Proven sustainable light-weight solutions that efficiently attenuate vehicle noise

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Abstract

Automobiles should be as quiet as possible, so noise emissions need to be minimized and controlled. Polyolefin foams are ideal for efficient noise absorption and sound deadening systems in vehicles and play an important role to reduce the overall weight of cars.

The paper describes acoustic noise control concepts and exemplifies how polyolefin foam solutions can address vehicle noise challenges.

Kurzfassung

Autos sollen heutzutage möglichst lautlos sein. Damit dies gelingt, müssen Lärmemissionen minimiert und kontrolliert werden. Mit Polyolefin-Schaumstoffen lässt sich eine effiziente Geräuschabsorption und -dämmung in Fahrzeugen perfekt umsetzen und sie spielen gleichzeitig eine wichtige Rolle das Gesamtgewicht des Fahrzeugs zu reduzieren.

In diesem Artikel werden Konzepte vorgestellt, wie Geräusche vermindert werden können und es wird an Beispielen veranschaulicht, wie Polyolefin-Schaumstoffe dazu beitragen können, die akustischen Herausforderungen in Automobilen zu meistern.

1. Introduction

Although there are many noise sources in automotive vehicles, the three dominant sources have typically been the drive train, the tires/suspension and the wind. With the electrification of vehicle propulsion some acoustic design requirements are changing. Although electric vehicles are almost always considerably quieter, the interior noise is marked by high-frequent noise components which can be subjectively perceived as annoying and unpleasant. Moreover, disturbing noise is no longer masked by combustion engine noise [1].

Improved acoustic comfort within automotive vehicles whilst at the same time reducing weight is becoming an increasingly important demand - not only for combustion engine vehicles, but even more importantly for electric vehicles.

This paper summarizes acoustic noise control concepts in automotive vehicles that can be addressed with polyolefin foam solutions, which can contribute positively to light weight design concepts compared to solid materials.

2. Automotive noise control concepts

2.1 Sound absorption materials

Sound absorption materials reduce the acoustic energy of a sound wave as the wave passes through the material. The sound energy incident (I_i) is partially absorbed by the material (I_a) and the remaining sound energy is reflected (I_r) as illustrated in Figure 1.

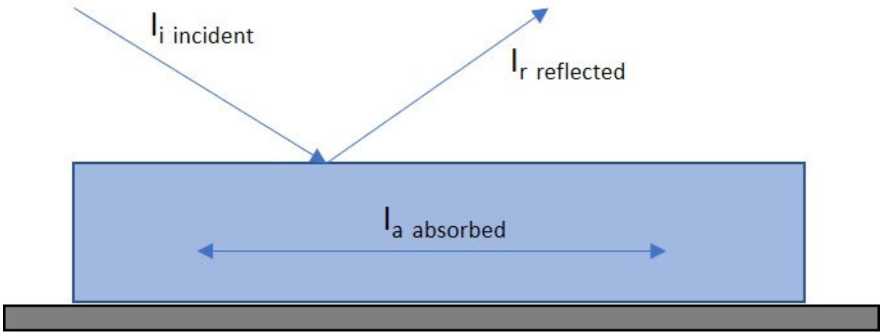

Figure 1: *Noise incident on an absorption material*

The sound absorption coefficient α is defined as:

$$\alpha = \frac{Acoustic\ energy\ absorbed\ by\ a\ surface\ (I_a = I_i - I_r)}{Acoustic\ energy\ incident\ on\ the\ surface\ (I_i)} \quad (1)$$

The absorption coefficient can have values between 0 and 1. Zero (0), means no sound absorption, and 1 means that 100% of the sound incident on a surface was absorbed by that surface.

In the case of porous absorbers, the material has to be porous, fibrous or open-cell, in order to have good sound absorption performance. Sound waves propagate into the material, and lose energy by viscous dissipation. This way, the amount of airborne energy that is reflected back into the enclosed space is reduced.

Closed-cell foams can be micro-perforated to achieve absorbing characteristics. The absorbing effect is attained when sound waves penetrate the perforated, partially open foam cells. These sound waves are then converted into kinetic energy (Helmholtz resonance effect) and, by friction, into heat energy (dissipation). Thanks to the combination of both effects a broad frequency spectrum is covered [2,3].

The sound absorption characteristics of a material are a function of frequency. As a rule of thumb, the material thickness should be a quarter of the wavelength of the sound wave to be effective. Therefore, material thickness is an important determinant of absorption performance [4]. Figure 2 shows the α-cabin measurements that were performed on a micro-perforated ALVEOCEL polypropylene foam and it illustrates how the absorption behavior can be tuned over the frequency range by choosing a different foam thickness.

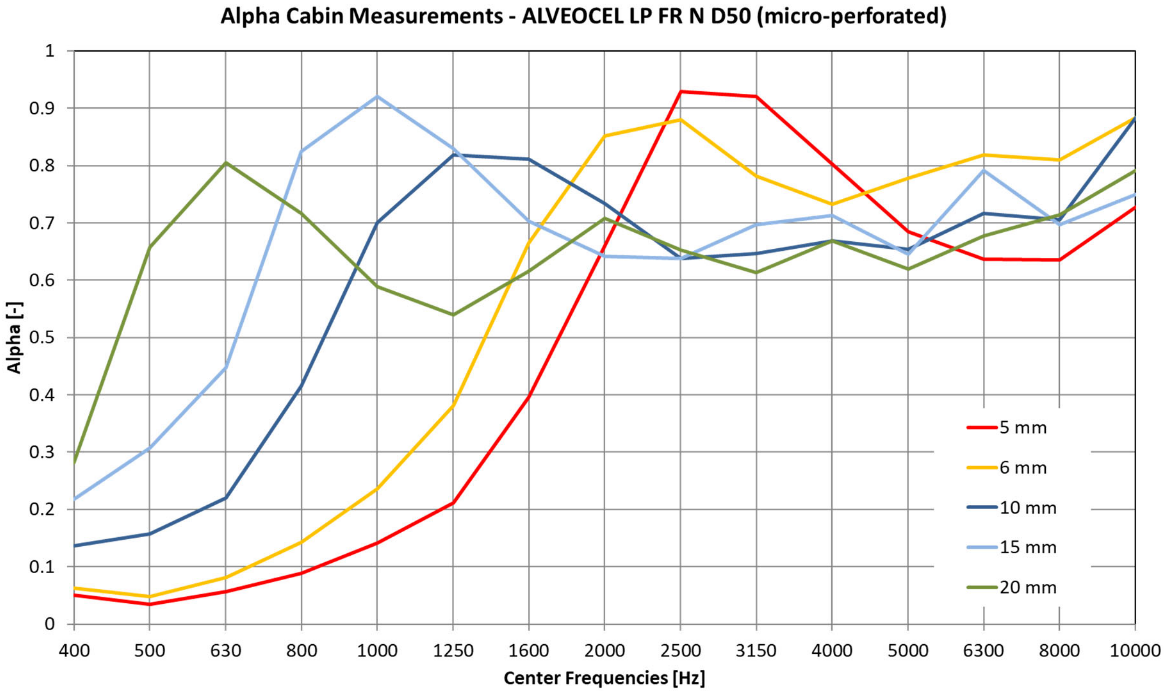

Figure 2: *Sound absorption as function of foam thickness*

Space under the bonnet is typically limited, so flat absorbers and box absorbers are in demand. While flat absorbers (see Figure 3) consist of multiple layers of micro-perforated polypropylene (PP) foam, PP foam sheets can also be thermo-formed with a box pattern (see Figure 4) where box shapes absorb a range of sound frequencies depending on their depth, volume and membrane thickness.

Figure 3: *Flat absorber (micro-perforated)*

Figure 4: Box absorber

Both technologies provide excellent acoustic efficiency, covering a broad frequency range. They meet all requirements for absorber materials in cars in a perfect way: broad frequency range of 1 to 10 kHz, long-term temperature resistance up to 140°C, resistance to hydrolysis, negligible moisture absorption and resistance to virtually all automotive fluids.

Absorption materials are most effective when placed over a large reflective surface. In this configuration the noise passes through the material twice, resulting in twice the absorption than if it only passed through once [4].

2.2 Sound barrier materials

A barrier is a material, which reduces sound energy as the sound wave is transmitted through the material as illustrated in Figure 5.

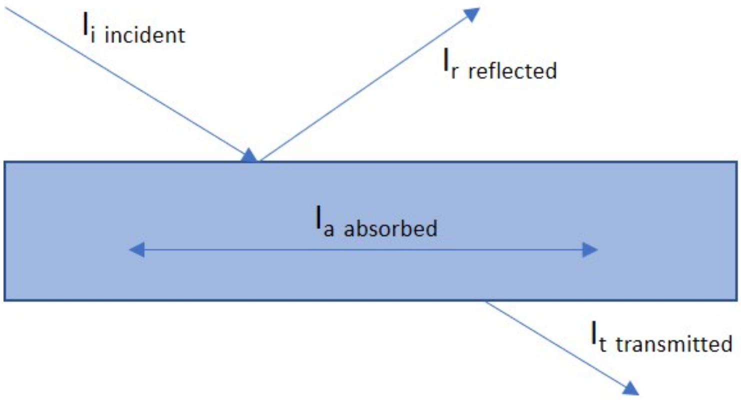

Figure 5: *Noise incident on a barrier material*

The measure of a material's effectiveness as a barrier is Transmission Loss (TL), which is measured in decibels as:

$$TL = 10\,log_{10}\frac{Incident\ sound\ intensity\ (I_i)}{Transmitted\ sound\ intensity\ (I_t)} \qquad (2)$$

Transmission loss is principally determined by the mass of the material. A doubling of the mass increases the transmission loss by 6 dB for most frequencies. The material should be impervious with respect to air, holes in the barrier reduce its performance [4].

Structural materials, such as the metals used to build automotive vehicles, can serve as sound barriers, but these stiff materials also support structural resonances within the audible frequency range of 20 Hz to 20 kHz and can add to the total noise problem. Limp mass barrier materials, such as flexible, weighted sheets, will not support resonances in the audible range and are generally added to the sheet metal shell of the vehicle passenger compartment as they block the sound waves and thus reduce the amount of sound, which is transmitted from sound sources such as the engine, transmission, suspension or tires [5].

Heavy-layer filled polyolefin foams with an area weight up to 1600 g/m² show acoustic insulation performance similar to that of heavy foils while offering potential weight reduction and better forming behaviour. Figure 6 shows a comparison of the transmission loss performance of ALVEOLEN filled foams with different thicknesses compared to a 1.6 kg/m² heavy foil. Additionally, the performance of a standard foam has been included and it can be seen that filled foams serve much better as a barrier material.

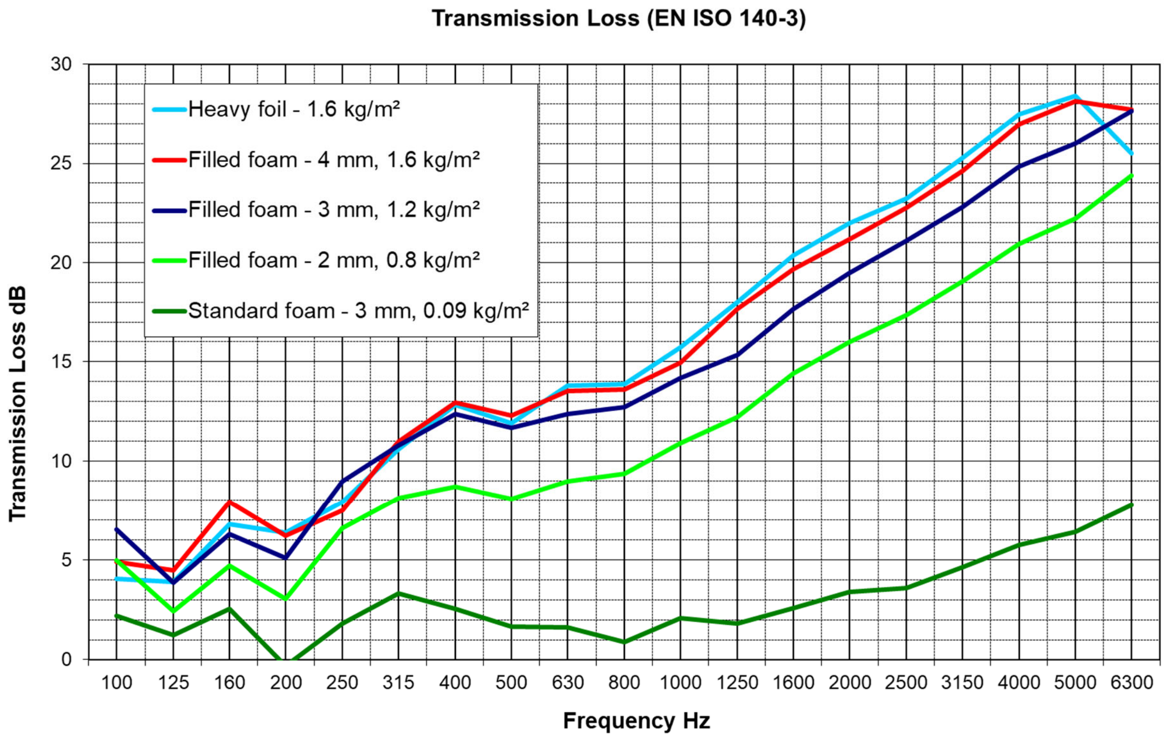

Figure 6: *Transmission loss comparison of ALVEOLEN filled foams with a heavy foil*

Filled polyolefin foams exhibit exceptional design freedom and can easily reproduce even complex geometries (e.g. undercuts) in thermo-forming processes. These foams can also be laminated with a very soft material to form a mass/spring system for an enhanced insulation effect.

Figure 7 and 8 show examples where heavy-layer foams are used in the car: as door inserts or as plugs to close off cavities in the car to reduce the amount of sound that can enter into the car.

Figure 7: *Door insert / water shield*

Figure 8: *Plugs*

2.3 Special case - Air ducts

The HVAC (Heating, ventilation and air conditioning) ductwork can direct noise from the engine compartment through the vents into the passenger compartment. Additionally, noise is also generated by the HVAC system itself - for example by the fan, the ducts or the louvers. Noises originating from the HVAC system become even more evident in electric vehicles as they are not masked by the constant rumble of an internal combustion engine.

This creates some challenges for engineers specializing in acoustics, who need to find new technologies and strategies for noise reduction in electric vehicles. ALVEOLEN foam material was developed specifically for use in a vacuum twin-sheet thermoforming process in which two layers of foam are simultaneously formed and welded into a lightweight and flexible air duct.

Tests have shown that foam air ducts reduce the mechanical noise of the system transmitted through the ducting up to 5-10 dB compared to solid ducts (see Figure 9). The data also shows that the sound pressure can be further reduced with an interlayer insert in the foam air duct as shown in Figure 10 (right picture). With foam air ducts there is also less rattle and squeak noise from the ducting touching other components.

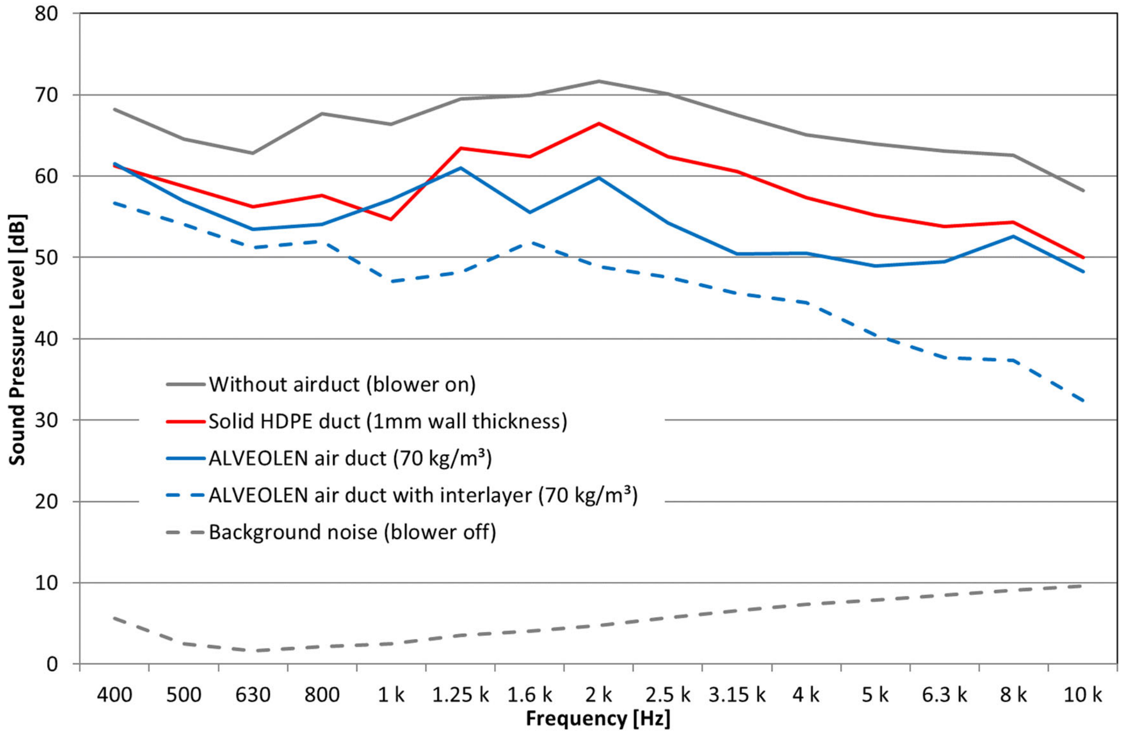

Figure 9: *Sound pressure reduction for ALVEOLEN air ducts versus solid HDPE duct*

Figure 10: *Solid HDPE duct (left), ALVEOLEN foam duct (middle) and ALVEOLEN foam duct with interlayer insert (right)*

Using foam as a duct material offers many additional benefits over solid plastic materials that are traditionally used for automobile air ducts. The excellent thermal insulation of foam improves the response time of the climate control system, saves heating/cooling energy, and minimizes problems with condensation. Foam materials reduce the car's weight and they are more flexible than rigid materials. The ducts can be squeezed and bent without being damaged during assembly. This allows foam ducts to be designed in longer pieces than solid ducts – which makes for fewer parts, easier mounting, and cost efficiency.

3. Environmental advantages

Foams from Sekisui Alveo not alone offer a range of environmental advantages based on their technical features, such as light weighting or energy saving.

Beyond that, Sekisui Alveo choose the "ISCC PLUS Mass balance approach" to support the accelerated transition to Bioeconomy and Circular economy along the entire supply chain. Products produced from bio-circular feedstock do not differ from the polymers produced from conventional feedstock and can be used for all applications. Also, to produce polyolefin foams - without needing requalification or recertification by customers.

4. Summary

Lightweight construction and acoustics are becoming increasingly important for optimizing efficiency and comfort in vehicles. Sekisui Alveo has developed various solutions with its foamed ALVEOCEL and ALVEOLEN materials to mitigate vehicle noise.

ALVEOCEL polypropylene foams serve as sound absorbing materials in flat absorbers or box absorbers and filled ALVEOLEN foams function well as barrier materials. Beyond that, ALVEOLEN foams are also used in twin-sheet formed air ducts to reduce sound pressure.

Compared to solid materials foams help to reduce the overall weight of cars and they improve energy-efficiency based on their excellent thermal insulation properties. The possibility to reproduce even complex geometries in thermo-forming processes or to use them as flat parts in the case of micro-perforated foams makes them an ideal choice for applications in the vehicles where space is limited.

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