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IMPACT WEAR EFFECT ON SOUND ABSORBING PANELS

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Abstract: *Noise pollution has been increasing in the last years which leads to significant interest in the technical solutions used to reduce it. This paper aims to realize the comparative analysis between two prototypes of sound-absorbing panels (one made from a raw material and the other one having a coating of epoxy resin) used in road traffic, subjected to an impact wear. Taking into account that the proposed sound-absorbing panels will be placed along roadways, we took into consideration the possibility that vehicles traveling on the road may throw stones onto the surface of the panels. Regarding the conducted experiment, its purpose was to demonstrate that the layer poured over the raw material provides it greater resistance to impact wear.*

Key words: *impact wear, sound-absorbing panels, impact angle, wear loss, resin coating.*

1. INTRODUCTION

The development of the automotive industry leads to an increase in traffic flow, particularly in large cities and the negative effects do not delay manifesting.

Besides the fact that heavy traffic results in high levels of air pollution, it also causes significant noise. Noise pollution is a widely discussed topic, as it can cause short-term issues such as lack of concentration or restful sleep, as well as long-term problems like hearing loss, cardiovascular accidents, high blood pressure, or even diabetes [1].

To reduce the noise level and create a comfortable environment for the population, authorities in charge of the reduction of noise pollution are planning to use sound-absorbing panels as a solution.

Sound-absorbing panels are devices with great absorption coefficient placed between sources that generate a high level of noise and receptors, especially in busy urban areas with intense car traffic [2]. Residents in residential areas, pedestrians, or individuals relaxing in parks can be protected from noise by these panels, thus ensuring the compliance with current legislation [3].

Regarding the categories of sound-absorbing panels, they are commonly categorized according to the materials used in their construction. These may include acrylic glass panels, reinforced concrete panels, plastic composite panels, metal barriers, and panels crafted from recyclable materials [4][5][6][7].

Simultaneously, these panels need to possess impact resistance since, in heavy traffic conditions, they may be exposed to inadvertent impacts at any moment (such as stones kicked up from the road or collisions with vehicles). These interactions can occur in diverse scenarios. Therefore, the study of impact wear represents also an important step in the design and construction of these panels.

Our paper investigates the wear caused by impact on certain materials utilized in the manufacturing of sound-absorbing panels. The study is conducted in a comparative manner, involving a wooden sample and another sample made of the same material but coated with a layer of epoxy resin.

2. IMPACT WEAR

Impact wear is a phenomenon in which a solid body undergoes damage or changes in its structure due to repeated impact or sudden force applied to it. The causes of this type of wear can include both repetitive blows and abrupt contacts between two or more solid bodies [8].

As for the effects of this type of wear, they can manifest as material cracking, fragmentation, or, in the case of smaller cutting forces, surface modifications that are less profound, such as scratches. Given that there may be confusion between impact wear and erosion wear, we can mention that impact wear, compared to erosion wear, is applicable in situations where we are discussing an instantaneous force, which can be attributed to either repetitive motion or a sudden shock. [9] Impact wear can occur even with a single powerful blow [10]. In some situations, even a single sudden and intense impact can cause significant damage or changes in the structure of a solid body.

Understanding and modeling impact wear are essential for developing effective prevention and maintenance strategies. Numerous models, including both mathematical formulations and simulations, exist in the literature to aid in assessing the response of materials subjected to impact conditions.

Wellinger and Breckel [11] studied the wear loss of different metallic materials using equipment for projectile rigs and hammering. Following the experimental studies, researchers obtained the following semi-empirical relationship:

$$W = KNV^{n_{Wellinger}} \qquad (1)$$

where: W and K are the wear loss (mm^3), respectively wear coefficient, N considers the number of cycles, V represents the impact velocity, (mm/s) and $n_{Wellinger}$ symbolizes the velocity exponent of the impact wear.

Another study [8] analyzes the impact wear for different types of metallic materials using an equipment that includes a pendulum tester with a hardened steel bearing as the impactor. The following relation was developed:

$$W = \frac{KeN}{H_s} \qquad (2)$$

where W, K and N have the same meaning as in relation (1), e signifies the energy of impact (J) and H_s indicates the hardness the softer material hardness (MPa).

Fricke and Allen model determined the wear rates through extensive tests correlated with the impact energy, on a specific material. related to The model relationship was described by the following formula, expressing an empirical power law:

$$W = KNe^{n_{Fricke}} \qquad (3)$$

where: W, K, N, e, have the same connotations as in previous models and n^{Fricke} is an empirical value, experimentally obtained [12].

An impact wear device was used to study the wear loss of a steel plate specimen [13]. The investigation was developed using steel balls as impactor. It was confirmed that the wear loss is influenced by the impact velocity, ball size and impact angle. Based on their studies, they developed the following equation:

$$W = K\,V^{\alpha}R^{\beta}e^{\theta\gamma} \qquad (4)$$

where: wear coefficient is K, α, β, γ are constant parameters, linked to the experiments, V is the velocity of impact (mm/s), R expresses the radius of the ball (mm), θ represents the impact angle. Compared to other studies, this mathematical model does not take into account the number of cycles, which may lead to reduced accuracy compared to other works that consider this variable.

Our paper considers the scenario in which sound-absorbing panels mounted along the road would be subjected to impact wear caused by stones on the road surface, under different angles of incidence. Considering this hypothesis, we can evaluate the wear loss resulting from impacts between panels and stones, using a new model.

The mathematical model is valid for our study which uses samples of wood and resin coated wood with an improved hardness. The model used is able to predict wear loss from impacts at various angles, at normal and sliding ones, simulating the occurrence of extensive wear at smaller impact angles [8].

Most of the time, by reducing the impact angle, a higher tangential force will be obtained, leading to more intense sliding, and potentially resulting in greater material loss. Within the examined mathematical model, the impact angle is characterized as the angle formed between the impactor's direction and the plane of the specimen. This impact angle plays a pivotal role in influencing the wear behavior of ductile and brittle materials.

A greater impact angle leads to increased impact force compared to a sliding impact scenario, making damage more prone to manifest as plastic deformation, along with surface fatigue resulting from cracking or delamination. However, a smaller impact angle implies a higher tangential force, less normal force, thus causing much greater material losses.

The general formula of the proposed model is as follows:

$$W = KNF_n^{n_{ZLS}} + \frac{KNxF_t^{m_{ZLS}}}{H_s} \tag{5}$$

where W (mm³) signifies the quantity of wear loss, K characterizes a normal coefficient for impact wear, N represents the cycles of impact, F_n and F_t (N) represents the normal, respectively the tangential components of impact force, k is the wear coefficient during sliding, x (mm) is the sliding distance, H_s (MPa) denotes the material's hardness, which is of a softer nature and the exponents for normal and sliding impact wear are denoted as n_{ZLS}, respectively m_{ZLS} [8].

3. METHODOLOGY AND EQUIPMENT

Our study is based on the hypothesis that vehicles moving on the roadway, due to their speed, may throw stones from the road onto the sound-absorbing panels surface placed in their proximity. To highlight this idea, we have used an experimental device that helps us project a stone onto the surface of the proposed material at a predetermined angle.

In order to prepare the material for the test, we selected a piece of pine wood (with a length of 100 cm, a width of 20 cm, and a thickness of 2 cm) and applied a layer of approximately 0.5 mm of epoxy resin onto its surface (Fig.1).

First, to pour the epoxy layer we used Izocor I4 type. Izocor I4 is a transparent, two-component epoxy casting resin designed for a wide range of substrates and casting molds, suitable for filling and finishing purposes. The product is manufactured based on synthetic resins and various additives, solvent-free, with an amine curing system that complies with the provisions of the SR EN 1504-5:2005 standard. After we pour the layer onto the surface of the material, we let it dry for 24 hours, in a room with a temperature between 16-18 ºC.

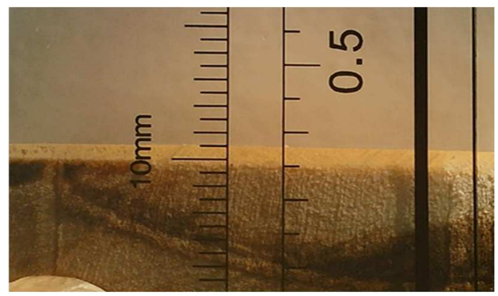


Fig. 1. Epoxy layer

Secondly, in order to implement the initial hypothesis, we chose a random stone that can be found on the road surface, of medium size, weighting 4.358 g. The stone has an irregular geometry, featuring corners and five different surfaces with various roughness.

The experimental device used consists of a manual pneumatic gun capable of reaching a maximum pressure of 8 bars, according to its factory specifications. The sample is placed at 90 cm from the pneumatic gun, and the stone, as you can see in the schematic from Fig. 2. The pneumatic gun was positioned at three different angles (30º, 45º, 60º) for both types of surfaces, thus obtaining a total of six specimens.

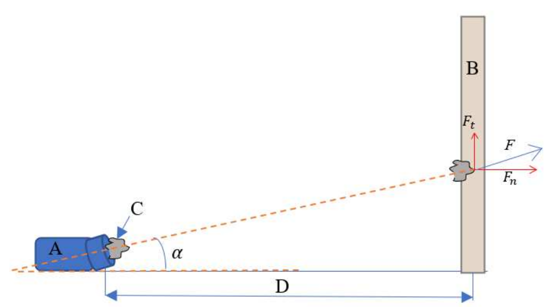


Fig. 2. Schematic of the experimental device (A - pneumatic gun, B - sample, C - stone, α - impact angle, D - distance between the gun and the sample.

Another step that we considered is represented by the experimental determination of the material hardness, both for the raw part and for the part with the epoxy resin coating, using CETR UTM tribometer (Fig. 3)

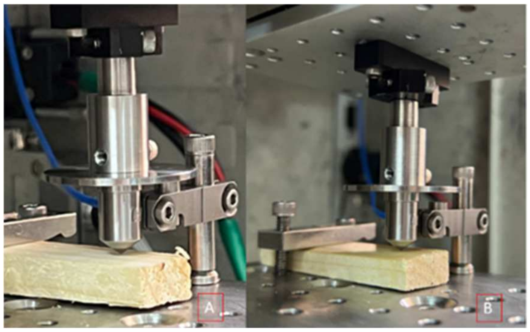


Fig. 3. Measuring the hardness of the sample. Picture A represents the raw material and B represents the material with the poured layer.

4. EXPERIMENTAL RESULTS AND DISCUSSION

To obtain all the necessary data for calculating the wear volume, we experimentally determined the hardness of each material. A force of 4N was applied progressively to the surface of the material. As expected, we observed a significantly higher hardness for the epoxy resin-coated material, as illustrated in the graphs in Fig. 4 and Fig. 5. We obtain a hardness for the raw material of 15.97 MPa and for the material with the layer of resin 92.685 MPa.

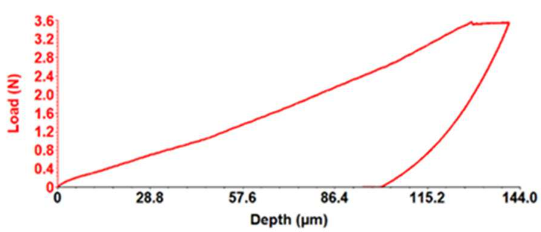


Fig. 4 Micro indentation for raw material

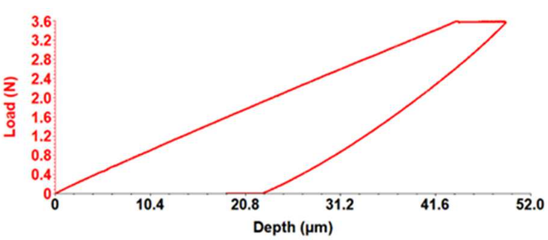
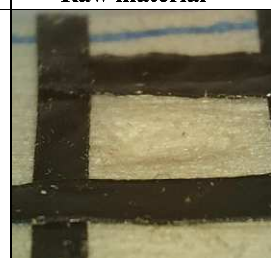


Fig. 5 Micro indentation for raw material with coating

As we already mentioned, we used an experimental device to obtain comparative results between the two types of samples. We started with an impact angle of 30º for both of the surfaces, then 45º and 60º. To obtain a clear view of the material loss, we studied the specimens on a stereomicroscope and the results can be found in Table 1. Initially, we attempted to use SEM analysis to obtain images of material losses, however, given that the chosen material is porous, the results were inconclusive.

Table 1

Material loss observed on a stereomicroscope for each angle of impact

α	Raw material	Epoxy coating
30º		
45º		
60º		

To use the mathematical modeling exemplified by relation 5, we calculated the areas of the surfaces resulting from the impact between the stone and the sample. With the help of the pressure, we applied on the stone, we managed to calculate the force F (graphically represented in Fig. 2).

For accurate results, we considered five possible cases, as the chosen stone has five geometrical surfaces with different areas. Therefore, we obtained a force value for each case, as in Table 2, where A_{Si} (mm^2) represents the area of stone, F_i(N) is the resulting impact force for the specified areas.

Table 2

Result for impact force for the five areas A_{Si}

Case i	A_{Si}	$F_i=P \cdot A_{Si}$
1	168	134.38
2	108	86.38
3	80	63.99
4	200	159.97
5	85	67.99

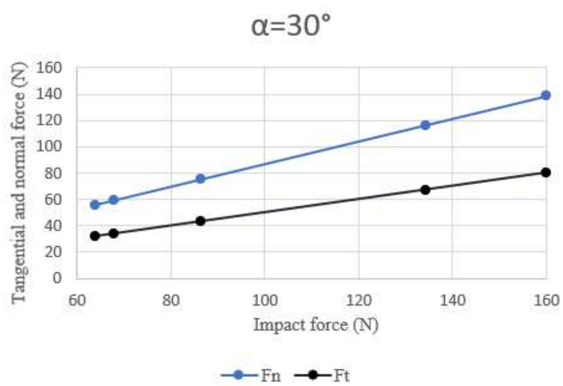


Fig. 6. Normal and tangential force for α=30°

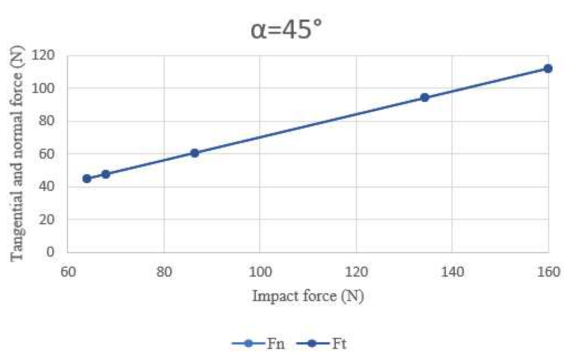


Fig. 7. Normal and tangential force for α=45°

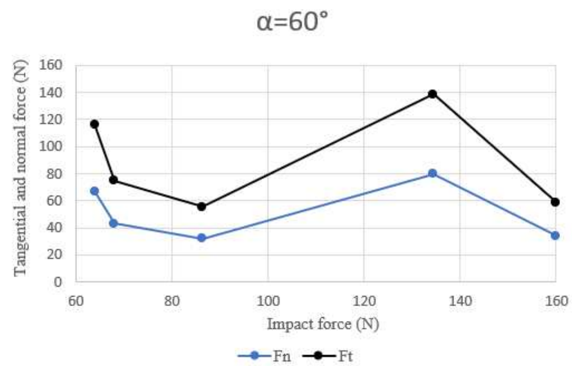


Fig. 8. Normal and tangential force for α=60°

Obtaining the force of impact F, we could calculate its normal component F_n and its tangential force F_t, for each case. Depending on the angle of impact, results can be deduced from the Figs. 6, 7 and 8.

Using a Taylor Hobson profilometer, we obtained results for maximum depth induced on the surface of the impacted material. We generated curves with which we can plot a profile of the crater formed in the sample. Fig. 9 and Fig. 10 show the profiles of these holes in the most conclusive situation when the loss of material is more important.

Fig. 9. Plot profile of the crater made in the sample surface for raw material at α=30°

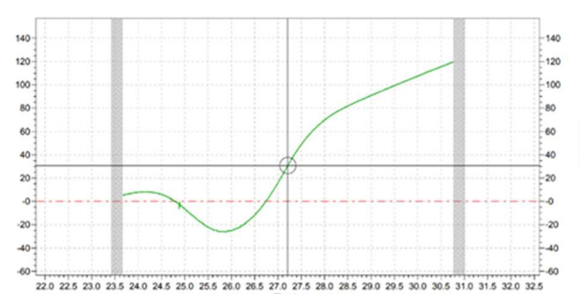


Fig. 10. Plot profile of the crater made in the sample surface for the raw material with an epoxy resin coating at α=30°

By effectively generating a graphical representation of the cavity formed in all our samples, excluding the resin-coated specimen at a 60° angle, we could empirically determine the volume of material lost as a result of the impact.

For the sample above mentioned, it wasn't applicable the material loss determination, due to the absence of a mark on the material surface, as can be observed in Table 1.

In our study we have characterized the friction coefficient as instantaneous. This particular definition of the friction coefficient finds acceptance within the domain of erosive wear, provided there is sliding occurring during impacts [13]. It is empirically estimated as being 0.19 for raw material and 0.31 for the material with coating.

To deduce the two exponents, n_{ZLS} and m_{ZLS}, necessary for our cases, we matched equation 5 with the experimentally obtained results, both for the base material and for the coated material, and obtained the results presented in the Table 3.

Table 3

Results for exponents n_{ZLS} and m_{ZLS}.

	Raw material	**Resin coating**
n_{ZLS}	0.45	-1.5
m_{ZLS}	-1	1

Determining the two exponents for each type of specimens, we calculated the volume loss due to the wear impact. We did the calculation for all samples, taking into consideration the five different cases for each area of the stone, resulting five cases for each angle, for both of the materials.

Applying relation 5, we managed to obtain the results shown in Table 4 and Table 5, where W_{RMi}(mm^3) is the wear loss for raw material and W_{RCi}(mm^3) represents the material loss for resin coating.

Table 4

Impact wear loss calculated for raw material

	W_{RMi}		
	30°	45°	60°
F_1	1.61	1.46	1.26
A_{S2}	1.32	1.20	1.03
A_{S3}	1.15	1.05	**0.90**
A_{S4}	**1.74**	**1.58**	1.36
A_{S5}	1.19	1.08	0.92

Table 5

Impact wear loss calculated for resin coating

	W_{RCi}		
α	30°	45°	60°
A_{s1}	0.22	0.157	0.00056
A_{s2}	**0.14**	0.101	0.00109
A_{s3}	0.10	0.075	0.00171
A_{s4}	0.26	0.187	0.00043
A_{s5}	0.11	**0.080**	0.00156

With the result shown in Table 4 and Table 5 we conclude which area of the stone impacts our sample, by fitting the calculated results with the ones we obtained experimentally, shown in Table 6. W_e(mm^3) represents the wear loss derived experimentally.

Table 6

Experimental results of the wear loss, depending on the angle of impact

	W_e	
α	**Raw material**	**Resin coating**
30°	1.8	0.137
45°	1.57	0.088
60°	0.7	0

In terms of the objective of this paper, the comparative study between a base material and the same material with epoxy resin coating, both the experimental results and those derived from calculations can be observed in Fig. 11. At a 60° impact angle, the material with resin coating doesn't suffer any visible damage, as results indicate. For 30° and 45° the specimen with coating has minor visible damages, but compared with the raw material, much smaller.

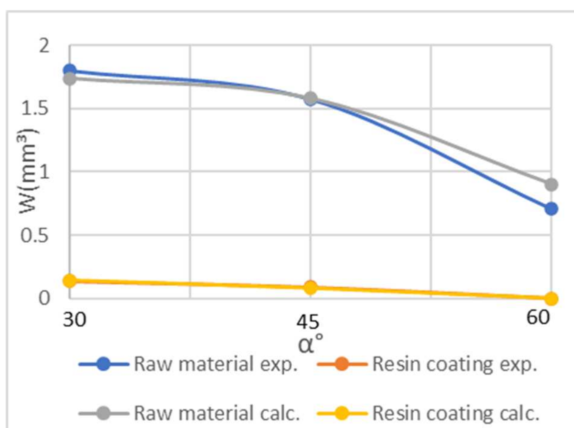


Fig. 11. Analyze of experimental and calculated results of wear loss for both materials, depending on the impact angle

5. CONCLUSIONS

Regarding impact wear, both from a theoretical and practical perspective, it can lead to substantial material losses. Regarding sound-absorbing panels and their applicability, impact wear can indeed be a contributing factor to their deterioration. As a first conclusion, considering our initial hypothesis, we can summarize that a phono absorbent panel, placed in the proximity of a roadway, could suffer damage due to the impact wear of projected stones. Our experiments showed that the angle of impact is an important factor to determine the wear loss. Placed at the same distance of the panel, having the same pressure of the projectile gun, we obtained different volumes of the material loss for the angles we considered. If the angle is increasing, the quantity of material wear is shrinks. Comparing the two types of samples used, the one made from raw material and the other one made from the same material, but with an epoxy resin coating, the results are showing great improvements of the material hardness and resistance during wear impact process. This result leads to a second conclusion, specifically represented by the fact that the material with coating has greater properties and, during impact, suffers evidently lower damage compared to the raw material. Considering the prototype price (between 6-10€/m^2), for long term exposure of the panels, a resin coating will be more profitable for the production of it.

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Uzura de impact asupra panourilor fonoabsorbante

Datorită creșterii poluării fonice în ultimii ani și impactului semnificativ asupra sănătății populației, există un interes considerabil în soluțiile tehnice pentru reducerea acestui fenomen. Acest articol se concentrează pe o analiză comparativă între două prototipuri de panouri fonoabsorbante supuse uzurii de impact, utilizate în traficul rutier. Având în vedere că panourile propuse pentru absorbția sunetului au scopul de a reduce zgomotul produs de trafic, am luat în considerare posibilitatea ca vehiculele să arunce pietre pe suprafața acestora. Bazându-ne pe această presupunere, am investigat uzura de impact între piatră și panoul fonoabsorbant, efectuând studiul atât teoretic, cât și experimental. În partea teoretică, am utilizat un model matematic pentru a analiza uzura de impact între două corpuri solide, sub influența unor unghiuri specifice. Am luat în considerare contactul realizat prin forța de impact, furnizând date privind pierderea de volum cauzată de uzură. În partea experimentală, am utilizat două eșantioane, unul dintr-un material brut și celălalt cu acoperire. Materialul brut ales are proprietăți bune de absorbție a sunetului, oferind o soluție relevantă pentru crearea de prototipuri de panouri fonoabsorbante. În ceea ce privește materialul compozit, am realizat un eșantion utilizând materialul brut, aplicând un strat de rășină epoxidică pentru a-l proteja în cazul uzurii de impact. Experimentul are ca scop demonstrarea că stratul de rășină aplicat conferă materialului brut o rezistență sporită la uzura de impact. Atât modelarea matematică, cât și partea experimentală sugerează că eficiența panourilor fonoabsorbante poate fi îmbunătățită, iar utilizarea acoperirii de rășină epoxidică poate genera un prototip cu performanțe notabile în ceea ce privește duritatea materialului și rezistența la impacturi accidentale.

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