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Research Article

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Investigation of micro-perforated plate structure and cavity used as Helmholtz resonator in wheel arch liner

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Abstract: Noise pollution, which is one of the pollutions in the developing world, affects human health and daily life. Cars make up a large part of this noise. This study focused on the transition noise reduction of automobiles by integrating the micro-perforated plate structure into the wheel arch liners. The noise absorption coefficients of the samples produced within the scope of the study were experimentally tested in Alpha Cabin and then validated with numerical simulations. When the results of the simulations were compared with the experimental test data, a compatible correlation was reached with the test data in terms of the reliability of the research. Finally, these structures were integrated and simulated in 4 different combinations on the wheel arch liners of a vehicle that is actively used in the market, and their noise absorption properties were compared with each other. As expected, while the noise absorption coefficients increased with the increase in perforated structures, combinations were obtained to meet the expectations of customers in the automotive industry. In addition, it is stated in the study results that the use of perforated structures in wheel arch liner (WAL) has the potential to reduce pass-by noise values.

Keywords: Wheel arch liner; acoustic; alpha cabin; micro-perforated plate; noise absorption; automotive.

1. Introduction

In today's world, pollution shows diversity. With the increase in the number of people and structures, one of the pollutions augmenting daily is noise pollution. Noise pollution negatively affects the lives of millions of people [1]. Noise-related problems include sleep disturbance, auditory loss, stress-regarding illnesses, slurred speech, high blood pressure, and loss of performance [2]. When it comes to the sources of the noise problem, traffic noise stands out. The noise emission created by vehicles in the daily distance they travel is an important problem [3]. Assorted tests are carried out for this problem, which is tried to be brought under control by administrative activities around the world [4]. In these tests, in which the pass-by noise is measured, the vehicles are operated at certain speeds and the noise produced by all their components is measured collectively [5]. For production conformity and type approval, automotive producers carry out pass-by noise measurement as mandatory [6]. From April 2014, 68 dB(A) is required as maximum noise in 2025 according to ISO 362, 51-03 noise test procedure. It is foreseen that the pass-by noise will be reduced by 2 dB every 2 years according to the regulations [7], [8].

Researchers actively seeking solutions to noise emissions try to prevent noise in certain parts of the vehicle. Along with alternative solutions such as the integration of noise absorber materials, there are studies on different acoustic absorber geometries. In a study, Bozca and Fietkau focused on reduce the noise produced by a gearbox using the empirical model approach. By considering various design parameters, the researchers optimized the number of teeth and the gaps in the gearbox in the design as geometrical, reducing the operating noise of the structure by 14% [9]. In another study, Nghiem and Wang, aimed to reduce vehicle engine noise and mainly focused on crankshaft strength and engine coatings. The researchers reduced the noise emission by 1 dB by rigidifying the crankshaft, and by using 3 different acoustic shields, a total of 3 dB noise emission [10]. There are also studies where researchers use Micro-perforated plates (MPP) structures to provide

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acoustic absorption in vehicles. In a study, Zhu evaluated MPP structures for use in an automobile body. Focusing on hole diameters, cavities, and pores, they examined the acoustic performance of the structures and compared the structures, and presented the result [11]. Allam and Abom examined the feasibility of developing sound-absorbing mufflers for automotive ventilation and exhaust systems. Their research involved incorporating MPP absorbers into noise sources and conducting acoustic experiments. The findings indicated that MPP-based mufflers could serve as an effective solution for reducing noise in automotive applications [12].

The noise produced by vehicles comes from certain parts of the vehicle[13]. The noise made by moving parts in automobiles is the majority, and the part that produces the highest noise emission is the wheels where the vehicles meet the ground[10]. WALs around the wheels have no effect on reducing noise emissions, but the idea of integrating MPP structures into WALs is the motivation of this study. With this innovation, which has no examples in the literature, it is intended to reduce the pass-by noise of an automobile. In the study, first of all, experimental tests were carried out on real samples in the alpha cabin. These experimental tests were then simulated and validated numerically. Based on these results, these structures were simulated by integrating into the wheel arch liner models of a vehicle in the market with 4 different combinations. With the realization of this process, it is aimed to respond to the different option expectations of automobile customers. According to the results of the pass-by-noise tests, the highest noise levels are observed in the 630-2000 Hertz range. Hence, this study examined the sound emission levels in this range.

2. Materials and Methods

2.1. Materials

In the noise-absorbing structure studied in the previous study, polypropylene was used as the perforated plate material. Polypropylene is a thermoplastic polymer material that is often used in various fields from automotive to aviation, from building construction to shipping [14], [15]. The biggest reason why it is frequently used in these areas is that it can be easily shaped with the effect of heat and pressure. In addition to this feature, it is light and cheap, which makes it preferred by manufacturers [16], [17]. Many automobile manufacturers in the sector have this product in various parts of the vehicles. It is a material that is often used in WALs, which is the subject of the study. The properties of polypropylene, which is used as the raw material of the perforated plate, which is one of the main themes of the study, are given in ▶**Table 1**.

WALs do not have noise absorbing properties on their own. For this reason, this feature is achieved by using absorbent materials on the backside. The properties of the absorbent product used in the structure in the study are as in ▶**Table 2**.

Table 1. Used Polypropylene's Properties for WALs[18]

Features	Values
Thickness (mm)	1.7
Density (g/cm3)	0.90-0.95
Melt flow rate (230oC; 2,16 kg)(g/10min)	9-14
Flexural modulus (2mm/min)(MPa)	≥700
Notched impact strength (Izod) (23oC) kJ/m2)	≥8
Hardness (D-shore)	56-60
Tensile stress (50 mm/min)(MPa)	≥16
Tensile strain at break (50 mm/min)(%)	≥40
Tensile modulus (1mm/min) (MPa)	≥750

Table 2. Properties of acoustic absorbent[18]

Features	Values
Compression resistance (40%, 4th cycle) (kPa)	2.5 - 5
Flammability (thickness 13 mm) (mm/min)	≤80
Thickness(mm)	8
Net density(g/m3)	400
Tensile strength (kPa)	120
Elongation at break (%)	200
Compression set (50% compression, 70°C, 22 h)(%)	3.1
Tear resistance (N/cm)	4.5
Odour (2 h, 80°C) (rate)	2.5
Acoustic on 10 mm (NRC value) (%)	30
Acoustic on 20 mm (NRC value) (%)	46
Fogging reflection (thickness 10 mm-3 h, 100°C)(%)	83
Fogging gravimetric (thickness 10 mm-16 h, 100°C)(mg)	0.7
Formaldehyde content(ppm)	2

2.2. Method

In this study, firstly, the plates to be tested in the Alpha cabin were prepared. The samples prepared to be tested in the Alpha cabin were prepared in 1x1.2m^2 dimensions by considering the studies in the literature. Based on the reference studies, the diameter of the holes was determined as 3 mm and the density was 7% on the plate[18]. In addition, the cavities behind the WAL were also applied to the test samples. The structure of the experimental test specimens is represented in ▶**Figure 1**.

The output of the experimental studies is the sound absorption coefficient (Sa). This value is a result obtained by examining reverberation times in the Alpha Cabin. In the second part of the study, the validation process was carried out. In this part of the study, the sound absorption coefficients of the combinations were compared. First, the perforated plate, second the absorbent material, and finally the whole structure was validat-

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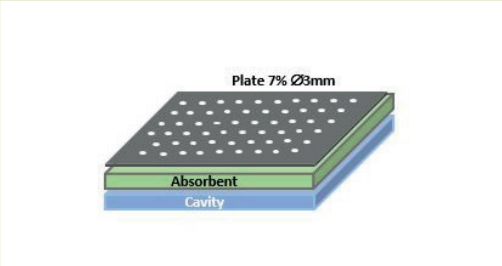

Figure 1. The structure of the experimental test specimens

ed with different cavity values. All this work was done with Matelys suite, based on the Transfer Matrix Method (TMM/FTMM) which predicts the vibro-acoustic response of multi-layer systems [19]. In the last part of the study, the WALs of a vehicle model that is active in the sector are modeled by integrating these MPP structures. Simulations were carried out without ignoring the cavities behind the WALs on the vehicle. Models of WAL's in this reference vehicle, acoustic absorbents, and the the values of the cavities behind them are given in ▶**Figure 2**.

In the study, instead of applying the integration of MPP structures to each wheel, it was applied in 4 different combinations. The aim here is to examine different scenarios on each wheel and to meet the option expectations of automobile drivers. The simulation combinations determined within the scope of the research are as in ▶**Figure 3**.

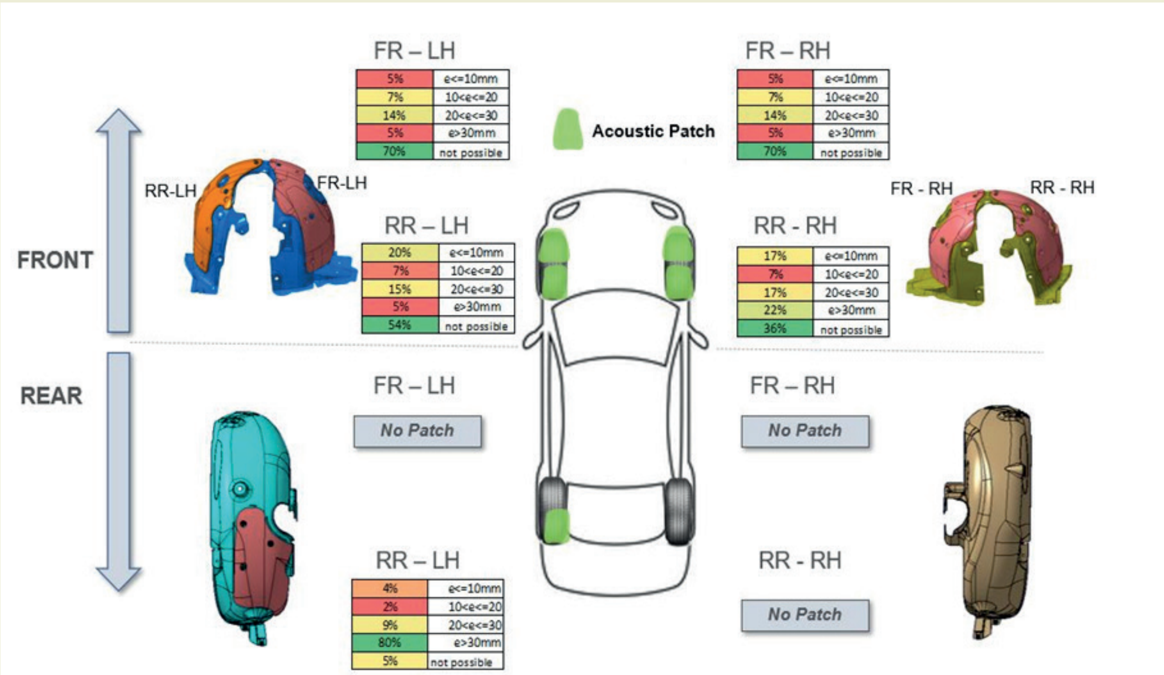

Figure 2. Models of WAL's in this reference vehicle, acoustic absorbents, and the values of the cavities behind WAL's

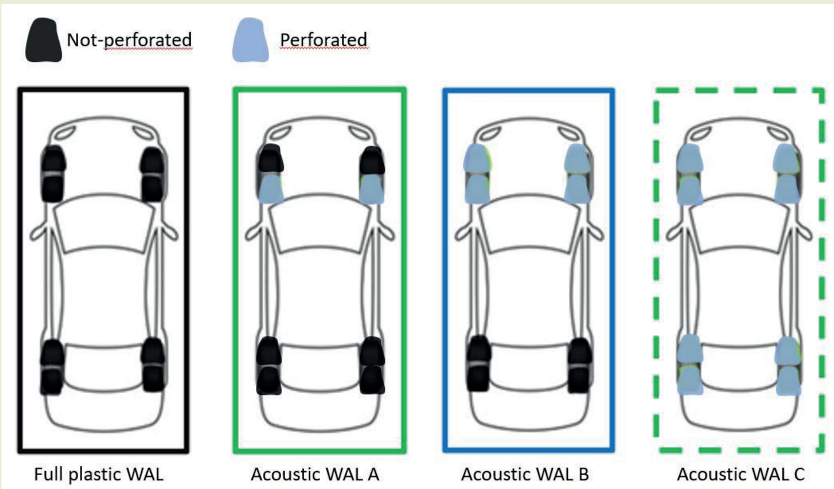

Figure 3. WAL combinations of simulations on current automobile in sector

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2.3. Acoustic material model

According to studies in literature, acoustic behaviour of porous material can be defined with some parameters. The main parameters that we will consider are:

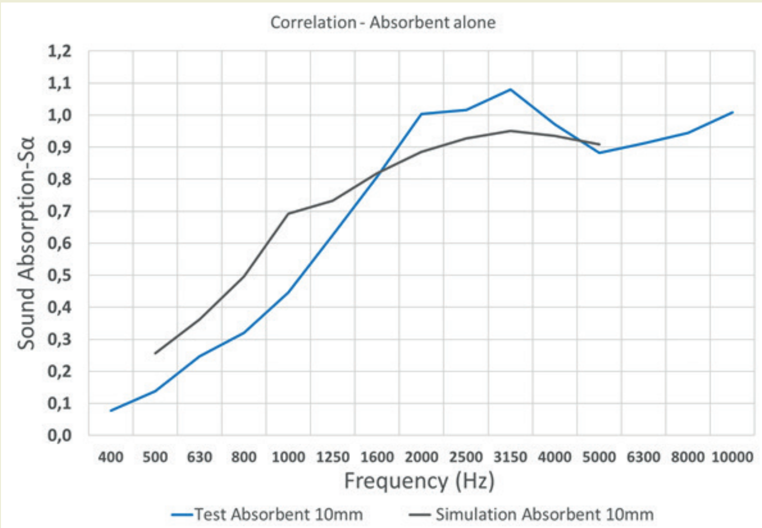
- the static air flow resistivity σ (N.s.m^{-4}),
- the open porosity ϕ,
- the high frequency limit of the dynamic tortuosity ,
- the viscous characteristic length Λ (m),
- the thermal characteristic length Λ' (m).

Static air flow resistivity σ and the open porosity ϕ of the material are the main parameters that should be measured with direct methods [20-21]. The other parameters are estimated from acoustic measurements in a stationary wave tube according to methods described in [22,23]. Parameters , (the high frequency limit of the dynamic tortuosity), Λ (the viscous characteristic length) and Λ' (the thermal characteristic length) are then estimated from their analytical expressions deduced from the Johnson-Champoux-Allard (JCA) model and the Johnson-Champoux-Allard-Lafarge (JCAL) model [24-26]. All the work was done using MATELYS software.

3. Results and Discussions

3.1. Comparison of Numerical and Experimental Results

In order to carry out the acoustic simulations of advanced WAL models in which WALs and MPP structures in a current car, which constitute the motivation of the study, are integrated, they must first be validated. Therefore, real plates and absorbents were modeled and simulated after being tested in the Alpha Cabin and the two types of results were compared with each oth-



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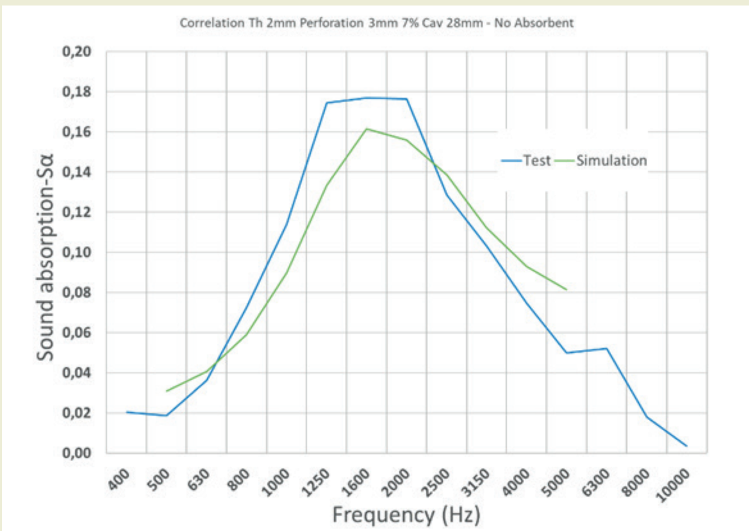
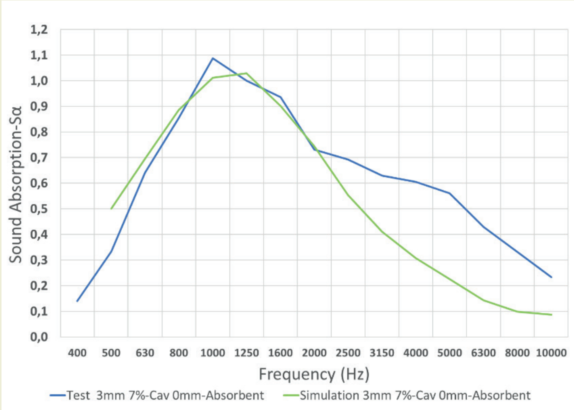


b)

Figure 4. graphics experimental tests and simulation a) absorbent alone b) WAL alone



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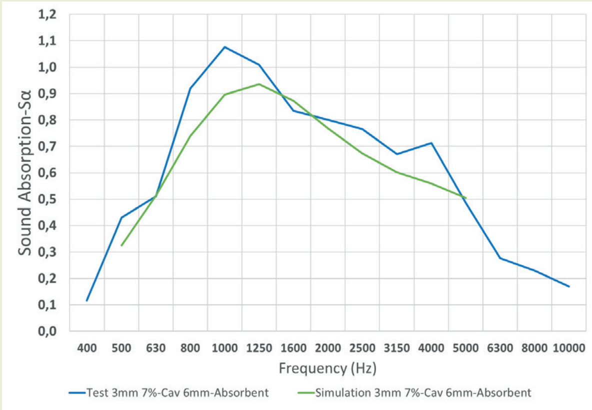

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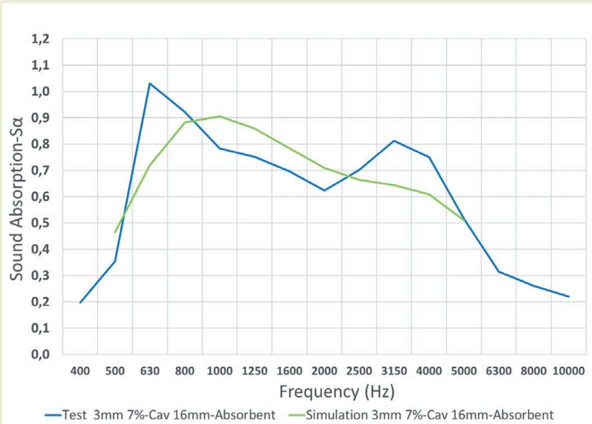

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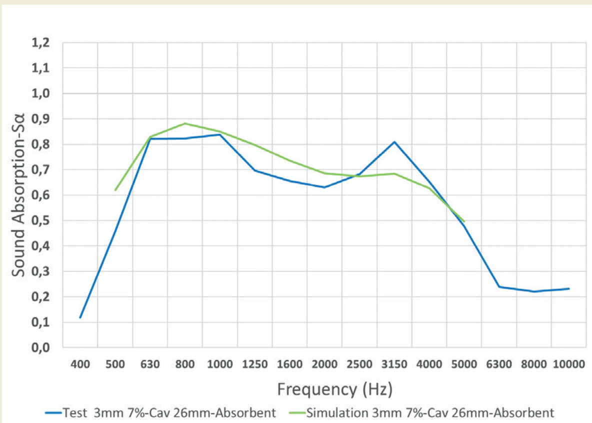

d)

Figure 5. Comparison between test and simulation of Acoutic WAL for different cavity sizes a) 0 mm, b) 6 mm, c) 16 mm d) 26 mm

er. By going from the specific to the general, firstly the absorbent was tested and simulated alone. Then, the same process was applied only to the perforated plate without absorbent. While the diameter of the holes in the plate was 3 mm and the hole density was 7%, the cavity behind it was determined as 28 mm. The absorbent thickness used in the validation process was 10 mm. Experimental tests and simulation graphics of absorbent and WAL are shown in ▶**Figure 4**.

As can be seen from the graphics, a good correlation was obtained between the experimental results and the simulations. Considering the absorbent, the highest sound absorption coefficient was 1.07 in the experimental test, while 0.96 was obtained in the simulation. The error rate was 10.3%. Considering only WAL, the sound absorption coefficient was found to be 0.16 in the simulation and 0.18 in the experimental test. The error rate was 9.04%. After the absorbent and WAL were validated alone, plates with both were produced and tested in the alpha cabinet to obtain sound absorption coefficients. Afterward, the models of these samples were created and examined in simulation and compared with the results obtained in experimental tests. The cavities behind the absorbents were determined as 0, 6, 16, and 26 mm, thus the effect of cavity increase was also examined. On the other hand, it is aimed to increase the reliability of the study by validating the results with 4 different cavity values. Experimental tests and simulation graphics of the plates according to the Cavity values are given in ▶**Figure 5**.

Experimental test results and acoustic simulation results had the same tendency and gave close results in combinations of absorbent and WAL alone as well as in combinations. When the experimental test results of the plates are examined, the highest sound absorption values were obtained as 1.09 in 0 mm cavity, 1.08 in 6 mm cavity, 1.03 in 16 mm cavity and 0.84 in 26 mm cavity. In the simulations, the sound absorption values were found to be 1.03, in the 0 mm cavity, 0.94 in the 6 mm cavity, 0.91 in the 16 mm cavity, and 0.88 in the 26 mm cavity, respectively. When the results are examined according to these cavity values, the error rates are 5.5% in the 0 mm cavity, 13% in the 6 mm cavity, 11.6% in the 16 mm cavity, and 4.7% in the 26 mm cavity, respectively. By considering both experimental tests and simulation results, it is clearly observed that cavity values have a significant effect on acoustic absorption values. In addition, the overlapping of the experimental data with the simulation results also showed the way for the continuation of the study. The results validated with different cavity values showed that there is potential for improvement in acoustic absorption by examining these values in detail.

3.2. Comparison of WAL combinations on current automobile

After the validations have been made, perforated structures have been integrated into the WALs of a real vehicle for 4 different combinations that will meet the expectations of automobile customers. In the simulations, WALs with acoustic patches, the cavities behind the WALs, and the percentages of these cavities are as shown in ▶**Figure 2**. Based on the automobiles on the market, the absorbent thickness was determined as 14 mm in this process. The sound absorption coefficient graphics obtained as a result of acoustic simulations of the combinations, one of which is a non-perforated full plastic structure and three of which are enhanced WALs, are shown in ▶**Figure 6**.

As seen in ▶**Figure 6**, the highest Sa value was seen in Acoustic WAL A with 1.11. The second highest val-

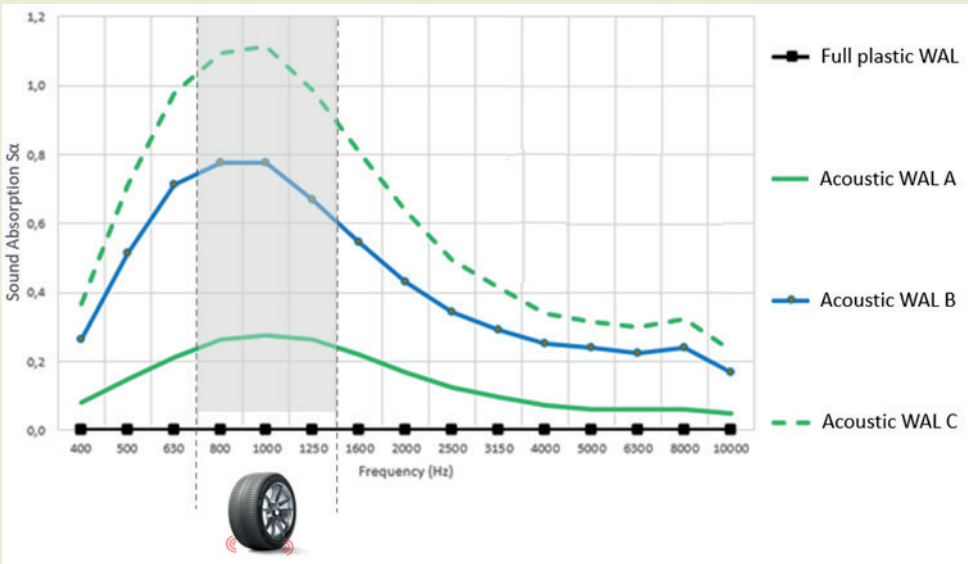

Figure 6. Results of numerical acoustic analysis of WAL combinations on current automobile

ue was found in Acoustic WAL B with 0.78, while the third highest value was in Acoustic WAL C with 0.28 Sa value. The acoustic absorption values of the non-perforated plate were close to zero. When the three acoustic WALs were compared to each other, Acoustic WAL A had 29.73% higher noise absorption values than Acoustic WAL B and 74.77% higher than Acoustic WAL C. When the acoustic absorption test results were evaluated, the increase in absorption values paralleled the increase in perforated structures. Considering consumer expectations, acoustic absorption values can be adjusted with various combinations. But it should not be forgotten that the strength of the WAL structure will decrease with the holes opened.

4. Conclusions

The effects of noise pollution on the environment and human health stand out as a fact of today's world. In this study, pass by noise in vehicles, which is one of the biggest sources of this problem in daily life, is discussed. The motivation of the research is to reduce the pass by noise by integrating the MPP structures into the wheel arch liners in the vehicles. First of all, the real samples created were tested in alpha cabin, then modeled and validated by performing numerical analysis. A very good correlation was reached between the numerical analyzes performed and the test results. In the continuation of the research, the wheel arch liners of a vehicle currently in the industry were modeled and the integration of MPP structures was made in 4 different combinations. Acoustic emission values increased as expected in regions where MPP structures are in the majority. As a result of this study, wheel arch liners developed with 4 different options were provided to the manufacturers. In the results, it was explained that the pass by noise can be reduced with improved WALs by integrating MPP structures. In the results, it has been stated that a good noise absorption performance can be achieved by optimizing the spaces behind MPP structures.

Research ethics

Not applicable.

Author contributions

Conceptualization: [Yasemin Gultekin, Thomas Jean], Methodology: [Thomas Jean], Formal Analysis: [Thomas Jean], Investigation: [Yasemin Gultekin, Thomas Jean, Umut Kumlu], Resources: [Yasemin Gultekin, Thomas Jean], Data Curation: [Yasemin Gultekin, Thomas Jean], Writing - Original Draft Preparation: [Mustafa Atakan Akar, Umut Kumlu], Writing - Review & Editing: [Mustafa Atakan Akar, Umut Kumlu], Visualization: [Thomas Jean, Yasemin Gultekin, Umut Kumlu], Supervision: [Mustafa Atakan Akar, Umut Kumlu], Project Administration: [Thomas Jean, Yasemin Gultekin]

Competing interests

The authors states no conflict of interest.

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Data availability

Not applicable.

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