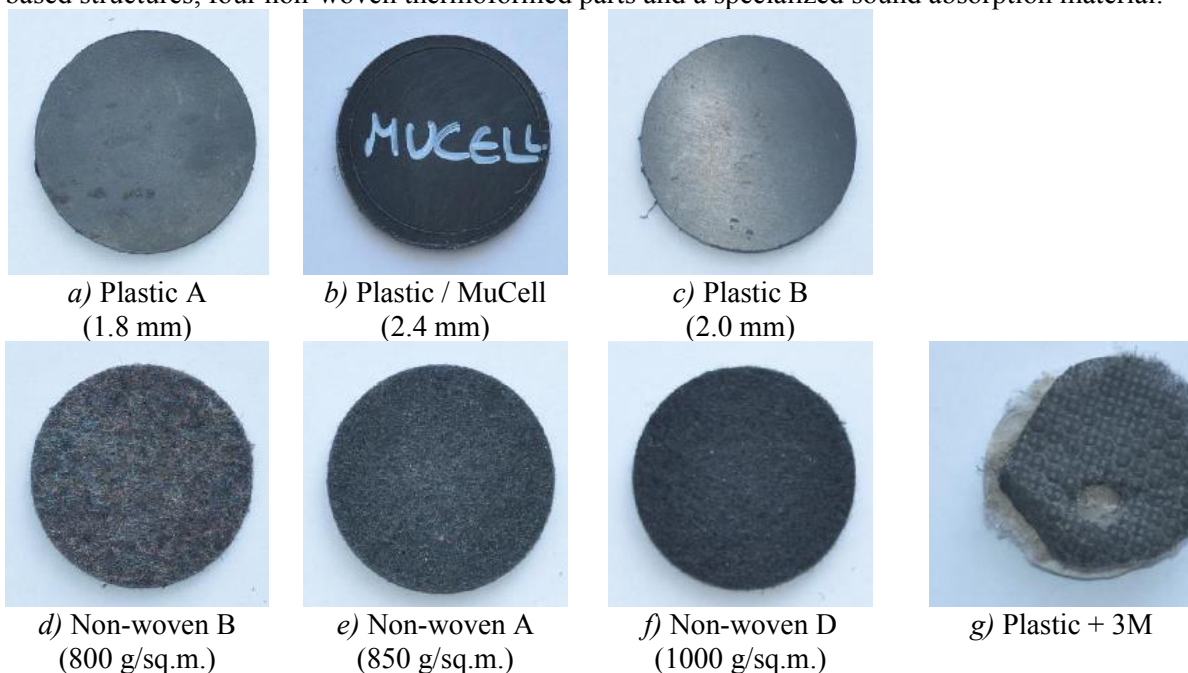


Figure 4. Samples (plastic, non-woven and insulating).

3. Results and sound performance analysis

For a first set of related parts (PP manufactured solutions) the Transmission loss parameter is presented in Figure 5. The low frequencies are difficult to be absorbed and a more breathable material should provide a better performance. The results follow a similar pattern showing the lowest performance in the range of 1000 - 1600 Hz (low frequencies).

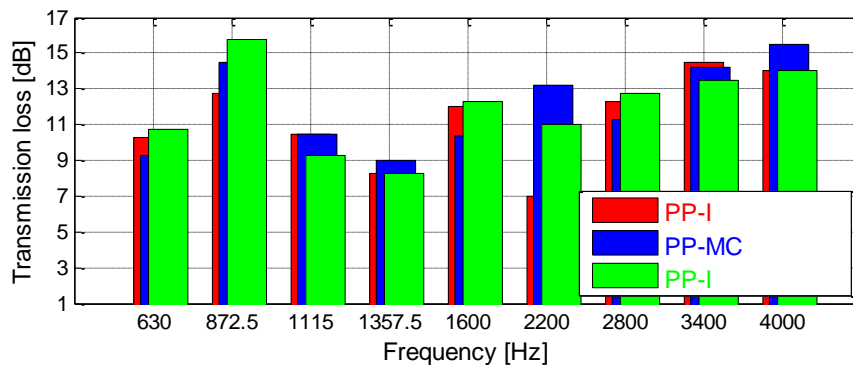


Figure 5. Transmission Loss performance for plastic specimens (a-c)).

However it can be noticed that there is a good performance of the solution with a foam core (MuCell) compared to solid structures. Figure 6 presents the results obtained for non-woven samples. The raw material was thermoformed to specific thickness reaching the mentioned specific weight.

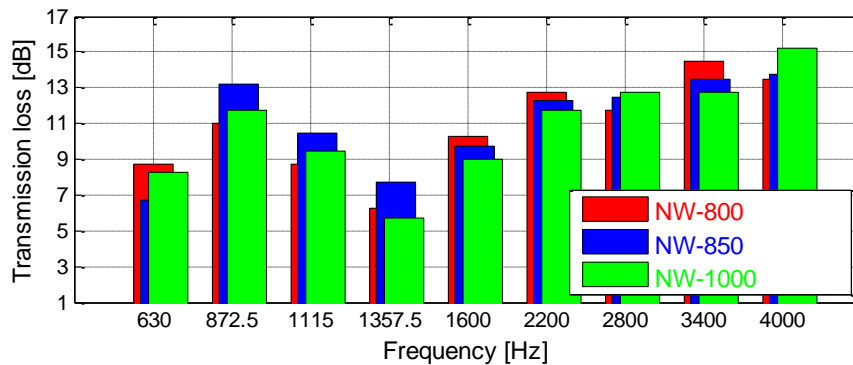


Figure 6. Transmission Loss performance for non-woven specimens (d-f)).

An analysis of the above presented results shows that the performance suffers in the range of 1000-1600 Hz and the result might be related to the thickness of the part. Further studies will involve the analysis of the structures. It is possible for the results to be related with the thickness [14] of the part a mandatory input when the total weight of the structure is in the focus. Figure 7 presents the relative performance of the structures uses as a solution for material selection criteria. Results show that the MuCell structure has a good performance on the investigated frequency range.

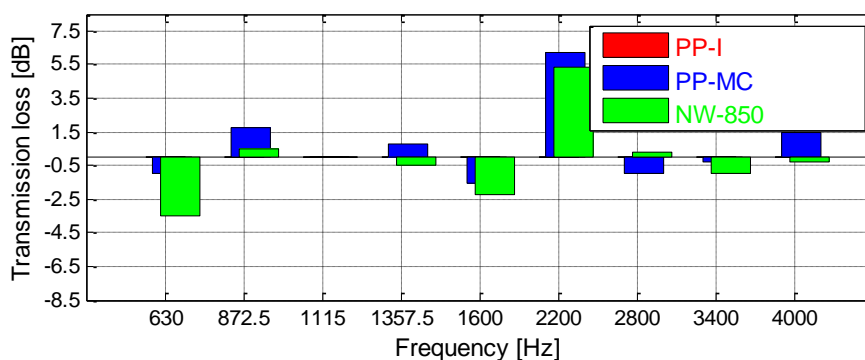


Figure 7. Transmission Loss relative performance for a specific product (wheel liner A). The results are referenced to the standard construction (PP) (a,b,e)).

A second solution was investigated involving parts manufacture using plastic, non-woven material and a combination of plastic and specialized insulator. Over all the solution of adding a specialized insulator provides the best results. This is according to method of soundproofing structures using a material to block and a material to absorb the sound [15].

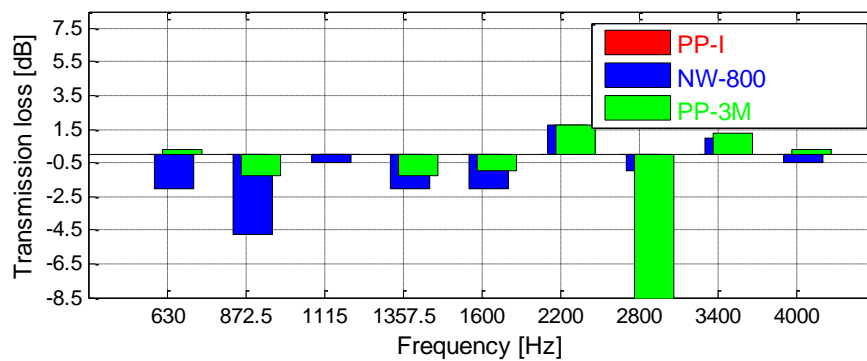


Figure 8. Transmission Loss relative performance for a specific product (wheel liner). The results are referenced to the standard construction (PP) (c),f),g)).

The relative performance analysis (Figure 10) shows that the use of specialized insulator provides a better performance in the range of low frequencies. This because that the sound is rather absorbed than reflected. The analysis is completed by the evaluation of the Sound Absorption Coefficient. At this point the performance of the foam core obtained by MuCell can be noticed.

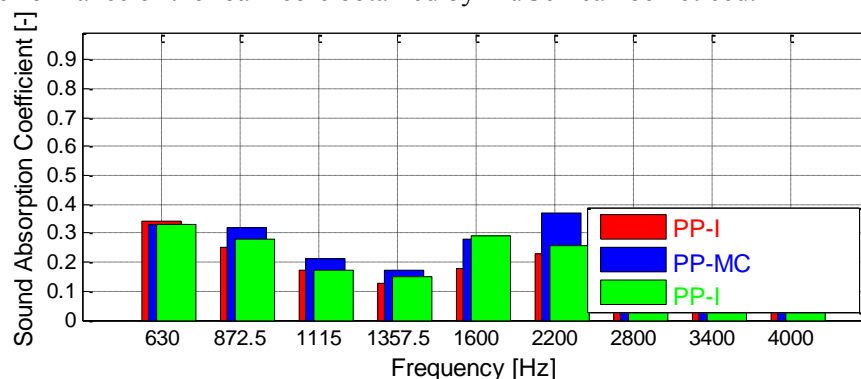


Figure 9. Sound Absorption performance for plastic specimens (a),b),c)).

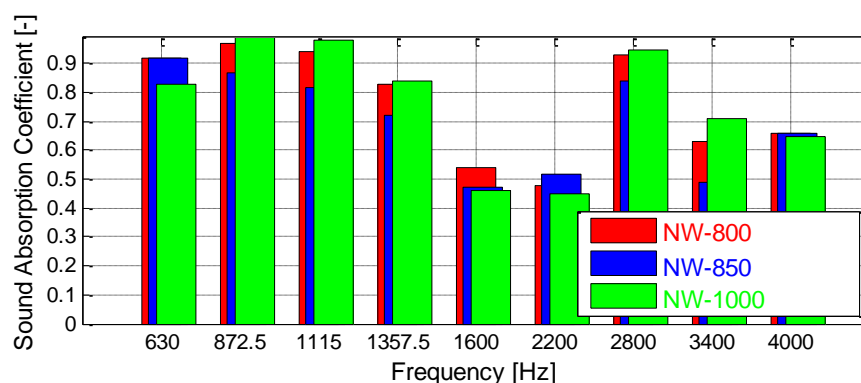


Figure 10. Sound Absorption performance for non-woven specimens (e),f),g)).

In order to look for a better solution Figure 11 provides the Sound Absorption Coefficient for solid plastic, MuCell structure and a non-woven.

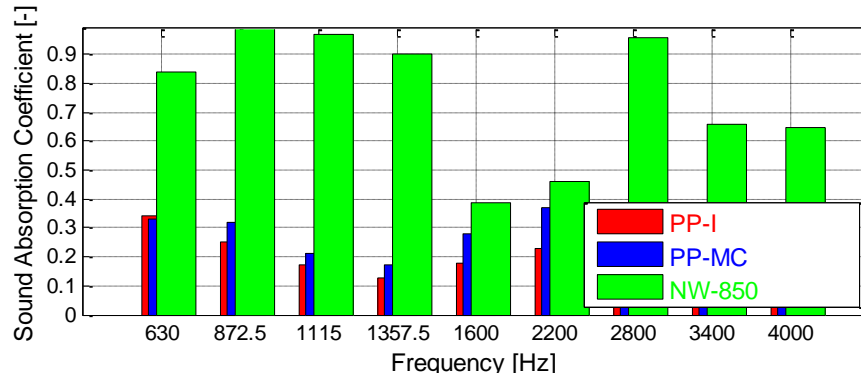


Figure 11. Sound Absorption performance for plastic and non-woven specimens applied to a given product solution (wheel liner A) ((a),b,e)).

Comparing the results Figure 7 and Figure 8 shows that a performance of $-2.5 \div -3$ dB is achievable by individual solution or by a combination [16].

4. Wheel liner study

Most efforts are paid in the direction of the vehicle body weight decrease and each individual component is investigated in order to achieve the maximum performance. Using non-woven that provides a good sound absorption is rather difficult to use because in order to obtain the required stiffness high forming thickness ratio are required. On the other hand the solid structures although individually show a good performance rather deflect the sound instead of capturing it.

A combination might be a good solution. A rigid frame provides the stiffness while the sound absorption material can be formed as a more breathable material.

In order to evaluate the performances of the structure a free-free eigenvalue analysis was performed. The recorded first two normal modes are reported in Figure 12.

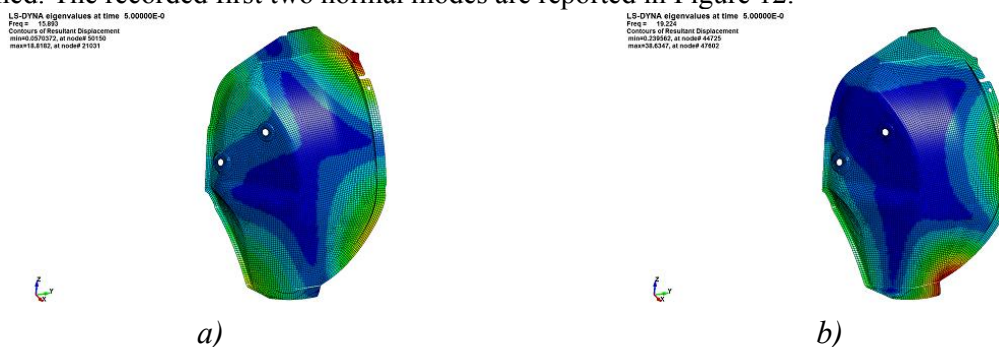


Figure 12. Normal model analysis. a) mode I, 15.9 Hz; b) mode II 19.2 Hz.

Following a design analysis of the structure the most reliable solution for a material replacement was defined. Figure 13 presents the model of the frame (solid frame) with the fixation points.



Figure 13. Updated frame model. *a)* finite elements model; *b)* contour (outline).

Considering the patches of the thermoformed non-woven material the results recorded from the numerical analysis are presented in Figure 14.

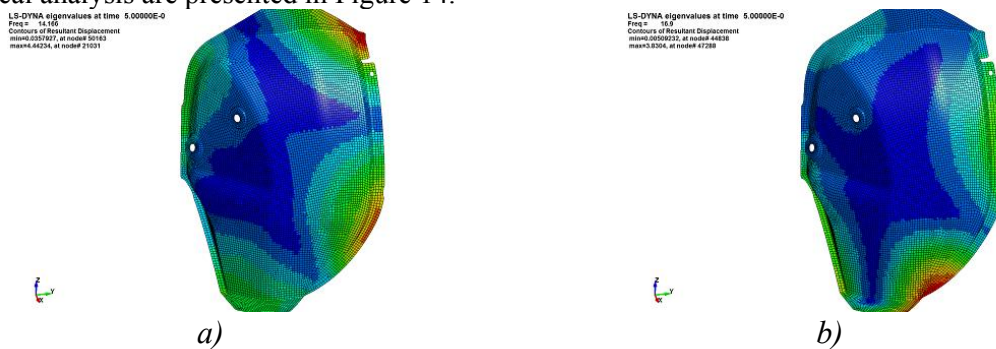


Figure 14. Normal model analysis. *a)* mode I, 14.2 Hz; *b)* mode II 16.9 Hz.

The recorded values are 14.2 Hz (-10%) and 16.9 Hz (-12%) with no overlapping with the body in white natural frequencies [17].

Figure 15 presents the finished part of the hybrid wheel liner with a solid frame and non-woven sound absorbing patches.



Figure 15. Hybrid wheel liner. *a)* inner side; *b)* visible side.

5. Conclusions

The presents study was focused on the possibility of defining a sound absorbing structure for the wheel liner. It debuted with the analysis of sound transmission loss performance for a number of material specimens. The study proved the performances of the MuCell processed part with a porous

core. However if the sound absorption coefficient has to be considered in order to evaluate the reflected sound the performance of non-woven materials has to be noticed. In this case a combination of the two materials may be a good solution as discussed and presented in our case study the resulted in the design of a hybrid wheel liner.

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