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EXPERIMENTAL ANALYSIS OF INNOVATIVE ACOUSTIC MATERIALS FOR ENGINE NOISE CONTROL IN VEHICLES

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Due to the continuous evolution of vehicle noise regulations, the automotive industry is increasingly looking for more efficient engine bay design solutions to control noise coming from the engine. To this aim, proper acoustic treatments and covers made of multilayered trimmed panels need to be selected. Hence, present study reports the results of an experimental investigation aiming to characterize the acoustic properties of innovative absorbing materials to be used in a new identified engine encapsulation solution. Both sound absorption and sound insulation properties of several selected materials were measured by using an impedance tube. A sound intensity method, as specified by ISO 15186 standard, was finally utilized to assess the sound insulation performance of prototypes of the acoustically-treated component. In the paper, the acoustic performances of the tested materials are compared with reference to standard polyurethane foam based materials, in order to identify more efficient engine encapsulation solutions both in terms of acoustic performance and ease of industrialization.
Keywords: absorption, engine encapsulation, transmission loss.

1. Introduction

Among the various targets of the industrial companies of transport engineering, one of the most recent and significant is the research and implementation of effective solutions for noise reduction [8], [10], according to the growing awareness for environmental protection and increasingly rigorous government standards about the pollution and safety. The NVH (Noise, Vibration, Harshness) performance are also becoming a crucial factor in the purchase decisions of numerous buyers as the customers demands for a more comfortable vehicle.

The most important noise source, within vehicle, is engine noise. Engine noise represents a substantial quote of the overall noise perceived inside and outside the automobile, whose limitation is mainly assigned to the engine cover and more in general to the engine area trim elements. Engine cover, if well designed [1], gives a great contribution to the sound quality of a vehicle. In general the engine covers are composed of rigid plastic such as nylon for the external skin and polyurethane foam used as sound absorption element. Even if deeply used, this configuration may not guarantee the sound attenuation requirements in all the circumstances. The most important issues, in terms of attenuation of sound, of an engine cover are at low frequency range, exactly in correspondence of the engine's combustion frequencies. For this reason, the research of innovative materials and innovative cover configuration is a very actual item.

2. Experimental methods

In acoustic design, the main factors to refer to for quantifying the effectiveness of acoustical treatments for engineering applications are the sound absorption and the sound insulation properties of the materials. While the sound absorption is related to the property possessed by materials and objects of converting sound energy to heat either by propagation in a medium or when sound strikes the boundary between two media, the sound insulation is the ability of structures to prevent sound energy from travelling through them.

In this section, the basic principles of sound absorption and sound insulation are underlined, including the description of the measuring facilities utilized to assess the acoustic performance of the identified innovative acoustic treatments for engine bay.

When sound reaches a barrier some of the acoustic energy is reflected, some is dissipated within the material and some is transmitted through it [5], as illustrated in Fig. 1. In the figure, W_i, W_r, W_a, and W_t are the incident acoustic energy, the reflected energy, the absorbed energy and the transmitted energy respectively. The proportion which is reflected, absorbed or transmitted depends on the properties of the barrier, its size and the frequency of the sound.

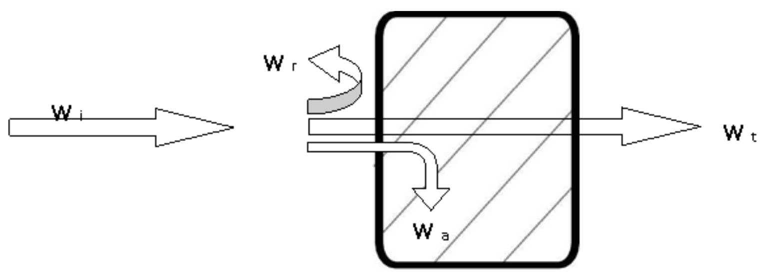


Figure 1: Reflection, absorption and transmission of sound at a barrier.

On this basis, the two fundamental acoustical parameters can be easily derived.

The absorption property can be expressed via the absorption coefficient defined as the fraction of sound energy absorbed by the material:

$$\alpha = \frac{W_a}{W_i} .$$

The insulation property can be expressed in terms of Sound Transmission Loss (STL) in decibels (dB), as a function of the transmission coefficient τ defined as the ratio of the sound energy transmitted through a treatment versus the amount of sound energy incident on the source side of the material:

$$STL = 10 \log_{10}\left(\frac{1}{\tau}\right), \text{ where } \tau = \frac{W_t}{W_i} .$$

2.1 Sound absorption measurements

One of the most used techniques for the measurement of the sound absorption coefficient is the impedance tube method. The impedance tube (or Kundt's tube) is typically made of straight sound proof and rigid tubing. As shown in Fig. 2, one end of the tube is connected to a sound source which outputs a broadband range of sound waves. The other end of the tube holds the sample to be tested. Therefore, the sound waves approaching the sample are both direct incidence and normal to the sample. The tube ends in a rigid termination. A pair of microphones are positioned just before the sample.

Figure 2: Impedance tube configuration for sound absorption measurement.

A BSWA model SW422/ SW477 impedance tube was used for the tests, which allows to perform absorption measurements according to ISO 10534-2 standard [6]. The tube has an internal diameter of 10 cm (corresponding to a lower frequency limit of 63 Hz and an upper frequency limit of 1600 Hz), a length of 56 cm and mounts two ¼'' microphones. Experiments were carried out by using samples of the test specimen, carefully cut to fit within the tube, taking into account that boundary conditions between the sample and the tube can greatly affect the resulting measurements. The absorption coefficient was obtained from the combination of the transfer functions measured in the two measuring microphones, placed inside the tube at a distance of 5 cm. Multiple averages were taken, in order to ensure that random noise on the measurement was averaged out.

2.2 Sound insulation measurements

The same experimental apparatus in a different configuration can be used for sound insulation measurements. In this case, according to Fig. 3, the element to be tested is mounted in the middle of the tube and two pairs of microphones are positioned just before and after the sample, so that measurement of both incident and reflected waves can be attained.

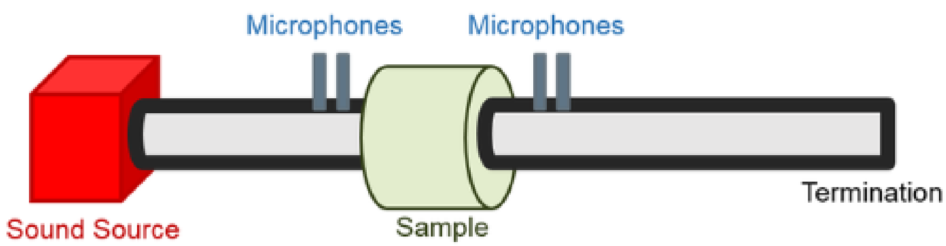


Figure 3: Impedance tube configuration for sound insulation measurement.

It is worthy to note that the obtained acoustical parameters refer to coupons of small dimensions (10 cm diameter), which cannot take into account more complex dynamics typical of larger elements (e.g. the modal effects of plastic components). Therefore, when analysing a component of different dimensions and shapes, other testing methods need to be adopted, as those specified in [7].

In this work, after testing the individual treatments the sound insulation performance of the most interesting solutions were assessed according to the ISO 15186 standard [7], by using a prototype of the real component. Figure 4 shows a schematization of the experimental layout. The testing procedure utilizes sound intensity to experimentally determine in laboratory conditions the Sound Transmission Loss of the cover component. In this case, a broadband sound source was placed in a reverberating box and the test article was placed on the box. The sound intensity incident on the material was calculated from the space averaged sound pressure measured by a microphone, under the assumption that the sound field was diffuse. The sound intensity transmitted through the material was then measured in the receiver room, using a sound intensity probe. The intensity probe was positioned perpendicular to the test sample and moved point by point over the material surface to obtain the averaged transmitted sound intensity.

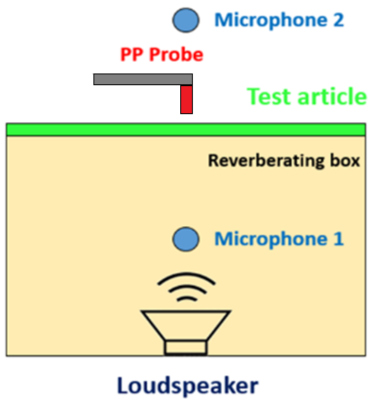


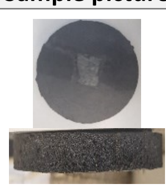
Figure 4: Experimental layout for STL measurement of engine cover based on sound intensity method.

In the next sections, after detailing the different sound absorbing materials taken into account, results of the experimental investigations will be presented, outlining the key steps which led to the identification of innovative and optimized solutions for improving the engine bay design in terms of acoustic performance.

3. Materials

Table 1 reports a list of the tested absorbing materials, where information about composition can be found.

Table 1: Tested absorbing materials.

Type of material	Sample picture	Type of material	Sample picture	Type of material	Sample picture
Polyurethan foam 60 Kg/m3 Th 10mm		Polyester fiber Th 10mm (Thinsulate)		Viscoelastic polyurethan foam 90 Kg/m3 Th 10mm	
Polyurethan foam 60 Kg/m3 + carbon fiber fabric Th 10mm		Polyester fiber Th 10mm (Thymet Poland)		Basalt Wool Th 10mm	

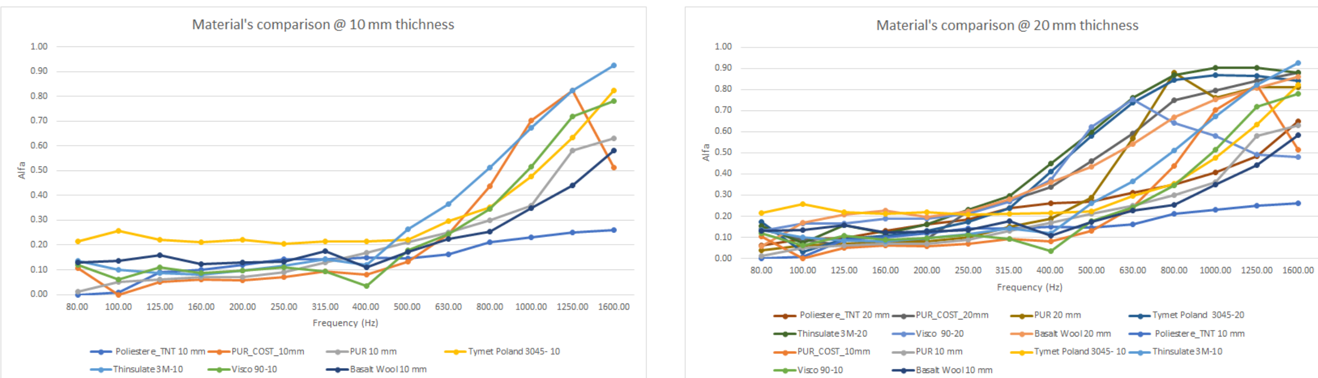
Among them it is possible to identify, the standard PU foam for the component, an upgraded material realized through the combination of a PU foam with a carbon fiber fabric (SapaFipur), an innovative viscoelastic PU foam, two polyester fibers materials and a basalt wool material.
These materials, on the basis of previous studies, have been selected for their potential effectiveness and also for their positive LCA evaluation; this aspect is fundamental in the design of environmental friendly vehicles.

4. Results

4.1 Sound absorption results

In Fig. 5 the sound absorption coefficients of the different materials are compared as a function of frequency at fixed thickness values (10 and 20 mm). The grey colour curve is regarded as the reference curve, referred to the PUR material currently used in automotive field.

The comparison at 10 mm thickness (see Fig. 5(a)) shows that most materials have better absorption properties with respect to the reference material up to 400 Hz. Above this frequency value, the Thinsulate (3M), the Tymet Poland 3045 and the viscoelastic 90-10 material, are worth to be considered.



(a) (b)

Figure 5: Absorption coefficient vs. frequency measured at 10 mm (a) and 20 mm (b) sample thickness by using impedance tube technique.

Also for a thickness of 20 mm (see Fig. 5(b)), many of the proposed alternative solutions present a more favourable absorption trend with respect to the PUR. Indeed, all fibrous materials take advantage of an increase in thickness, more than the PUR, thanks to their more pronounced porosity.

4.2 Sound insulation results

For the evaluation of the sound insulation properties, rather than considering the STL of the sole absorbing materials listed in Table 1, the STL comparison was established for the coupled "plastic + absorbent" systems, since the combined effect is not easy to determine based on "single" results. For this reason, the test articles were developed so as to be similar to the engine cover configuration. Thus, the individual samples of absorbent material were always tested in the impedance tube in combination with a 3 mm thick polyamide plastic, as shown in Fig. 6.

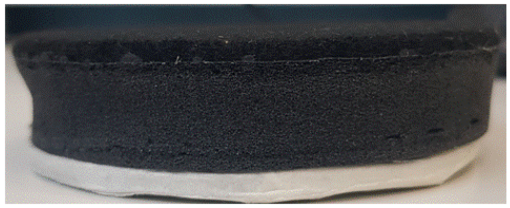
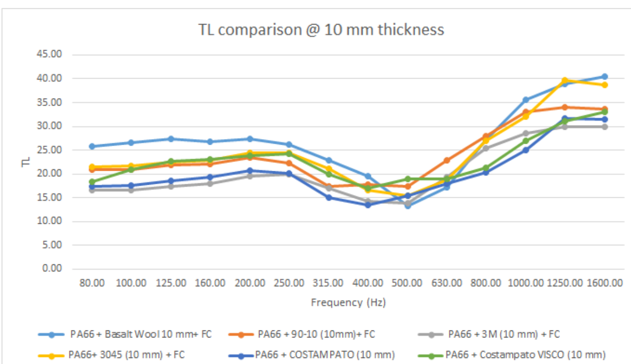
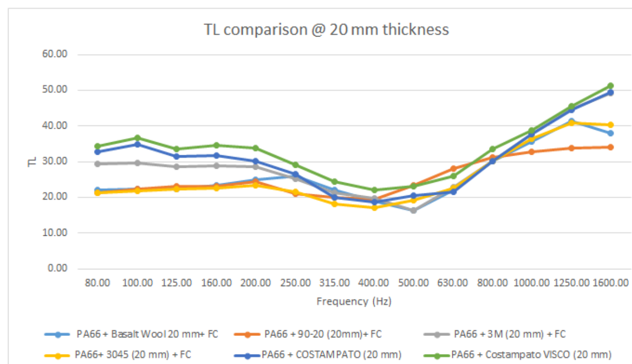


Figure 6: Example of coupled material (plastic + absorbent) for STL measurement.

For the tests carried out relating to the transmission loss, as specified above, there was a division between the material tested with carbon fiber and without, in order to simulate a co-moulded.
In all cases, the external surface was coated with carbon fiber, to favor the comparison between the co-moulded reference solution with any alternative solutions.
By comparing the STL of the different solutions with a 10 mm thick absorbing material (see Fig. 7(a)), three interesting trends can be noted which exceed the reference PUR-related blue curve. For frequencies below 400 Hz, the Basalt Wool light blue curve presents higher STL values. When the 400 Hz threshold is exceeded, the curve referred to the viscoelastic material can be regarded as a valid alternative to the standard current solution. The same comparison is reported in Fig. 7(b) for the solutions with a 20 mm thick absorbing material.



(a)



(b)

Figure 7: STL vs. frequency measured at 10 mm (a) and 20 mm (b) sample thickness by using impedance tube technique.

As specified in Section 2, after evaluating the acoustic performance of the different materials samples by using the impedance tube technique, the most interesting solutions were finally tested according to the ISO 15186 standard, for the identification of the most valid solutions both in terms of the acoustic performance and the possibility of industrialization. In this final analysis, materials were compared with reference to a thickness of 10 mm, which will characterize the final engine encapsulation configuration. From the comparison shown in Fig. 8, an interesting behaviour of the solution co-moulded with viscoelastic foam emerges, which presents higher STL values in almost the entire frequency range. Only in the range between 63 Hz and 125 Hz, the polyester fibers materials presents better acoustic insulation properties.

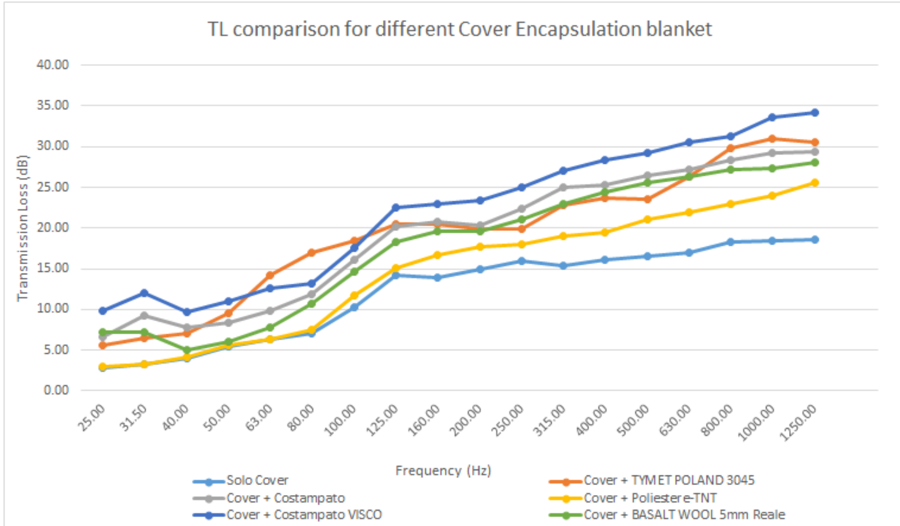


Figure 8: STL vs. frequency of component prototype measured by using sound intensity technique.

5. Conclusion

In the framework of the present study, several materials have been tested as candidate alternative to the poro-elastic material generally implemented in the engine beauty cover design. The direct comparison of acoustic insulation performances have demonstrated the effectiveness of some innovative solutions. Among them, the co-moulded visco-elastic PUR and carbon fiber fabric seems to have the higher performances and also represent the solution that requires a very short time to market as it does not involve huge processes modification. In any case, fibrous materials have shown some interesting performances that, most probably, will drive the future research toward a combination of materials, into a sandwich structure.

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