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Research Article

Acoustic emission reduction in vehicles by using MPP structures in wheel ARCH liner structures

Yasemin GULTEKIN[1], Thomas JEAN[2], Mustafa Atakan AKAR[3], Umut KUMLU[3,*]

[1]*NOVARES Turkey Otomotiv A.Ş. TOSB TAYSAD, Kocaeli, 41420, Türkiye*
[2]*NOVARES GROUP, 9 Rue des Poissonniers, Lens, 62300, France*
[3]*Çukurova University, Department of Automotive Engineering, Adana, 01330, Türkiye*

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ABSTRACT

Noise emission is an important problem of vehicles. An important part of the general noise of the vehicle, which is called pass-by noise, is composed of the wheels and the engine. In this study, it was aimed to design a wheel arch liner (WAL) that can absorb the sounds coming from the wheels of the vehicles by creating micro-perforated panel (MPP) structures. While examining the diameters, pattern, and frequency of the holes in the MPP structures within the scope of the research; The effect of the cavity, which can be left behind the wheel arch liner structure to be used in the vehicle, on the acoustic absorption values was also included in the scope of the research, and studies were carried out to reduce the acoustic emission. In order to observe the effect of this cavity, 2 different cavity sizes (18-28 mm) were used with a without cavity MPP structure. In the results of the research, the highest acoustic absorption value ($S\alpha$) was observed as 0.97 in the sample with 7% hole density and 3 mm hole diameter. In addition, when the cavity behind the MPP structure is examined, the best $S\alpha$ value was found in the sample with an 18 mm cavity. This research, which sought to reduce pass-by noise, revealed the potential of integrating MPP structures into wheel arch liners to reduce wheel noise.

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INTRODUCTION

With the increasing population growth, the number of vehicles in our world is increasing day by day. The effect of this uncontrollable increase on the daily life of human beings is growing negatively. The most important of these negative effects are seen as emissions, and an important type of these emissions is noise emission. Noise generated by automobiles is one of the components of noise pollution in the environment. The outside noise of a moving vehicle is part of its character and can be an important aspect of its appeal; however, the public traffic noise from thousands of cars and trucks is considerable. In the design of a vehicle, external noise must be limited according to regulatory requirements and internal noise must be kept at

***Corresponding author.**
*E-mail address: ukumlu@cu.edu.tr, umutkumlucrlmkl@gmail.com

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a level acceptable to the customer [1]. Administrative regulations regarding noise from cars have become increasingly stringent in recent years [2]. While passing noise limits for all types of land vehicles are determined by government institutions to reduce the noise in our environment, these stand out as critical regulations that must be followed [3]. Pass-by noise measurement is mandatory for automotive manufacturers for the type approval and conformity of production. ISO 362 from April 2014 imposes 68 dB(A) as a maximum of noise in 2025 according to the 51-03 pass-by noise test procedure [4,5]. According to regulation, the pass-by noise should be decreased by 2 dBA every 2 years.

In a normal road vehicle, pass-by noise mainly consists of tires, powertrain, air intake systems, and exhaust. Tires make up most of the pass-by noise [6]. When the wheels of the vehicle rotate, acoustic waves are produced due to the contact between the tire and the road. In addition, acoustic waves are also generated by radiation from the tire itself when excited by contact. Acoustic waves are also produced by the impact of water droplets or gravel, which are reflected on the surface of the wheel arch by the rotation of the wheel when the vehicle is moving on a wet or gravel road. For certain wavelengths, a phenomenon of cavity resonance occurs for frequencies called modal frequencies. For these frequencies, there are standing waves, that is, waves whose pressure maxima are always at the same points. To avoid this phenomenon of cavity resonance, called Helmholtz resonance, it is necessary to absorb acoustic waves as they are reflected. Absorbing the noise generated by the tires will play an important role in adapting to the new noise regulations. For this reason, a significant majority of researchers have focused on reducing wheel noise. Bao et al. aimed to reduce tire acoustic cavity resonance (TACR) noise in a study. The researchers designed a tire-rim assembly using a Helmholtz resonator and worked to reduce the TACR value. In the tests performed, a decrease was observed at the peak of the noise and in the specified frequency range [7]. In another study, Wan et al. investigated the porous structure of the liner placed in the tire to reduce tire cavity resonance noise. The researchers explained that both resonance noise control and material configuration must be considered to decide the thickness and width of the porous material adhered to the inner surface of the tire. They also stated that thicker or larger porous material performed better in controlling cavity resonance noise [8]. The acoustic emission performances of porous and perforated geometric structures are higher than other structures. Cavity absorbs most of the noise. These structures have been popularly used and developed to reduce noise in developing technological areas [7,9,10]. Naderzadeh et al. studied the performance of noise barriers applied with different diffusers with or without perforated plates. The researchers, who stated that the diffuser performance increased with the addition of the perforated plate, also stated that the acoustic performance of the structure formed by the addition of these perforated plates was improved by 3.59 dB [11]. In a study, Padavala et al. aimed to reduce the noise of the drivetrain of electric vehicles. To reduce powertrain noise and improve interior sound quality, the researchers applied a passive noise reduction method. The study also demonstrates the development of several types of mufflers, including a new innovative MPP muffler for reducing intake noise from the air compressor [12]. Allam and Abom explored the possibility of creating noise-absorbing mufflers for use in automotive exhaust or ventilation systems. In the research, MPP absorbers were placed in noise sources and acoustic tests were performed. The researchers have stated that micro-perforated muffler solutions for broadband damping of sound have the potential to be used in automobile noise sources [13]. The absorption properties of MPP structures are also investigated independently of the automotive field. The cavities between these structures also affect the noise absorption properties of the structure [14,15]. In a study, Yan et al. studied the sound absorption properties of a double-layer micro-perforated plate structure with a variable cross-section back gap. In the research, it was revealed that sound absorption properties improved by increasing the cavity distance and cross-sectional area of the MPP structure on the inner side. In the results of the tests performed on the impedance tube, it was stated that the sound absorption coefficient reached 0.8 with the increase in the cavities in the structure, while the noise reduction performance of the designed with cavity MPP structure rose [16]. In this current study, MPP structures on which many acoustic absorption studies were carried out were created to generate a Helmholtz resonator and tested in the acoustic cabin. Acoustic emission values were examined by focusing on the hole diameters, hole density, hole pattern, and the width of the cavity to be left behind the MPP structures in the created MPP structures, and the effects of these parameters on the acoustic absorption value were discussed. The aim and motivation of the research is to optimally configure these parameters in the designed MPP structures and to reveal the potential of these structures to be used as noise absorbing WAL in vehicles.

EXPERIMENTAL

Materials

Polypropylene, which is used for wheel arc liner in the study, is a preferred polymer in various industries such as aviation, construction, and automotive [17−19]. This raw material, which is a thermoplastic that can be easily shaped by applying heat and pressure; is frequently used in plastic automotive parts with its advantages such as lightness, durability, and cheapness [20−22]. This product, which can be shaped by plastic injection, is attractive to companies in serial production as it provides ease of

Table 1. Used polypropylene's features for wheel arch liner

Features	Values
Thickness	1.7
Density (g/cm^3)	0.90-0.95
Melt flow rate (230°C; 2,16 kg) (g/10min)	9-14
Tensile stress (50 mm/min) (MPa)	≥16
Tensile strain at break (50 mm/min) (%)	≥40
Tensile modulus (1mm/min) (MPa)	≥750
Flexural modulus (2mm/min) (MPa)	≥700
Notched impact strength (Izod) (23°C) kJ/m^2	≥8
Hardness (D-shore)	56-60

production. In addition, the recyclability of this material stands out as another feature that makes this material stand out [23,24]. Due to the superior properties of this material, the raw material of most wheel arch liners used in the automotive market has been polypropylene. The properties of the polypropylene used in the study are shown in Table 1.

Wheel arch liner in polypropylene doesn't bring any noise absorption. For this reason, absorbent material must be placed inside the hood. However, absorbent material has to be used and defined according to cost, package, and performance constraints. In the study, polyurethane foam which is used with acoustic absorber function in various sectors was used as an acoustic absorbent. Table 2 shows the properties of the absorbent product.

Table 2. Features of acoustic absorbent

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

METHOD

Alpha Cabin

Acoustic absorption properties of structures are measured by several test methods such as impedance tubes and alpha cabins. In this study, Alpha Cabin was used as an acoustic emission test method. Alpha Cabins, named after the sound absorption coefficient "alpha", is a reverberating chamber prototype. The sound absorption coefficient of the sample tested in this system is determined from the basic formula based on Sabine's theory, consistent with the measurement made in a normal-sized reverberation chamber:

$$\alpha = \frac{0,163 \times V}{S}\left(\frac{1}{TR} - \frac{1}{TR_0}\right) \times C \tag{1}$$

- V is Cabin Volume
- S is Sample Area
- TR is Reverberation Time with the sample in the Cabin
- TR_0 is Reference Reverberation Time without the sample in the Cabin
- C is the correction coefficient of the cabin

The sound absorption coefficient (α) is calculated using the difference between the reverberation time of the room with and without sample. The cabin correction coefficient (C) is found by comparing measurements of reference samples made in a reverberation chamber and an alpha cabin under the same conditions [25,26]. The alpha cabin volume of 6.98 m^3 allows a cut-off frequency of almost 300 Hz. Above this, the acoustic field of the reverberation chamber has the potential to disperse and measurements are taken in the frequency range 400 Hz-10000 Hz [27-29]. The alpha cabin test setup schematic view is shown in Figure 1.

Sample Characteristic

In the wheel arch liners that are actively available in the market, there is the wheel arch liner itself, the absorbent placed on the wheel arch liner, and the cavity before

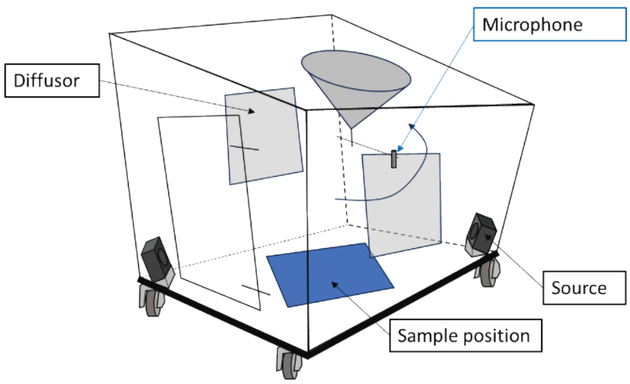

Figure 1. Alpha cabin test setup schematic view.

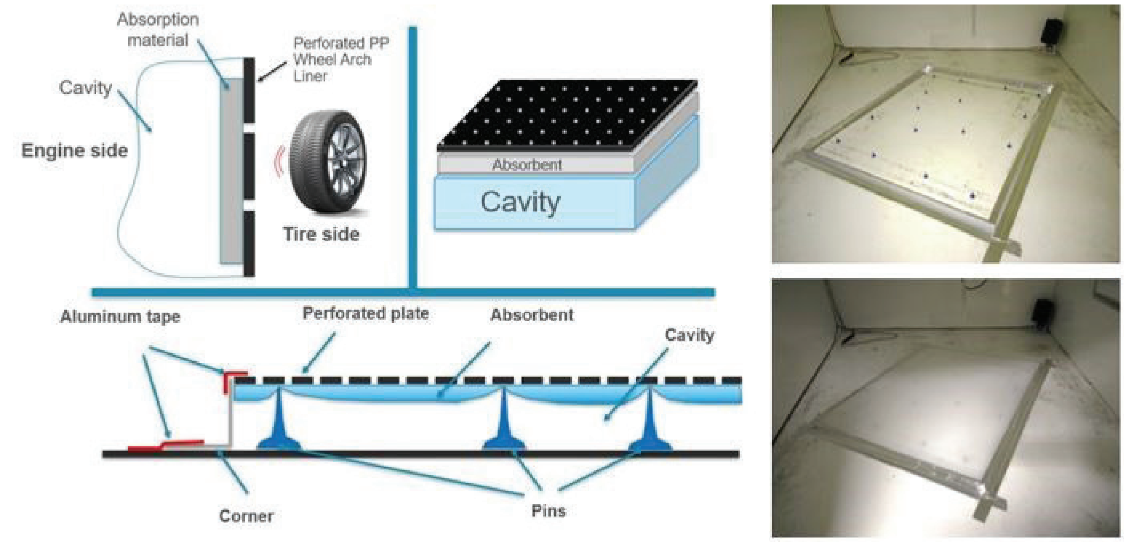

Figure 2. Sequence examples and placement of samples in the Alpha Cabin.

the engine part, according to the order of proximity to the wheel. The samples to be subjected to acoustic testing in Alpha Cabin are also listed in this order. As a result of the literature research, it was decided that the sample plates to be placed in the test cabinet should be a with surface 1x1.2 m^2 [30]. The absorbent product was used in the same thickness and properties in all samples produced within the scope of the study and tested in the Alpha Cabin. Sequence examples and placement of samples in the Alpha Cabin are shown in Figure 2.

Test Configurations

The first point was to list all the parameters that should impact acoustic performances on the roadside with absorbent that reach body side requirements from the original equipment manufacturer. Hole size and perforated area were taken into account. Preliminary studies have been made for the design of the MPP structure to be created. The optimum design was obtained by varying the hole diameters and the density of the holes. Holes with diameters of 2 mm, 3 mm, and 5 mm were used, while hole densities of 3% and 7% were used. According to the findings obtained from the pass-by-noise tests, the highest noise levels are seen in the range of 630-2000 Hertz. For this reason, acoustic emission values in this range are examined in this study. In the preliminary studies, the pattern of the holes in the plate was changed and positive results were obtained. In order to get a uniform hole pattern and to keep a high mechanical resistance, It was decided to use the model presented in Figure 3 as MPP structures.

In the continuation of the study, the effect of the cavity created in the MPP structure was examined. A total of 3 structures, 18 mm, and 28 mm, together with the structure without gaps, were examined in this content.

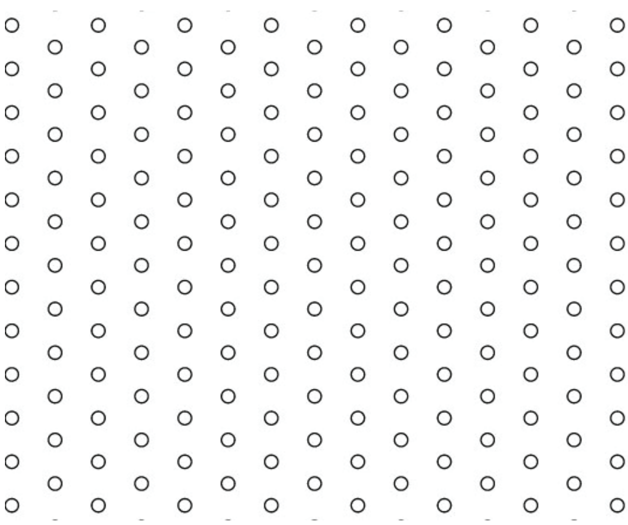

Figure 3. The pattern of holes on MPP structure.

RESULTS AND DISCUSSION

Holes Diameter and Density

Hole diameter and density are important parameters to reduce acoustic emission in MPP structures. In the study, 3 different hole diameters, 2 mm, 3 mm, and 5 mm, together with the hole-free structure; Two different hole densities, 3%, and 7%, are combined. The test results performed in the Alpha cabin according to the relevant standards are as in Figure 4.

Acoustic absorption comparisons are made by examining $S\alpha$ values. When the test results are examined, it is seen that the acoustic absorption value of the sample with 3% hole density and 2 mm diameter is higher. However, the $S\alpha$ value of this sample is not in the frequency range where the

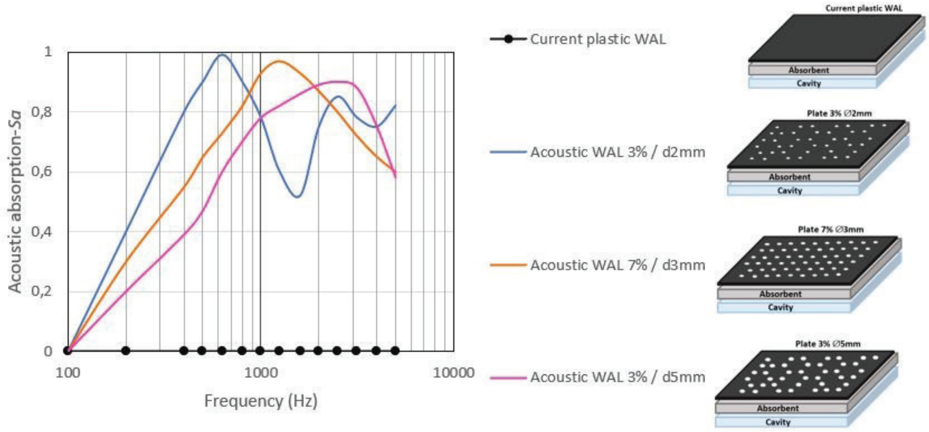

Figure 4. Effect of hole density and diameter on acoustic absorption value.

wheel and motor noise are intense and the pass-by noise is the highest (630-2000 Hertz). Comparisons of samples are made at 1000 Hertz. The optimum combination is observed in the sample with a hole density of 7% and a diameter of 3mm, with a value of 0.97 *Sα* at a frequency of 1000 Hertz. Although the tendency of the other samples is different, the *Sα* values at 1000 Hertz for two are 0.78. The 19.6% difference calculated according to the high *Sα* value is of great importance when it is foreseen that these structures can be used in vehicles. Although combinations at different frequency values reach values as high as 0.99 (%3 hole density- 2 mm hole diameter), they are at low acoustic emission levels in the range where pass-by noise is most important. According to this result, it is obvious that while increasing the hole density increases the acoustic absorption performance, the hole diameter should be optimized. Because in the combination of holes with a diameter of 3 mm as an intermediate value, the higher *Sα* value indicates that the increase or decrease in diameter does not have a linear correlation. As seen in the studies in the literature, it has been understood that hole diameters and patterns are of great importance in terms of acoustic emission [31]. In addition, in another study by Tayong, these results cannot be ignored considering the effects of heterogeneous hole distribution on acoustic emission [32]. In the continuation of the study, the cavity parameter, which will be located behind the MPP structure, has been examined. By determining the hole density and diameter, the dimensions of the sample to be used in cavity exploration are as shown in Figure 5. This hole pattern is that of the sample with 7% hole density and 3 mm diameter holes.

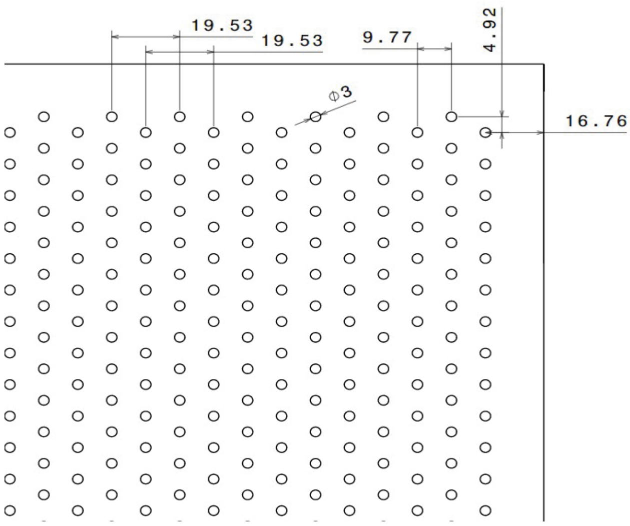

Figure 5. Hole pattern and measures on plates.

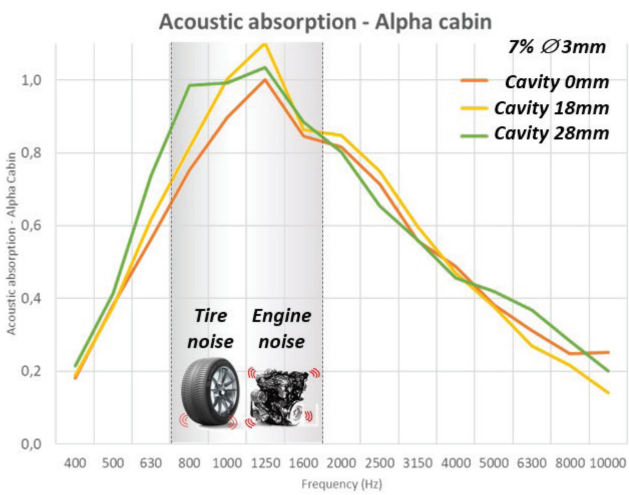

Figure 6. Influence of Cavity size on acoustic absorption performance.

Hole Pattern and Cavity Effect

After performing the hole pattern study in the MPP structure, tests are carried out for the voids in the created samples. MPP structures without cavity, with 18 mm gap and with 28 mm gap are compared with each other as a result of applied tests. Test data are as shown in Figure 6.

Considering the values between 630-2000 Hertz, the highest extreme absorption $S\alpha$ value is observed with 1.1015 in the sample with an 18 mm cavity. While the highest value of the sample without a cavity is 1.001, the acoustic absorption value of the sample with a 28 mm cavity is 1.035. According to the results, the sample with an 18 cm Cavity shows 9.12% better acoustic absorption performance than the sample without a cavity and 6.04% better than the sample with a 28 mm Cavity. Considering the data, it should be noted that a Cavity can reduce acoustic emission up to a certain point, but after a significant point, the increase in cavity distance causes a decrease in acoustic absorption performance. In the study of Yan et al., it was stated that as the cavity between two MPPs increases, acoustic absorption performance increases. In this current study, instead of two panels, when the distance between the designed new MPP structure and the engine wall increased, the acoustic absorption performance increases, showing the same trend as in the study of Yan et al., but the increase of this cavity reduces the noise absorption values after a point[16]. Also, based on the results, it is understood that by integrating the MPP structures with a cavity into the wheel arch liner used in the vehicles, it can significantly reduce the pass-by noise.

CONCLUSION

Today, noise emission is a problem that the automotive industry focuses on. In this study, the focus is on wheel noise, which is the biggest source of these noise emissions from cars. In the study, perforated and cavity structures were created by considering the wheel arch liner, and the acoustic emission values of these structures were examined. According to the study;

The hole pattern in the MPP structure affects the strength of the structure as well as its acoustic properties. The cross-hole pattern used in the study reduces noise better than the other smooth pattern. It has been stated that the density and diameter of the holes in the created MPP structures also affect the acoustic data. The highest acoustic absorption was observed in structures with holes of 3 mm in diameter and where these holes were located at 7% density under the conditions specified in this article. Within the scope of the study, the space behind the wheel arch liners in MPP structures was also examined. It is observed that the created space reduces the acoustic emission; It is concluded that the increase of this cavity tends to decrease in the acoustic absorption value after a certain level. This is due to an efficiency shift down. With this concept, which aims to reduce pass-by noise by integrating the MPP structure into the wheel arch liner, it is thought that a significant level of sound noise will be reduced. With the positive results of the study, it is strongly recommended to use wheel arch liners with MPP structures in the automotive industry.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

NOMENCLATURE

α	Sound absorption coefficient
V	Cabin volume
S	Sample area
TR	Reverberation time with the sample in the cabin
TR_0	Reference reverberation time without the sample in the cabin
C	the correction coefficient of the cabin

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