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Tests of acoustic insulation of multilayer composite modified with rubber recyclate

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Abstract The paper presents acoustic studies of a multilayer composite made based on Synolite 1967-G-1 polyester resin and glass fabric with a three-way arrangement of +/-45° fibres, Triaxial type and a weight of 860 g/m². As an addition, rubber recyclate created in the process of disposal of car tires was used. The material was made using the vacuum infusion method. By the vacuum lamination method, composite materials were produced in the form of plates with the addition of rubber recyclate in four variants of the amount of recyclate used in the produced composite – 20%, 30%, 40% and 50%. Each variant contained 6 layers of fabric and five layers of rubber recyclate. The samples were tested in the vibroacoustic laboratory on a dedicated measuring station of a set of reverberation chambers without flanking transmission, in which the specific acoustic insulation Rw was determined following PN-EN ISO 10140-2 and related standards, i.e. PN-EN ISO 10140-1, PN-EN ISO 10140-2, PN-EN ISO 10140-4, PN-EN ISO 10140-5 and PN EN ISO 717-1. All manufactured variants of the composite material with the addition of rubber recyclate were characterized by acoustic insulation in the range of R_w = (30.0 ÷ 35.7) dB.

High sound insulation parameters for tested panels up to 12 mm thick act as a barrier to counteracting the spread of unwanted airborne noise. Combined with good mechanical properties such as tensile strength, toughness and hardness, they form the basis for the easy design of all shields in many industries. The use of rubber recyclate obtained in the process of disposal of car tires has a positive impact on improving environmental protection.

Keywords: acoustic insulation, polyester-glass composites, rubber recyclate.

1. Introduction

Acoustic insulation is a parameter determining how well a building structure isolates a room from noise coming from other rooms or the environment. Insulation from air sounds applies, for example, to walls and ceilings [1].

The measure of sound insulation is the difference in airborn sound pressure levels measured in front of and behind the partition, taking into account the surface area of the sample and the reverberation conditions of the receiving room. Specific acoustic insulation, determined in the acoustic laboratory without flanking transmission [2], is described by the following relationship [3]:

$$R = L_1 - L_2 + 10\, lg\left(\frac{S}{A}\right) \text{ [dB]} \tag{1}$$

where: L_1 – energy average sound pressure level in the source room, [dB], L_2 – energy average sound pressure level in the receiving room, [dB], S – area of the free test opening in which the test element is installed, [m²], $A=0,161\ V/T$ is the acoustic absorption of the receiving room, [m²], V- is the receiving room volume, [m³], T- is the reverberation time of the receiving room [s].

The sound insulation of glass composites depends on several factors, such as the density and structure of the fibres, the type and properties of the resins used and the construction of the composite [4-5]. Properly designed glass composite can act as a barrier to sound waves, reducing the penetration of sound from one medium to another [6]. Acoustic insulation of glass fibre-based composites is one of the important parameters to be taken into account when assessing their effectiveness in noise reduction [7]. Polyester-glass composites modified with various additives can have the potential to provide good sound insulation in a variety of applications.

Conducting sound insulation tests enables us to measure the effectiveness of composite materials in blocking out noise. These tests assist in evaluating the material's ability to reduce sound and determine its suitability for different purposes.

To enhance the sound insulation, rubber recyclate was incorporated into the fibreglass-based composite. This is because rubber possesses vibration damping qualities as a material. The rubber recyclate present in the composite can function as an extra layer of absorption that effectively lessens sound energy and curtails sound penetration through the composite material. Rubber recyclate may have some sound-insulating properties, but the effectiveness of these properties may vary depending on the type of recyclate, its quality and how it is processed. To assess the sound-proofing effectiveness of rubber recyclate as a modifier in a glass composite, it is worth conducting laboratory tests.

There are studies in literature that describe the acoustic properties of composite materials which include organic additives [8-11] and inorganic additives [12-14]. The article [15] presents the use of a composite based on granules from used car tires for the production of noise-dampening screens as well as vibration isolation in the food processing industry. The article [16] presents an experimental and numerical study of the effect of battery deposition in carbon fibre laminates and sandwich panels on vibration and acoustic properties. The study [17] describes the acoustic properties of bamboo fibre-reinforced hybrid epoxy composites.

As part of the presented research, a new composite material with favourable parameters in terms of sound insulation and specific strength properties was made. This multilayer composite was produced based on Synolite 1967-G-1 polyester resin based on DCPD, which is low viscous and unsaturated, and glass fabric with a three-way fibre system +/-45°, Triaxial type and a weight of 860 g/m^2. As an addition, rubber recyclate created in the process of disposal of car tires was used. The material was made using the vacuum infusion method.

In most of the technical and construction solutions used, the addition of recyclate is aimed at using the maximum amount of rubber additive as a filler and flexible material with a limited range of strength parameters of finished elements. The article describes a material that maintains technical and strength parameters while providing good sound insulation. This material is also cost-effective to produce, making it economically justifiable to use.

2. Description of the test material and research methodology

To create selected variants of composites by vacuum infusion, glass fabric with a three-way arrangement of +/-45°, Triaxial type fibres, with a weight of 860 g/m^2 and Synolite 1967-G-1 polyester resin with Currox hardener were used. The materials were made with reinforcement in the form of 6 layers of fabric. A hardener of 0.06 % by weight of the applied amount of resin was used.

By vacuum lamination, composite materials with the addition of rubber recyclate were produced in four variants of the amount of recyclate used in the produced composite – 20%, 30%, 40% and 50%. Each variant contained 6 layers of fabric and five layers of rubber recyclate. Tables 1 and 2 present data on the composition of selected materials, values of strength parameters and percentage differences in these parameters between pure composite material without the addition of rubber recyclate and materials with 20%, 30%, 40% and 50% added rubber recyclate. The rubber recyclate used came from recycled car tires. The recyclate was sieved using the laboratory sieve shaker LAB 11-200, from EKOLAB to precisely separate its fractions with a grain size of 0.5 mm to 2 mm.

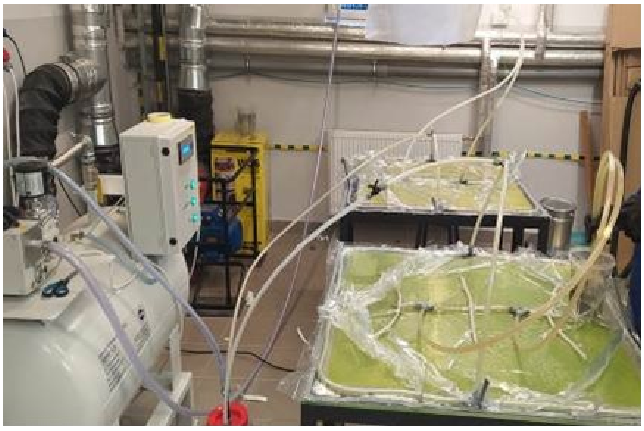

Figure 1. Fabrication of materials by vacuum infusion.

Table 1. Percentage of components of layered composites based on glass fabric, rubber recyclate and polyester resin made by vacuum infusion.

Composite designation/ photo of manufactured test materials	Number of layers of fabric	Resin content, %	Fabric content, %	Number of layers of rubber recyclate	Addition of recyclate in relation to the weight of the fabric, %
0% FABRIC	6	30	70%	0	0%
20% FABRIC	6	30	70%	5	20%
30% FABRIC	6	30	70%	5	30%
40% FABRIC	6	30	70%	5	40%
50% FABRIC	6	30	70%	5	50%

Table 2. The weight content of components of polyester-glass sandwich composites with the addition of rubber recyclate as sandwich layers, made by vacuum infusion.

Composite	Number of layers of glass fabric	Resin content by weight [g/m^2]	Weight fabric content [g/m^2]	Number of layers of rubber recyclate	Recyclate content, weight [g/m^2]	Composite Surface mass [g/m^2]
0% FABRIC	6	2211	5160	0	0	7371
20% FABRIC	6	2211	5160	5	1032	8403
30% FABRIC	6	2211	5160	5	1548	8919
40% FABRIC	6	2211	5160	5	2064	9435
50% FABRIC	6	2211	5160	5	2580	9951

2.1. Strength tests of manufactured materials

The samples to be tested were cut by water cutting from the produced composite plates. 10 pieces were intended for research. samples from each composite variant considered. Samples made following the PN-EN ISO 527-4 2000P plastics standard were subjected to static stretching on a universal Zwick & Roell testing machine, with variable load parameters, with a hydraulic drive type MPMD P10B. TestXpert II version 3.61 was used for the trial. Test results for samples were recorded using Zwick & Roell-TestXpert II version 3.61 software.

Strength and vibroacoustic properties were tested on the materials made. The scope of the planned strength tests of the analyzed materials includes a static tensile test for a series of 10 samples from each of the material variants. Charpy hammer impact testing for a series of 12 samples from each variant. Table 3 presents the values of strength parameters obtained during the tests. Table 4 presents the obtained impact values of the analyzed materials.

Table 3. Strength parameters of the tested materials obtained from the static tensile test.

Composite	Tensile strength σ_m [MPa]	Strain ε [%]	Young's modulus E [MPa]
0% FABRIC	310,18	2,73	16709
20% FABRIC	119,80	2,11	8629
30% FABRIC	69,49	2,05	3386
40% FABRIC	76,74	1,93	4122
50% FABRIC	79,70	1,76	6189

Table 4. Strength parameters of multi-layer composite materials based on glass fabric and Synolite 1967-G-1 resin with a percentage of rubber recyclate.

Composite/ Parameter	Maximum Force F_{MAX} [N]	Deflection f [mm]	Work W [J]	Resilience U [average] [kJ/m^2]
0% FABRIC	1475	1,29	8,39	268
20% FABRIC	1489	1,59	10,81	233
30% FABRIC	971	2,74	5,68	72
40% FABRIC	769	2,50	5,68	70
50% FABRIC	1819	1,83	12,73	136

2.2. Sound insulation tests

Acoustic insulation tests of materials were carried out in the Vibroacoustic Research Laboratory of the Ship Technology Center in Gdańsk. The specific acoustic insulation R in the reverberation chamber assembly without flanking transmission was determined, following the PN-EN ISO 10140-2 standard and related standards, i.e. PN-EN ISO 10140-1, PN-EN ISO 10140-4 and PN-EN ISO 10140-5. Plates with an area of $A=1m^2$ were tested. Reverberation chambers, together with the location of the test are shown in Fig. 2.

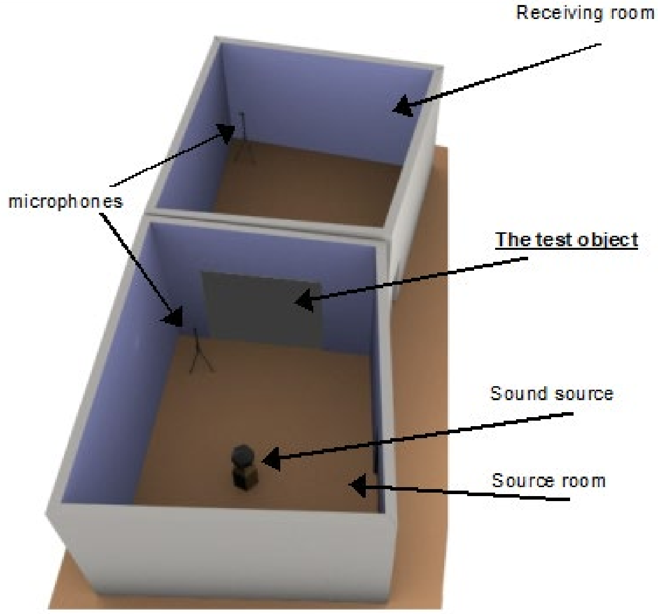

Figure 2. Reverberation chambers with the test object and measuring system for airborne sound insulation measurement.

From the obtained results in bands 1/3 of the octave, a single-numeric, weighted sound insulation index R in [18] was determined. The results are presented in Table 5, Figure 3 and Figure 4 graphs.

Table 5. Acoustic insulation for tested variants of materials within the scope of PN-EN ISO 10140-2:2011

Frequency [Hz]	Sound insulation R [dB]				
	FABRIC 0%	FABRIC 20%	FABRIC 30%	FABRIC 40%	FABRIC 50%
50	16,3	19,2	19,2	17,3	18,2
63	18,9	18,0	9,9	22,1	21,5
80	18,8	17,9	14,9	17,5	24,6
100	17,5	20,5	17,3	17,2	22,4
125	17,4	18,7	17,7	18,0	18,6
160	22,7	22,8	18,4	23,5	24,3
200	21,1	22,3	19,1	22,6	24,9
250	23,4	24,9	22,5	24,8	27,7
315	24,9	26,4	23,5	26,2	29,3
400	24,3	26,5	23,6	26,2	29,2
500	24,2	26,8	24,5	27,2	30,2
630	25,8	28,4	26,5	29,7	32,2
800	26,9	29,4	29,0	31,6	34,5
1000	27,4	29,7	30,6	32,9	35,7
1250	28,2	29,0	31,9	34,5	37,4
1600	28,7	29,0	33,7	36,5	39,1
2000	29,1	29,6	35,1	37,5	39,8
2500	29,7	31,6	36,3	38,3	40,1
3150	31,0	33,7	37,1	37,8	38,0
4000	32,6	36,0	37,8	32,3	34,6
5000	34,2	36,5	36,4	29,3	35,0
R_w	**28,2**	**30,0**	**30,4**	**33,2**	**35,7**

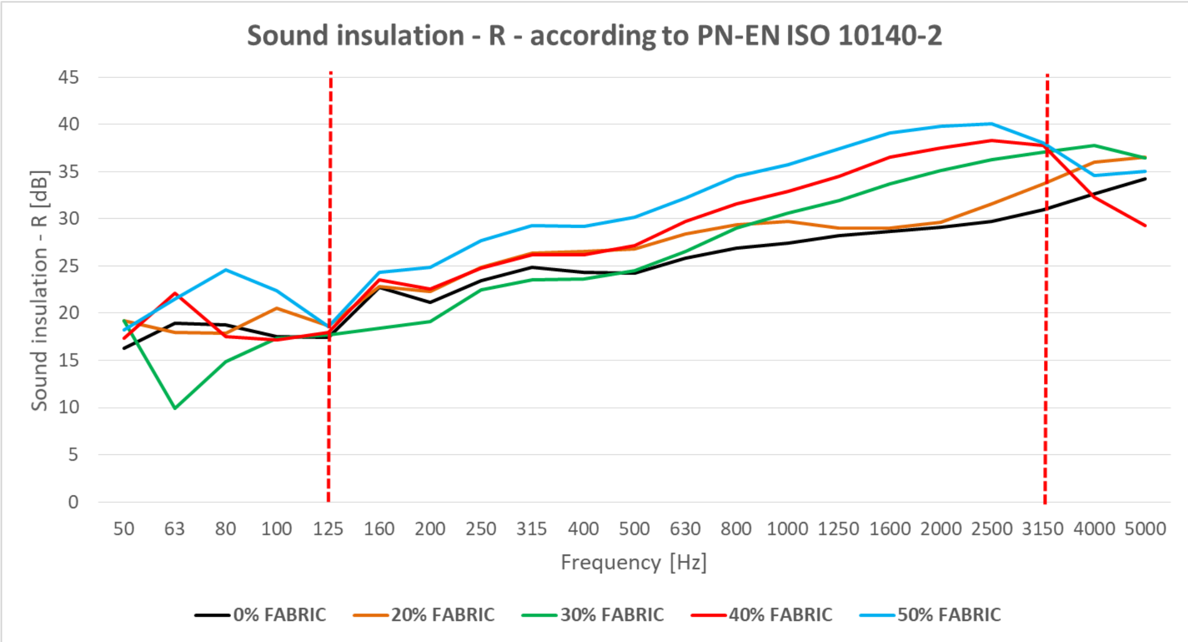

Figure 3. Acoustic insulation of the tested variants of laminate materials.

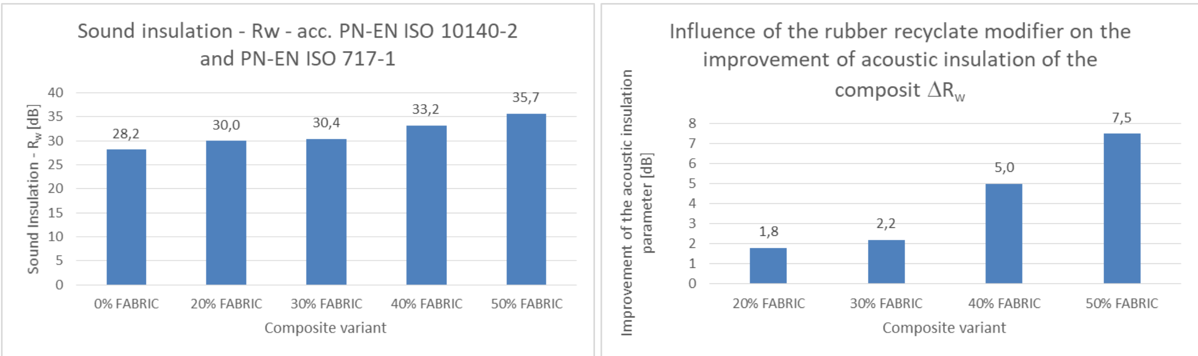

Figure 4. Acoustic insulation of the tested material variants.

To estimate the sound-insulating properties of panel building partitions, the relationship between the surface mass of the partition and single-number specific acoustic insulation indices R_w is used. This relationship is referred to as the "law of mass", where for the tested laminates the relationship is shown in Fig. 5.

All manufactured variants of composite material with the addition of rubber recyclate are characterized by better acoustic insulation parameters and are in the range of R = 30.0 ÷ 35.7 dB, an improvement from 1.8 ÷ 7.5 dB for for 20% ÷ 50% addition of rubber recyclate.

By comparing sound pressure spectra, it can be shown that in the frequency range from 125 ÷ 3150 Hz, composites with rubber recyclate additives show increased sound insulation at the level of 5 ÷ 10 dB compared to laminates without the addition of rubber recyclate.

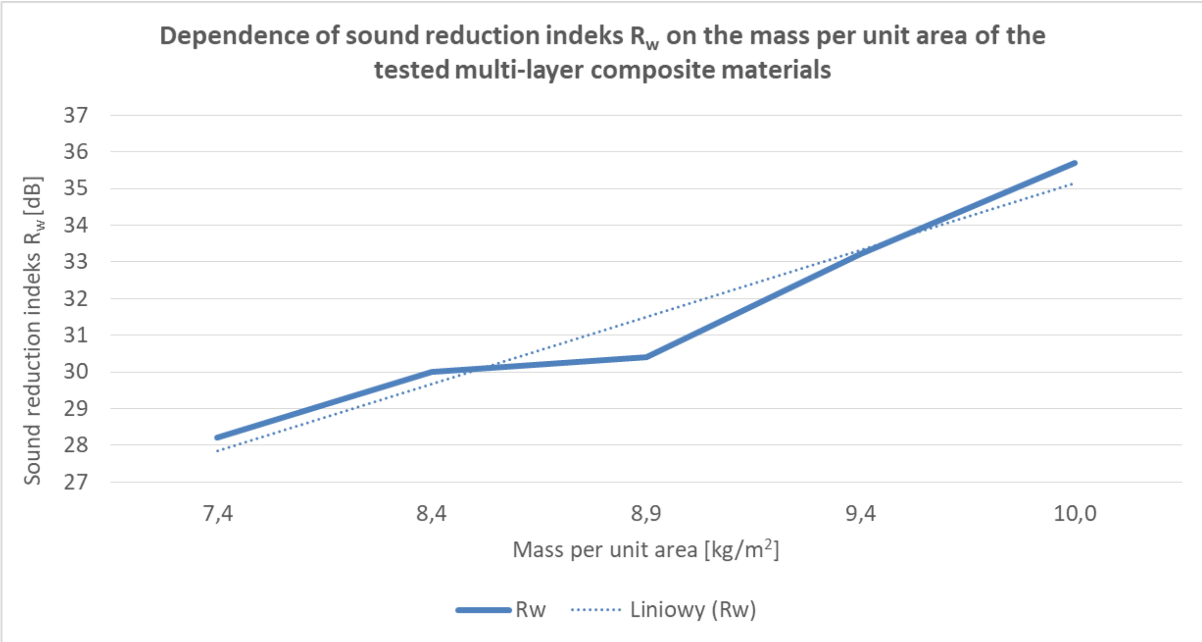

Figure 5. Dependence of sound reduction indeks R_w on the mass per unit area.

3. Conclusions

Research on acoustic insulation of composite materials provides valuable insights that can be used to enhance the production technology of these materials. By analyzing test results, modifications can be made to improve insulation properties, leading to superior products.

Well-designed and manufactured composites that incorporate rubber recyclate can achieve high levels of sound insulation, resulting in effective sound attenuation and reduction of sound penetration. Such composites find wide application in the construction, automotive, aerospace, marine, and other industries where noise reduction is critical.

However, sound insulation of a given material is a complex issue, and the effectiveness of insulation depends on several factors, such as material thickness, construction, layer arrangement, and other insulation methods. While rubber recyclate can be one of the components of a comprehensive sound insulation system, other agents or combinations of materials may also be required to achieve the desired sound insulation results.

An increase in acoustic insulation with an increase in surface mass was demonstrated, resulting from the higher density of the rubber recyclate compared to the base laminate.

The proposed materials, with their high sound insulation parameters, can be used as a barrier to unwanted noise and as the basis for the production of sound-absorbing partitions and insulation chambers. The results of the research indicate that materials with the addition of rubber recyclate can be used extensively in different material solutions, enhancing the properties of these materials. The addition of rubber recyclate to composites improves their impact and vibroacoustic parameters, thereby allowing for their wide use in various industries, considering market demand and significant savings and benefits in terms of environmental protection.

Potential customers in the yacht, shipbuilding, machinery, automotive, road infrastructure, construction, and gardening industries can benefit from the proposed solution. For a specific recipient from any of these industries, the composition and distribution of rubber recyclate in the material can be developed according to their requirements, after the recipient has determined their needs for the new material. Closer cooperation between the industry and material production technology developers can enable the implementation of the new composite material.

The use of vacuum infusion technology for the production of glass or carbon fiber elements in composite manufacturing allows for the incorporation of other additives/modifiers that affect the achievement of new physical properties of composites, leading to further development of these materials.

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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. M. Kosmal, A.Kuśnierz; Airborne sound insulation test of fireproof glass; Izolacje, 2023, 28(3), 106-108
2. PN-EN ISO 10140-2; Laboratory measurement of sound insulation of building elements - Part 2: Measurement of airborne sound insulation, 2021
3. L. Dulak, A. Nowoświat; Sound insulation – parameters and indicators; 2016, 21(2), 56-63
4. K. Abramczyk, M. Barburski, J. R. Blaszczak, B. Samuel; Fabric as an acoustic barrier; Lodz University of Technology Press, 2022
5. D. A. Bies, C. H. Hansen, Engineering noise control: theory and practice: CRC Press, 2003
6. W. Mikulski; Sound-absorbing and insulating enclosures for ultrasonic devices, limiting the level of noise penetrating into the environment. Results of own research; Occupational safety. Science & Practice, 2021, 600(9), 22-28
7. A. Wawrzynowicz, M. Krzaczek, J. Tejchman; Sound insulation of composite panels in residential construction; Building Inspection, 2012, 83(10), 33-38
8. N. H. Bhingare, S. Prakash, V. S. Jatti; A review on natural and waste material composite as acoustic material; Polymer Testing, 2019, 80
9. L. Prabhu, V. Krishnaraj, S. Sathish, S. Gokulkumar, M. R. Sanjay, and S. Siengchin; Mechanical and acoustic properties of alkali-treated sansevieria ehrenbergii/camellia sinensis fiber–reinforced hybrid epoxy composites: incorporation of glass fiber hybridization; Applied Composite Materials, 2020, 27, 915-933
10. T. Hassan, H. Jamshaid, R. Mishra, M. Q. Khan, M. Petru, J. Novak, R. Choteborsky, M. Hromasova; Acoustic, mechanical and thermal properties of green composites reinforced with natural fibers waste; Polymers, 2020, 12(3), 654
11. S. Gokulkumar, P. R. Thyla, L. Prabhu, S. Sathish; Characterization and comparative analysis on mechanical and acoustical properties of camellia sinensis/ananas comosus/glass fiber hybrid polymer composites; Journal of Natural Fibers, 2021, 18(7), 978-994
12. W. Zhao, W. Zhou; Cluster analysis of acoustic emission signals and tensile properties of carbon/glass fiber–reinforced hybrid composites; Structural Health Monitoring, 2019, 18(5-6), 1686-1697
13. S. Sair, S. Mansouri, O. Tanane, Y. Abboud, A. El Bouari; Alfa fiber-polyurethane composite as a thermal and acoustic insulation material for building applications; SN Applied Sciences, 2019, 1, 1-13
14. S. Backens, J. Unseld, N. Glück, A. Wolter; Incombustible, inorganic fiber-reinforced composites for shipbuilding; Lightweight Design worldwide, 2019, 12(6), 38-43
15. P. Pioś; Composite based on rubber granules from used tires as a sound-absorbing and vibration-insulating material in the food processing industry; Advances in food processing technology, 2019
16. J. Galos, A. A. Khatibi, A. P. Mouritz; Vibration and acoustic properties of composites with embedded lithium-ion polymer batteries; Composite Structures, 2019, 220, 677-686
17. A. S. Ismail, M. Jawaid, J. Naveen; Void content, tensile, vibration and acoustic properties of kenaf/bamboo fiber reinforced epoxy hybrid composites; Materials, 2019, 12(13), 2094
18. PN-EN ISO 717-1:2021-06; Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation, 2020