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The influence of adding rubber recyclate to laminated composites on the insulation from impact sounds

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Abstract This paper examines how the manufacturing technology of composite materials influences the insulation parameters against impact sound and the capability to dampen structural vibrations. This is achieved by modifying the composite material's structure through the addition of rubber recyclate. Acoustic insulation tests were conducted on a sandwich composite made from Epidian® 6 epoxy resin, combined with Z-1 hardener, and a randomly arranged glass mat with a density of 350 g/m^2. Rubber recyclate, obtained from the disposal process of car tires, was used as a damping-enhancing additive. The composite materials were fabricated using the hand lamination technique and tested in three configurations, varying the number of sandwich layers containing recyclate: one, two, and three layers. Field tests were conducted under "in-situ" conditions to measure the reduction of impact sound levels. The setup compared a structure comprising a "concrete slab + composite slab + ceiling" to a reference structure of "concrete slab + ceiling." The parameter $\Delta L'_n$ was determined in accordance with PN-EN ISO 16283-2 and PN-EN ISO 717-2 standards. Additionally, the reduction of impact sound levels in a ceiling fitted with the composite plate was compared to a ceiling without it, also conforming to PN-EN ISO 16283-2 and PN-EN ISO 717-2 standards. The results indicate a significant decrease in impact sound levels for the composite board with three sandwich layers compared to a composite board without rubber recyclate. This demonstrates the effectiveness of rubber recyclate additives in attenuating structural sounds. The integration of rubber recyclate, sourced from car tire disposal, not only enhances acoustic performance but also contributes to environmental protection efforts.

Keywords: sound insulation, structural born sound, composite materials, rubber recyclate.

1. Introduction

Impact sound insulation refers to the ability of a material or structure to limit the penetration of sounds generated by impacts, vibrations or mechanical impulses [1, 2]. To improve the sound insulation from the impact sounds of the material, cushioning layers can be used between structural materials. These additional layers can reduce the transmission of impact sounds by absorbing energy and dissipating vibrations. This is often used in sandwich composites, which include polyester-glass composites. The material used as a modifier can be rubber recyclate, a derivative of rubber waste with good sound insulation properties.

One effective modifier for such applications is rubber recyclate, a by-product of rubber waste known for its excellent sound insulation properties. In Poland alone, approximately 150,000 tons of car tires are removed from use annually, creating a significant amount of non-degradable waste [3, 4]. While legal regulations mandate an increase in rubber waste recycling, its utilization remains significantly lower compared to materials like metals, glass, and paper. A readily available form of this waste is ground rubber, or rubber recyclate, which can be employed as a filler in the creation of new composite materials.

Current research emphasizes the development of composites enriched with recycled rubber from used tires [5–7]. The integration of rubber waste into glass fiber-based composites enhances both mechanical and physical properties [6, 8, 9]. Such composites, modified with rubber fillers, show promise for a variety of applications [7, 10, 11], particularly where high strength and impact resistance are crucial [3, 12, 13]. Studies have highlighted that fibrous composites, used in multilayer laminate engineering structures, are notably sensitive to shock loads [14].

For sandwich composites, incorporating additional damping layers can positively influence sound insulation performance [14–16] Literature documents various investigations into the acoustic insulation properties of composites modified with different substances and materials [17, 18]. Adding rubber recyclate to a fiberglass and epoxy resin-based composite enhances its ability to absorb sound energy from impacts. Given that fiberglass is inherently rigid and exhibits limited sound-damping capabilities, the inclusion of a flexible material like rubber can significantly improve its performance by mitigating these low-damping characteristics.

This article presents research focused on evaluating the impact of modifying sandwich composites with rubber recyclate, and the effect of its distribution within the composite layers, on acoustic insulation from impact sounds. The goal of the research and analysis was to identify the composite variant that demonstrates optimal impact sound insulation properties.

2. Description of test material and test methodology

2.1. Material manufacturing technology

The research materials were developed from EM 1002/300/125 construction glass mat, weighing 350 g/m^2 and with a random arrangement of fibres. This glass mat is made of cut strands of glass fibre, glued together with an emulsion binder. Epoxy resin Epidian®6 together with Z-1 hardener was used as the matrix of the composite. The detailed composition of the glass mat and epoxy resin is presented in Tables 1-2. The composite test plates were made by manual lamination with the use of constant double-sided pressure in all variants. A steel rectangular mould with dimensions of 900 x 900 mm, brushes and rollers were used for lamination.

Table 1. Properties of glass mat EM 1002/300/125.

Parameter	Description
Glass Type	E
Nominal Diameter of Monofilament	12 μm
Linear mass of the band	30 tex
Nominal length of strand segments	50 mm
Binders	Emulsion
Surface Weight	Gramature 300 g/m^2

Table 2. Characteristics of epoxy resin Epidian®6.

Parameter	Unit	Value
Epoxy number	[Mole/100g]	0.510-0.540
Density at 25°C	[g/cm^3]	1.17
Viscosity at 25°C	[mPa·s]	1000-1500
Gel time 100 g at 20°C	[min]	20
Curing time at 20°C	[days]	7

The reference material used for comparison with other composite variants was the K0 composite, which did not contain any rubber recyclate. The K0 composite was composed of 12 layers of glass mat, each impregnated with Epidian® 6 resin, mixed in a fixed ratio with the Z-1 hardener. In all composite samples, the hardener was added at a concentration of 13 g per 100 g of the matrix. The glass mat constituted 40% of the total weight of the K0 material.

Using selected materials and a specified fraction of rubber recyclate with a grain size ranging from 0.5 mm to 1.5 mm, three different variants of research materials were produced. Each composite contained a consistent 5% addition of rubber recyclate, differing only in how the recyclate was distributed between the composite layers. These material variants were labeled as K1, K2, and K3. The details of the lamination process and the arrangement of the rubber recyclate in the composites are provided in Table 3 and illustrated in Figures 1 and 2.

Table 3. Characteristics of the composition of research materials.

Composite designation	Method of decomposition of recyclate layers	Number of layers of mat	Resin content [%]	Recyclate content [%]
K0	lack	12	60%	0%
K1	1 layer	12	55%	5%
K2	2 layers	12	55%	5%
K3	3 layers	12	55%	5%

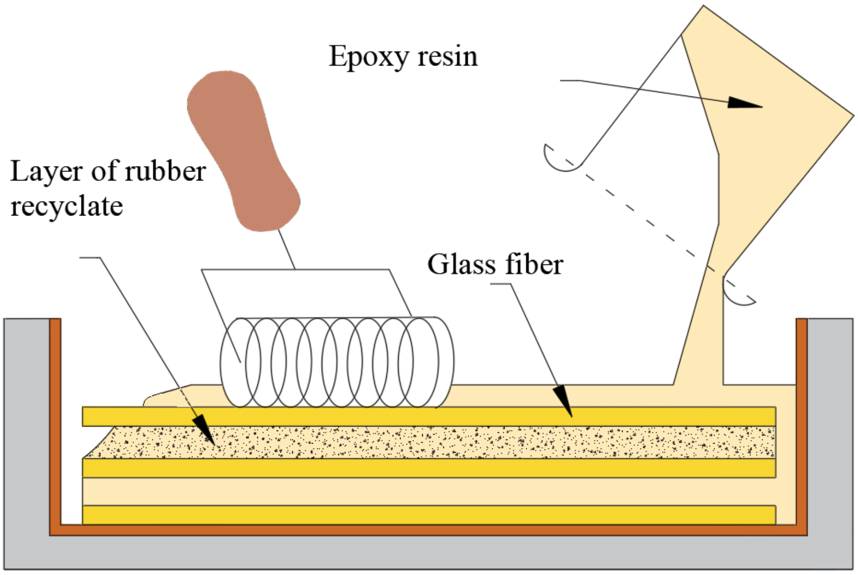

Figure 1. Fabrication of research materials by hand lamination.

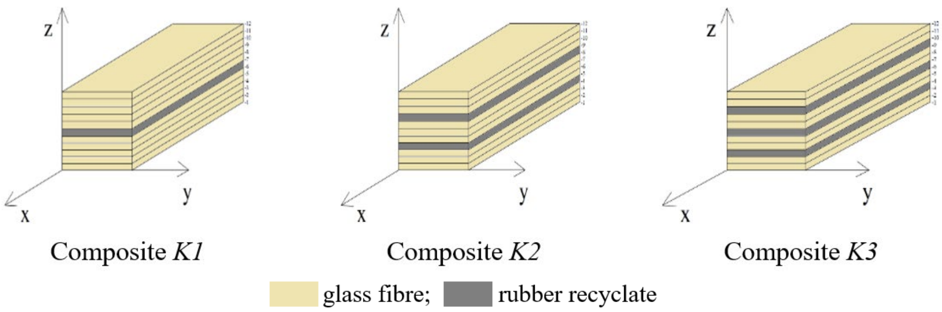

Figure 2. Scheme of the arrangement of rubber recyclate layers in *K1*, *K2*, and *K3* composites.

2.2. Properties of the rubber recyclate used

Orzel-Base rubber recyclate derived from processed car tyres with a grain size of 0-3 mm was used for the study [19]. The recyclate was pre-sieved using the LAB 11-200 laboratory sieve shaker from EKOLAB to precisely separate its various fractions. As an addition to the matrix of composites, a recyclate fraction with a grain size from 0.5 mm to 1.5 mm was used. The percentage composition and physicochemical parameters of the rubber recyclate used in the tested materials are presented in Tables 4 and 5.

Table 4. The chemical composition that of the granules obtained in the recycling process does not differ from of the tyre tread.

Ingredient	Content [%]
Natural rubber	15
SBR (styrene-butadiene rubber):	20
BR (butadiene rubber):	10
IIR/XIIR (butyl and halogenated-butyl rubber):	5
Silica	15
Soot	15
Sulphur	2
Resin	2
Mineral and vegetable oils	10
Other (Zinc oxide, stearic acid)	6

Table 5. Physical and chemical properties of rubber recyclate used in materials.

Parameter	Value
Density	360-370kg/m^3
Flash point	>350 ^{o}C
Thermal decomposition	>180 ^{o}C

To determine the impact of the amount of rubber recyclate used in laminated composites on mechanical strength properties, two criteria were adopted. The first criterion involved a random distribution of recyclate across all layers of the composite in amounts of 3%, 5%, 7%, and a control sample with 0% recyclate. Strength tests clearly demonstrated a decrease in mechanical strength parameters as the percentage of recyclate in the composite increased.

In the second case, a constant 5% addition of recyclate was used in the composite, with the variable parameter being the number of layers containing recyclate: "K1", "K2" and "K3". This scenario also showed a reduction in the mechanical strength parameters obtained from static tensile tests as the recyclate content increased. However, the use of discrete layers resulted in higher mechanical property values compared to the variants from the first criterion. Specifically, tests with two layers of recyclate produced superior mechanical parameters in impact testing compared to all other variants, including the control sample with 0% recyclate.

The research findings indicate that the maximum amount of recyclate that can be used in the composite to produce a stable, non-delaminating material is 15% when using the hand lamination method.

2.3. Mechanical properties of materials used in yacht construction

In larger motor sea yachts, which have more powerful drives, to reduce noise and vibrations, vibration isolators, multilayer plating, silencers, susceptible elements, and materials characterized by increased vibration damping coefficient, i.e. lower dynamic stiffness are commonly used [20–22]. These systems dissipate vibration energy or partially store it. A very popular and inexpensive solution is the use of sound insulation enclosures for drive systems, mainly the engine and auxiliary units. The multilayer wall bulkheads used should be characterized by high acoustic vibration insulation, i.e. acoustic insulation from air and impact sounds. Proper selection of the material and its parameters is related to the selection of appropriate damping properties and is associated with the dissipation of mechanical energy converted, for example, into thermal energy. Such effects can be obtained by structural and parametric modification of the material, which can be obtained, for example, by introducing additional modifiers into the structure in the form of rubber recyclate, disturbing the continuity of the structure, and consequently obtaining vibroacoustic properties. All guidelines relating to the design of hulls from laminate materials are described in the PRS (Polish Register of Shipping) [23].

2.4. Vibroacoustic tests of sound insulation from impact sounds

Impact sound is characterized by the fact that once it is introduced into the structure of the material, it is transmitted even over very long distances. The best protection in this case is vibration isolation from vibration sources of machines and devices, through the use of materials with damping properties, i.e. hindering the propagation of energy over long distances. One of the materials can be mats, which are successfully used, among others for insulation of buildings, foundations of machines and devices, i.e. between vibration sources with planes to which the source of vibration is attached.

To demonstrate the influence of the technology of composite material production using vacuum infusion on the improvement of the insulation parameter from impact sounds and the ability to dampen structural vibrations by modifying the structure of the composite material with the addition of rubber recyclate, appropriate laboratory tests were carried out.

A well-known method was used in the standards for performing insulation tests for impact sounds. Because the samples made by the laboratory method showed a small surface area, an appropriate methodology was selected for scientific and cognitive purposes, taking into account the laboratory facilities. The research methodology was developed considering the research standard for insulation measurements from impact sounds in "in-situ" conditions, according to the no. PN-EN ISO 16283-2 [24].

When the impact source is the tapping machine, normalized impact sound pressure level L'_n, increased by a correction term that is given in decibels, being ten times the common logarithm of the ratio between the measured equivalent absorption area, A, of the receiving room and the reference equivalent absorption area, A_0, which is calculated using the formula:

$$L'_n = L_i + 10lg\frac{A}{A_0}, \tag{1}$$

where L_i is average sound pressure level in the receiving room (under the ceiling), A is the equivalent absorption area in the receiving room, A_0 the reference equivalent absorption area.

A - hypothetical area of an absorbing surface without diffraction effects which, if it were the only absorbing element in the room would give the same reverberation time as the room under consideration and is calculated using Sabine's formula in the formula:

$$A = \frac{0{,}16 \cdot V}{T}, \tag{2}$$

where V is the receiving room volume, T is the reverberation time in the receiving room.

The standardized impact level depends both on the floor structure and on the acoustic parameters of the ceiling on which the floor was laid. The same floor arrangement used on different ceilings may have different acoustic performances. For this reason, it is assumed that the acoustic parameters of floors are determined by measurements relating to the floor laid on the standard ceiling, and the basic parameter of sound insulation from impact sounds in the case of floors is the reduction of the impact level L. A simplified method of converting these values in indicator form was used for floors laid on any massive ceiling. According to the PN-EN IS0140-8:1999 [25] standard, the reduction of the impact level by the standard ceiling as a result of the use of an additional floor layer is determined from the dependencies ΔL:

$$\Delta L = L_{n0} - L_n \tag{3}$$

where ΔL is impact level reduction, L_{n0} – normalized impact level of the reference floor, L_n – standardized impact sound pressure level of the reference ceiling with the floor.

As a receiving chamber, a reverberation chamber was used to measure sound power with a volume of V = 200 m^3. For the reference alloy, the reinforced concrete ceiling of the reverberation chamber is used, with a prepared horizontal concrete screed for the assembly of the tested laminates. As the sound source, a standardized hammer taper from Bruel & Kjaer type 3204 was used. A photo of the laminate test stand on the chamber ceiling is shown in Figure 3.

Figure 3. Stand for testing laminates on the ceiling of the reverberation chamber.

Reverberation chamber is vibroisolated from the floor of the hall and the ground, it has a door with high acoustic insulation from air sounds at the level of $R_w \sim 49$ [dB], therefore only sounds coming from the ceiling and walls of the chamber itself reach the chamber. A diagram of the entire station is shown in Figure 4.

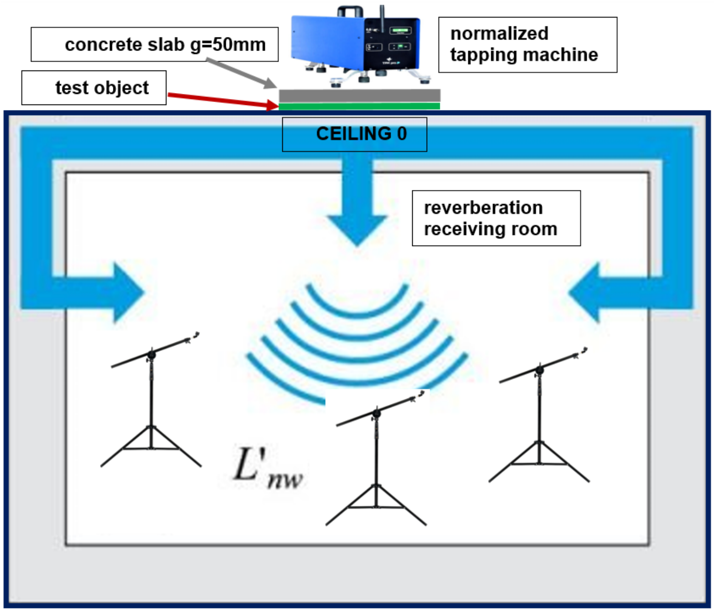

Figure 4. Diagram of the test bench.

To determine the effectiveness of isolating the tested composites against impact sounds, the impact sound insulation result of the 'reference ceiling connected to the 50 mm concrete slab' system was subtracted from the impact sound insulation result of the "reference ceiling, tested composite slab with rubber recyclate connected to a 50 mm thick concrete slab" system, according to the diagram in Fig. 4.

Due to the fact that the tests were not carried out in a specialized laboratory station without flanking sound transmission, but in conditions of a reverberation chamber adapted for air-borne sound transmission tests, the methodology was used as "in-situ" conditions, which involves determining the parameter L'_n [dB].

A single-digit weighted test result, determined in accordance with the PN-EN ISO 717-2 standard, is marked with the symbol $L'_{n,w}$ [dB] [26] The result of the tested composites was given as the difference in impact level and was marked with the symbol $\Delta L'_{,n}$ [dB]. The results for all the samples tested are summarized in Figures 5-8.

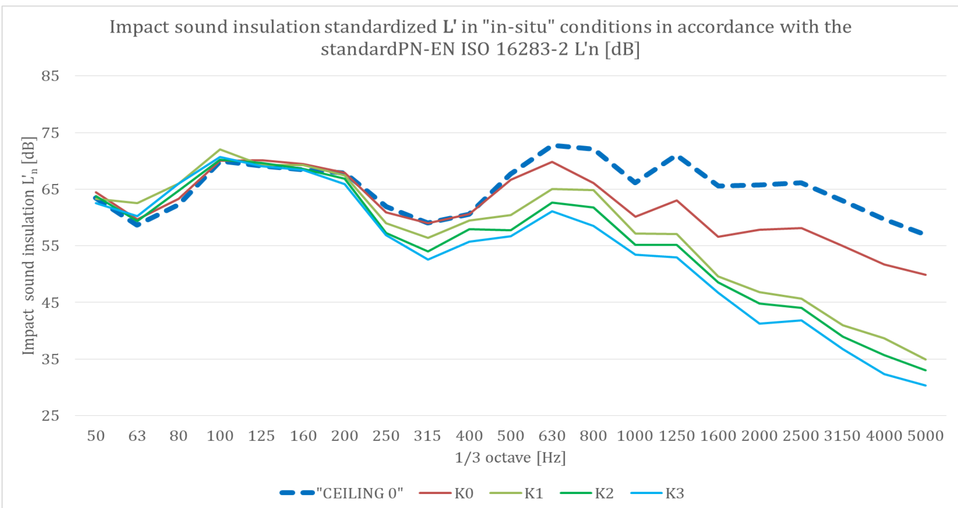

Figure 5. Spectrum impact sound insulation as a function of the frequency of composite materials with "ceiling 0".

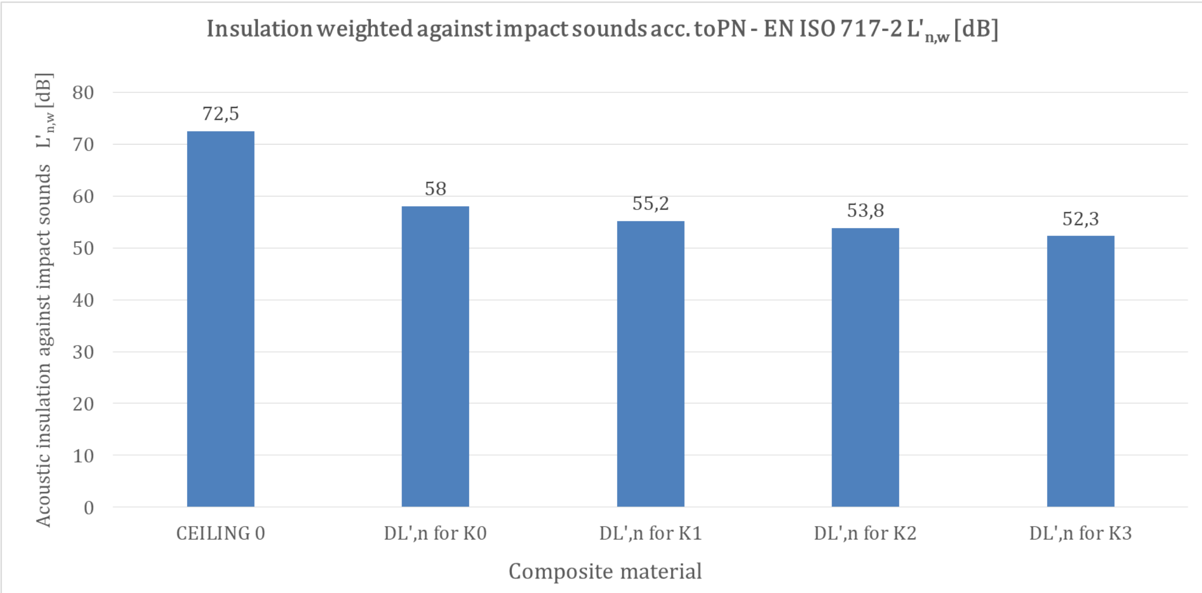

Figure 6. Impact sound insulation $L'_{n,w}$ with "ceiling 0".

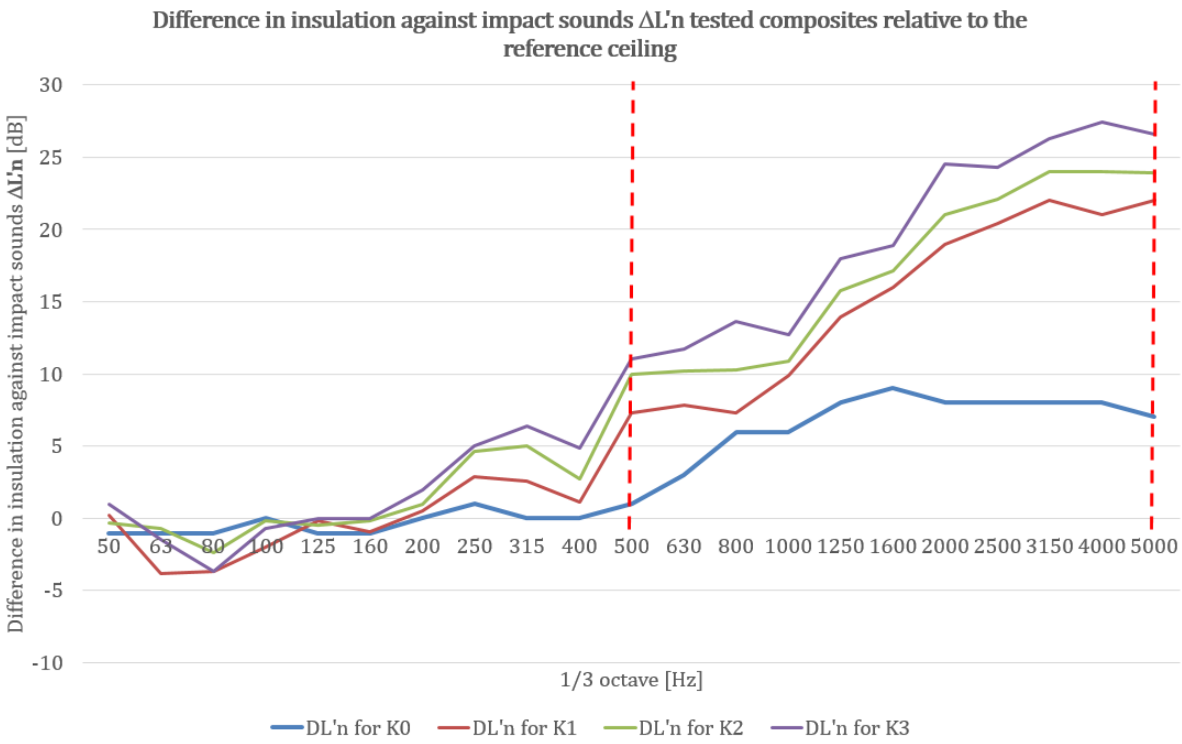

Figure 7. The spectrum of the difference in impact sound insulation as a function of the frequency of the tested composite mats without the base "ceiling 0", only from the tested composites.

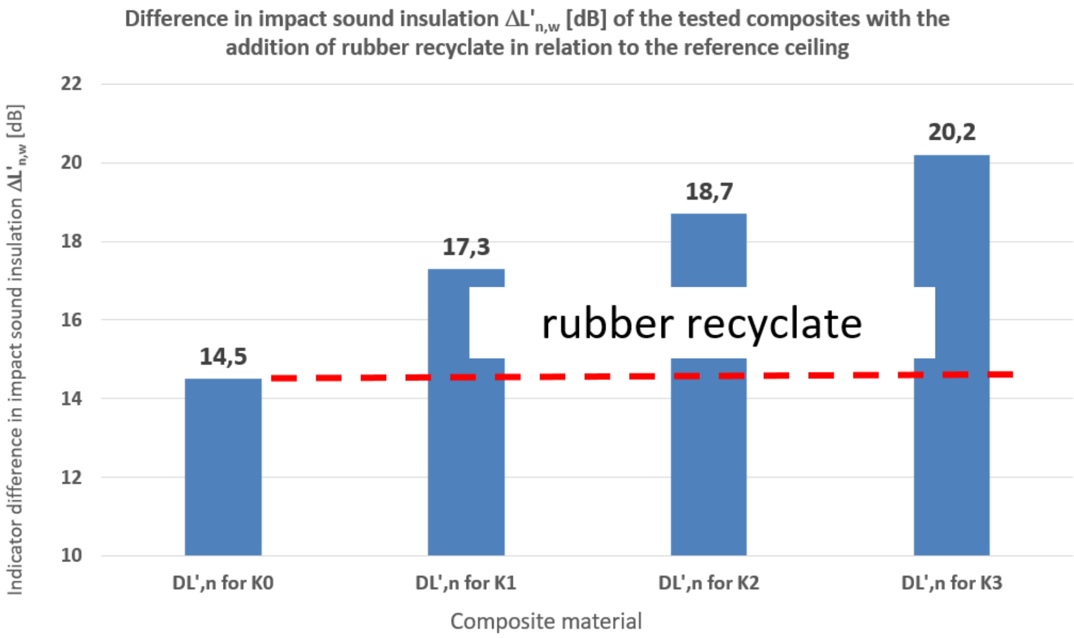

Figure 8. Reduction in impact sound pressure level measured $\Delta L'_{n,w}$ [dB] of the tested composites with the addition of rubber recyclate $L'_{n,w}$, without the base "ceiling 0".

3. Conclusions

An innovative method of producing composites using both infusion and vacuum for the production of glass or carbon fibre composites was developed and applied, enabling the introduction of additives into the mould, and obtaining uniform distribution of composite structure components.

The conducted research shows that the tested epoxy glass composites with the addition of rubber recyclate as layers of spacers made by hand lamination method, show good insulation from impact sounds, and for the composite K3 the result $\Delta L'_{n,w}$ = 20.2 [dB] was obtained. Composites can also be used as an additional layer in concrete floor structures.

The highest impact sound insulation efficiency occurs in the frequency range from 500 – 5000 [Hz] for K3 composite, which resulted in a reduction of the impact sound level $\Delta L'_n$ in the receiving chamber by 8 – 20 [dB]. The influence of recycled rubber additives on the ability to increase acoustic insulation against impact sounds was determined and for the K3 composite board it is $\Delta L'_n$ = 5.7[dB], (Fig. 8).

Composites in the form of boards can be successfully used in the design of all enclosures and shields aimed at separation from spaces with noise, vibration or other oppressive environmental conditions. in terms of acoustic insulation against airborne sounds was achieved improvement at the level of $\Delta L_{eq} \sim 20$ [dB]. Composites are also characterized by good mechanical properties, which classify the composite as a structural material. Composites are often used in the construction of yachts and boats, and after analyzing the current PRS regulations, the tested composites in combination with the properties of good insulation from impact sounds and vibration damping, are a good material that can be used in the shipbuilding industry.

The use of rubber recyclate obtained in the process of utilization of car tyres has an impact on improving environmental protection through the reuse of secondary raw materials.

The innovative technology of manufacturing composites using vacuum infusion and by hand lamination for the production of glass or carbon fibre elements enables further development of composites through the use of other additives/modifiers that affect the achievement of new physical properties of composites.

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. L. Dulak, A. Nowoświat; Izolacyjność akustyczna–parametry i wskaźniki; Izolacje, 2016, 21(2), 56–63
2. L. Nowotny; Izolacyjność akustyczna stropu o lekkiej konstrukcji nośnej; Materiały Budowlane (in Polish); ITB, 2021, 15
3. A. Naimušin, T. Januševičius; Development and Research of Recyclable Composite Metamaterial Structures Made of Plastic and Rubber Waste to Reduce Indoor Noise and Reverberation; Sustainability, 2023, 15(2), 1731
4. A. Fazli, D. Rodrigue; Waste rubber recycling: A review on the evolution and properties of thermoplastic elastomers; Materials, 2020, 13(3), 782
5. M. Al-Shablle, M. Al-Waily, E. Njim; Analytical evaluation of the influence of adding rubber layers on free vibration of sandwich structure with the presence of nano-reinforced composite skins; Archives of Materials Science and Engineering, 2022, 116(2), 57–70; DOI: 10.5604/01.3001.0016.1190
6. M. Allouch, M. Kamoun, J. Mars, M. Wali, F. Dammak; Experimental investigation on the mechanical behavior of recycled rubber reinforced polymer composites filled with aluminum powder; Construction and Building Materials, 2020, 259, 119845; DOI: 10.1016/j.conbuildmat.2020.119845
7. M. Dadfar, F. Ghadami; Effect of rubber modification on fracture toughness properties of glass reinforced hot cured epoxy composites; Materials & Design, 2013, 47, 16–20
8. B. Dębska, L. Lichołai, P. Miąsik; Assessment of the Applicability of Sustainable Epoxy Composites Containing Waste Rubber Aggregates in Buildings, Buildings, 2019, 9(2), 31; DOI: 10.3390/buildings9020031
9. A.Hejna, J. Korol, M. Przybysz-Romatowska, Ł. Zedler, B. Chmielnicki, K. Formela; Waste tire rubber as low-cost and environmentally-friendly modifier in thermoset polymers – A review; Waste Management, 2020, 108, 106–118; DOI: 10.1016/j.wasman.2020.04.032
10. B. Grynkiewicz-Bylina, B. Rakwic, B. Słomka-Słupik; Tests of rubber granules used as artificial turf for football fields in terms of toxicity to human health and the environment; Scientific Reports, 2022, 12(1), 6683; DOI: 10.1038/s41598-022-10691-1
11. D. Żuk, N. Abramczyk, K. Panasiuk; Analysis of strength parameters at tension of epoxy-glass composites with rubber recyclate addition; Journal of KONBiN, 2022, 52(1), 131–150
12. N. H. Bhingare, S. Prakash, V. S. Jatti, A review on natural and waste material composite as acoustic material; Polymer Testing, 2019, 80, 106142
13. F. C. Cabrera; Eco-friendly polymer composites: A review of suitable methods for waste management; Polymer Composites, 2021, 42(6), 2653–2677
14. B. Marques et al.; Vibro-acoustic behaviour of polymer-based composite materials produced with rice husk and recycled rubber granules; Construction and Building Materials, 2020, 264, 120221
15. R. M. Salih; Study of heat and sound insulation for polymeric composites reinforced with nano clay; Polymers and Polymer Composites, 2021, 29(9), S1216–S1226
16. X. Yang, S. Tang, X. Shen, W. Peng; Research on the Sound Insulation Performance of Composite Rubber Reinforced with Hollow Glass Microsphere Based on Acoustic Finite Element Simulation, Polymers, 2023, 15(3), 611
17. S. Benin, S. Kannan, R. J. Bright, A. J. Moses; A review on mechanical characterization of polymer matrix composites & its effects reinforced with various natural fibres; Materials Today: Proceedings, 2020, 33, 798–805
18. D. Dissanayake, D. Weerasinghe, L. Thebuwanage, U. Bandara; An environmentally friendly sound insulation material from post-industrial textile waste and natural rubber; Journal of Building Engineering, 2021, 33, 101606
19. URL: https://orzelsa.com/wp-content/uploads/2020/10/Karta-techniczna-1-3-mm.pdf (accessed on 2025.05.31)
20. W. Oleksiewicz, A. Zbiciak, C. Kraśkiewicz, C. Lipko; Parameters characterizing vibration insulation under-panel mats used in the construction of railways and methods of their examination; Scientific and Technical Notebooks of SITK RP, Branch in Krakow, 2015, 2(106)
21. J. Gardulski; Vibroacoustic protection of the crew of motor sea yachts with a stationary engine; 1-2008 rational Problems 161, Polish Naval Academy, 2011, 18(3)

22. P. Tomczyk; Measurement of dynamic stiffness of the anti-vibration layer as an element of acoustic assessment of floating floors; Building Research Institute - Quarterly, 2005, 4(136), 53-65
23. Polish Register of Shipping, RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF SEA-GOING YACHTS, PART II HULL, July 1996, Chapter 4.4, 15
URL: https://prs.pl/wp-content/uploads/jac_p2.pdf (accessed on 2025.05.31)
24. PN-EN ISO 16283-2:2021-02; Field measurements of sound insulation in buildings and acoustic insulation of building elements - Part 2: Impact sound insulation; PKN, 2021, chapter 3, 4
25. PN-EN ISO 140-8; Measurement of acoustic insulation in buildings and acoustic insulation of building elements - Laboratory measurements of impact sound attenuation by floors on a massive reference ceiling, PKN, 1999, chapter 3, 5
26. PN-EN ISO 717-2:2021-06; Assessment of sound insulation in buildings and sound insulation of building elements - Part 2: Impact sound insulation, PKN, 2021, chapter 4.4, 5