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Article

Sound-Absorbing and Thermal-Insulating Properties of Cement Composite Based on Recycled Rubber from Waste Tires

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Abstract: This article describes an experimental study aimed at investigating the potential use of recycled rubber granulate from waste tires of fractions 0/1 and 1/3 mm in cement composites as a 100% replacement for natural aggregates. The use of waste in the development and production of new building materials represents an important aspect for the sustainability and protection of the environment. This article is focused on the sound-absorbing and thermal-insulating properties of experimental cement composites based on recycled rubber from waste tires. The article describes the grain characteristics of recycled rubber, sound absorption capacity, thermal conductivity and strength characteristics. The results of this research show that the total replacement of natural aggregate with recycled rubber in cement composites is possible. Replacing natural aggregate with recycled rubber has significantly improved the thermal and acoustic properties of the prepared cement composites, however, at the same time; there was also the expected decrease in the strength characteristics due to the elasticity of rubber.

Keywords: waste tires; recycling; rubber; cement composites; acoustic properties; thermal properties; strength properties

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1. Introduction

The use of waste in the development and production of new materials is an important aspect for the sustainability and protection of the environment. Recycling and utilization of waste materials in building industry has recently been the goal of many research teams and manufacturers of building materials. Their objective is to reduce the consumption of primary minerals [1–4].

New building materials, especially concrete construction material called eco-concrete, are more and more frequently used in building industry, thus reducing the human ecological footprint on Earth. Eco-concrete is concrete in which the binder or filler is replaced by a waste material. Fly-ash, granulated blast furnace slag, steel slag, glass, glass fibres, recycled plastic fibres or plastic granules, and last but not least, material from waste tire recycling are used as the replacement [5–11]. Many research teams are already working on the incorporation of waste products into building materials and the subsequent study of their properties. One example is the efficient use of recycled concrete aggregate (RCA) in the building industry, which attracts a lot of attention because aggregates make up from 60 to 75% of the concrete volume. The use of recycled aggregates will therefore reduce the amount of the used primary raw material—natural aggregates—and, at the same time, will save money spent on the storage and disposal of waste concrete [12]. With respect to its non-uniform quality, the use of RCA can have a negative effect on the durability of concrete and can significantly reduce its tensile and compressive strength, depending on the amount of the used natural aggregate replacement [13–18].

Another waste material that has recently received a lot of attention is waste tires. Due to their insufficient biodegradability and their shape, tires do not allow efficient landfilling and they also act as a breeding ground for various pathogenic organisms and insects, which contributes to the spread of different types of diseases, such as malaria [19,20]. Nowadays, tires are either disposed of by thermic processes or landfilled as a whole, or as crushed material [21–23]. The incineration of tires is technically demanding as far as the machine equipment is concerned and, despite that, a large amount of CO_2 and SO_2 is released. A large amount of stored waste tires poses a high risk of fire [24], and this kind of disposal has already been banned in the EU [25,26].

The building materials incorporating crushed recycled rubber in their structure, such as plywood/waste tire rubber (PWTR) composite chipboard [27], can help addressing the issues related to reducing acoustic pollution in urban areas. The need to control noise in urban environments has been more and more important and has become a technical problem in modern society as a result of the recognition of noise as a health risk [18,28,29].

The main factors affecting sound absorption include: porosity; aggregate grain size; type of aggregate; sample and additive thickness. The material used as a structural element, such as aerated concrete, can also act as an acoustic pollution absorber, thanks to its properties [30–32]. It was found that aerated concrete with 4-8 mm aggregates was the most suitable for sound absorption [33]. Sound-absorbing materials with porous structure absorb most of the energy, which allows the sound wave to penetrate through the material, while the energy of the waves is dissipated through internal friction and converted into thermal energy. Cavities, channels and gaps provide absorption properties, depending on their frequency, composition, thickness and surface finish [29,34–37]. In order to reduce noise, various attempts have been made to develop sound-absorbing building materials. The acoustic properties were investigated in an experimental research focused on the addition of cenosphere to cement composites. The experiment results have shown that the sound absorption of composites increased with the addition of cenospheres in the volume of up to 40% [38].

Research dealing with the sound properties of rubber-concrete composites has revealed that the sound absorption coefficient was increasing with the increasing replacement of fine aggregate by crushed rubber in the amount of up to 30% [39].

This article describes an experimental study aimed at investigating the potential utilization of recycled rubber granulates in cement composites as a 100% replacement for natural aggregates. The combination of cement paste and recycled rubber has resulted in a new material that benefits from the strength of the concrete matrix, and the elasticity and energy absorption of rubber. The research was focused on the evaluation of the acoustic capabilities, strength characteristics and thermal-technical properties of the newly developed material.

2. Materials and Methods

Two mixtures of cement composites were prepared within the scope of the research. They were based on 100% volume replacement of aggregate with recycled rubber. Blast furnace cement CEM III/A 32.5 N from Považská cementárna, JSC. EN 197-1 (Ladce, Slovakia) was used as the binder in the mixtures [40]. The mixtures contain different ratios of rubber granulate. The suggested proportion ratio of the individual fractions of recycled rubber (fr. 0/1 mm: fr. 1/3 mm) was based on the results of tests of workability of fresh concrete mixture. The workability test of a fresh cement composite mixture was performed according to ČSN EN 1015-3 before the design of the final formulae presented in this article. The results of the test revealed that increasing share of fr. 0/1 mm to fr. 1/3 mm in the volume ratio of 60:40, 70:30, 80:20, 90:10 and 100:0 resulted in a deterioration of the workability of the mixture, the particles of recycled rubber were not completely coated with cement. The cement composite mixture was very difficult to process. During the spill test, the mixture was not compact; the initial cone for the spill test fell to pieces. Formulae Z2 and Z3 were designed on the basis of these tests. After removing the formwork, the test specimens were stored in a humid environment for 3, 7, 14, 28 and 90 days.

2.1. Mixture Water

According to the Czech standard CSN EN 1008 [41] was used tap water as mixing water for cement composites

2.2. Filler

2.2.1. Standardized Aggregate

Standard sand (manufactured by the company Filtrační písky, Ltd., Chlum, Czech Republic) was used as the filler for the preparation of the comparative samples. This sand meets the requirements of the ČSN EN 196-1 standard [42]. It is a mixture of 3 grain fractions PG1, PG2 and PG3.

2.2.2. Recycled Rubber

Rubber granulate, styrene-butadiene rubber (SBR) is a product originating from the recycling of waste tires and it comes from the company Bonus CB Ltd. (České Budějovice, Czech Republic). Two types of granulate were used as the filler, one referred to as SBR 0/1, which had a grain size of 0–1 mm, and the other type was SBR 1/3, which had a grain size of 1–3 mm. These 2 types of rubber granule were used as a complete replacement for standardized aggregate in the mixtures for the preparation of the test specimens.

2.3. Cement Composite Mixtures

Based on previous research [43], mixtures Z2 and Z3 were used for the preparation of the cement composites. Their composition is presented in Table 1. In mixtures Z2 and Z3, the filler in the form of rubber granules of fractions 0/1 and 1/3 mm was used as the substitute for natural aggregate. These granulates were mixed in the ratio of 40:60 and 50:50 between fine fraction 0/1 and coarse fraction 1/3 mm. The dose of natural aggregate for one mixture is 1350 g, which corresponds to a volume of 820 mL in case of volumetric dosing. When replacing the standardized sand with rubber granulates in a ratio of 1:1, i.e., 820 mL, the final amount of the prepared mixture was lower, which is why the volume of rubber granulate was increased to 1100 mL. All the other input raw materials were recalculated as percentages.

Table 1. Compositions of experimental mixtures of cement composites containing rubber granulate.

Mixture	Comparative	Z2	Z3
CEM III/A 32.5 N [g]	450	450	450
Pure mixture water [g]	225	225	225
Standardised sand [mL]	820	-	-
Rubber granulate fr. 0/1 [mL]	-	410	328
Rubber granulate fr. 1/3 [mL]	-	410	492

2.4. Sieve Analysis of Standardized Aggregate and Rubber Granulate

The input materials, which had been used as the filler in the cement composites based on recycled rubber granulate, were subjected to a particle size analysis. This analysis was performed in accordance with CSN EN 933-1 standard [44] using HAVER EML 300 device (Haver & Boecker, Oelde, Germany). A series of sieves with mesh sizes of 0.063, 0.125, 0.25, 0.5, 1, 1.6, 2, 2.5, 3, 4, 5 mm according to CSN EN 933-2 [45] was used to determine the particle size of the input raw materials.

2.5. Determination of Tensile Flexural and Compressive Strength

The test specimens corresponding to the standard of CSN EN 196-1 [42] with the dimensions of 40 × 40 × 160 mm were prepared in order to determine the flexural and compressive strengths. After removing the formwork, the specimens were stored in a humid environment until the tests. The testing of the prepared specimens was performed after 3, 7, 14, 28 and 90 days using Form+Test Mega 100 testing device (FORM+TEST Seidner & Co. GmbH, Riedlingen, Germany).

2.6. Determination of Density of Hardened Mortar

Test specimens according to CSN EN 1015-11 standard [46] with the dimensions of 40 × 40 × 160 mm were prepared in order to determine the density of mixtures Z2 and Z3. After removing the formwork, the test specimens were stored in a humid environment for 28 days and then dried to a constant weight. The density of hardened mortar was determined on the specimens prepared in this way according to CSN EN 1015-10 standard [47].

2.7. Determination of Sound Absorption Capacity of Cement Composites

The determination of sound absorption capacity of cement composites was performed according to CSN EN 1793-1 [48]. The test specimens were prepared on the basis of the designed mixtures in the shape of a cylinder with the diameter of 98 mm and the thickness of 10 mm, 30 mm and 50 mm. These dimensions of the test specimens were manufactured using a mould printed on a 3D printer. The dimensions of the test specimens had been designed to correspond to the dimensions of the Kundt tube in which the sound absorption capacity was measured. The specimens were stored in a water bath for 28 days, and then they were dried and tested. The measurements were performed for audio frequencies of 125, 250, 500, 1000 and 2000 Hz. The range of frequencies used was chosen based on a tube diameter of 100 mm, which also corresponds to the work of Oancea et al. [18].

The tested material was placed into a holder at one end of the Kundt tube. The acoustic signal source was mounted on the other end of the Kundt tube. A sound wave of a defined frequency was transmitted from the source into the tube. The sound wave was reflected from the tested material, while, together with the incident wave, it created a standing wave in the Kundt tube, which was caused by the interference of both waves. The sound reflected from the tested material was read by a microphone and analyzed using an octave filter so that the frequency dependence could be determined as well. Depending on the distance of the microphone from the measured material in the tube, the values of the maximum and minimum pressure of the acoustic signal can be determined.

The microphone with an amplifier was connected to a voltmeter. The maximum acoustic pressure P_{max} and the minimum acoustic pressure P_{min} correspond to the respective voltages measured on a voltmeter, i.e., U_{max} and U_{min}.The ratio of acoustic pressures is then proportional to the voltage ratio:

$$n = \frac{P_{max}}{P_{min}} = \frac{U_{max}}{U_{min}} \tag{1}$$

Their ratio n makes it possible to calculate the reflection coefficient or absorption coefficient α. Since we do not take into consideration the energy penetration, $\tau = 0$ and the reflection coefficient expressed by acoustic pressures:

$$r = \frac{P_R^2}{P^2} \tag{2}$$

where p is the sound pressure of the incident wave and p_R is the sound pressure of the reflected wave

This means:

$$n = \frac{P_{max}}{P_{min}} = \frac{P + P_R}{P - P_R} \tag{3}$$

After adjustment:

$$\frac{P_R}{P} = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \tag{4}$$

$$r = \left(\frac{P_R}{P}\right)^2 = \left(\frac{P_{max} - P_{min}}{P_{max} + P_{min}}\right)^2 \tag{5}$$

$$\alpha = 1 - r = 1 - \frac{p_R^2}{P^2} = \frac{4p_{max} \cdot p_{min}}{(p_{max} + p_{min})^2} \tag{6}$$

2.8. Thermal Property Determination Methods of Cement Composites

ISOMET 2114 (Applied Precision Ltd., Bratislava, Slovakia) instrument was used to measure the coefficient of thermal conductivity of the examined samples at a specific surface temperature. The measurement was performed using the attached measuring probes with a measuring range of 0.3–2.0 and 2.0–6.0 $W \cdot m^{-1} \cdot K^{-1}$ on the prepared specimens measuring 140 × 160 × 40 mm (see Figure 1). After removing the formwork, the specimens were stored in a humid environment for 28 days and then dried to a constant weight. The measuring probe was placed on the surface of the prepared test specimen and, after the temperature values of the probe and the specimen was stabilized, the measurement of the thermal technical properties was initiated.

Figure 1. Setup used for the measurement of the thermal properties.

The measurement using this instrument is based on the analysis of the course of the time dependence of the temperature response on the heat flux pulse into the analyzed material. The heat flux is generated by dissipated electrical power in the probe resistor, which is thermally and conductively connected to the surface of the analyzed material. The measured temperature is sampled as a function of time and is directly evaluated using polynomial regression. The coefficients obtained by means of this regression are then used to calculate the measured value of the thermal conductivity coefficient.

3. Results and Discussion

3.1. Grain Size of Recycled Rubber from Waste Tires

The sieve analysis of rubber granulate fr. 0/1 mm and fr. 1/3 mm was performed according to CSN EN 933-2—Determination of grain size—Sieve analysis [46]. A comparative sieve analysis of natural standardized aggregate was performed as well. The results of the sieve analysis are presented graphically (Figure 2). The presented results of the grain size analysis of the tested samples make it possible to determine the mean grain size d_{50}. For recycled rubber fr. 0/1 mm, the mean grain size d_{50} = 0.68 mm. For recycled rubber fr. 1/3 mm, the mean grain size d_{50} = 2.25 mm. For standardized aggregate, the mean grain size d_{50} = 1.20 mm.

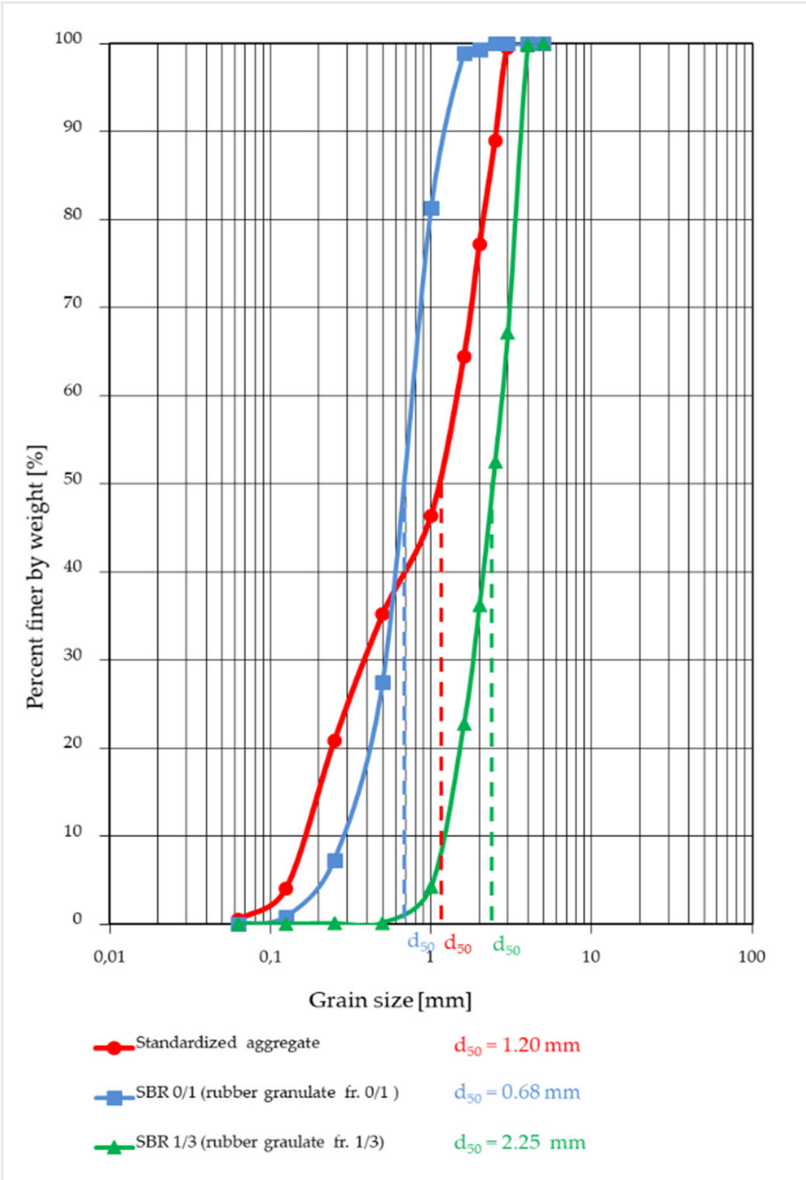

Figure 2. Grain size curve of standardized aggregate and rubber granulate fr. 0/1 mm, fr. 1/3 mm.

3.2. Tensile Flexural Strength and Compressive Strength

The results of the determination of the flexural and compressive strengths for the comparative mixture containing standardized aggregate according to CSN EN 196-1 [42] and the experimental mixtures Z2, Z3 based on recycled rubber are shown in Figures 3–5. The strengths were determined after 3, 7, 14, 28 and 90 days.

Figure 3 presents the values of tensile flexural strength and compressive strengths depending on the age of the comparative test specimens. The trend of increasing compressive strength has a linear character with a reliability value of R = 0.96, which means that it is a very narrow dependence. This also applies to flexural strength, where the reliability value R = 0.97. The determination of the flexural strength and compressive strength of the test specimens based on natural aggregates was performed only to verify the strength characteristics of the binder (cement CEM III/A 32.5 N). This type of cement was used as the binder for mixtures Z2 and Z3.

Figure 4 presents the results of the flexural strength of mixtures Z2 and Z3. Both mixtures show the same trend of increasing flexural strength in the specified time intervals with the value of the reliability coefficient of R = 0.98 for Z2 mixture and of R = 0.97 for Z3 mixture as the comparative mixture based on natural aggregate. This trend of increasing flexural strength of mixtures Z2 and Z3 (with recycled rubber) correlates with the trend of increasing flexural strength of the comparative mixture (see Table 1) containing natural aggregate (standardised sand as filler).

Figure 5 shows the compressive strength results of mixtures Z2 and Z3. Both mixtures show the same trend of increasing compressive strength as the test specimens of the comparative mixture based on natural aggregate. The value of the reliability coefficient for Z2 is R = 0.99 and for mixture Z3, R = 0.99. This trend of increasing compressive strength of mixtures Z2 and Z3 (with recycled rubber) correlates with the trend of increasing compressive strength of comparative mixture (see Table 1) containing natural aggregate (standardised sand as filler).

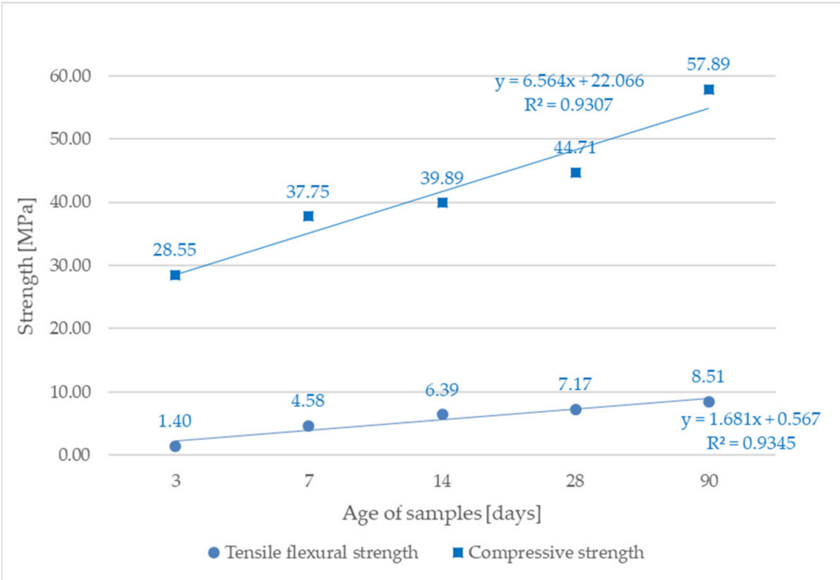

Figure 3. Tensile flexural strength and Compressive strength of comparative mixture.

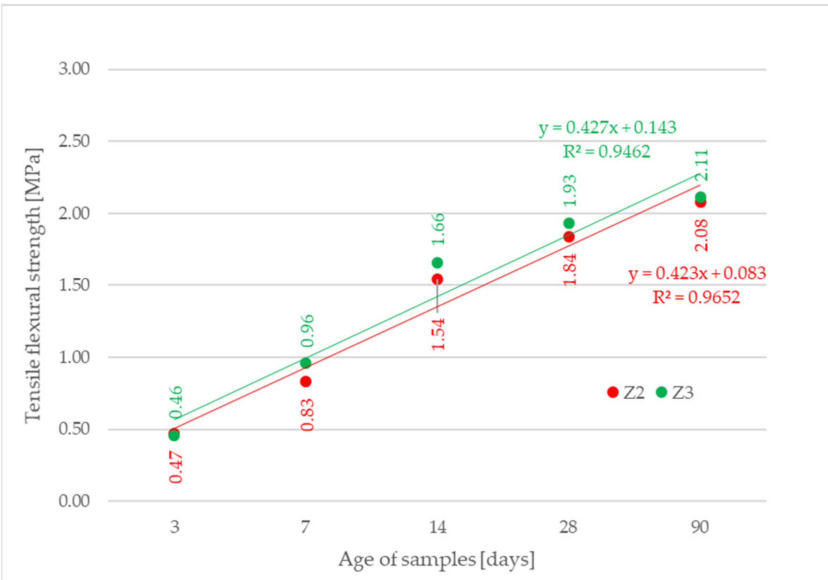

Figure 4. Tensile flexural strength of mixtures Z2 and Z3.

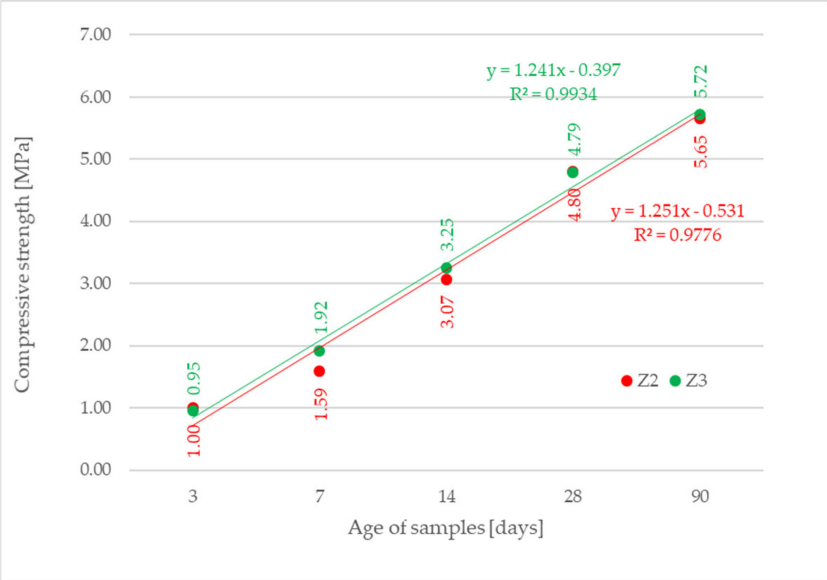

Figure 5. Graphical expression of Compressive strength of mixtures Z2 and Z3.

Based on the results of the strength characteristics of the mixture based on natural aggregate and the mixture based on recycled rubber, it is evident that the recycled rubber used as the filler caused a decrease in both compressive and flexural strengths. The decrease in tensile flexural and compressive strength values is caused by the high elasticity of rubber compared to the comparative sample with aggregate [49], which has no elastic properties at all. This causes lower tensile flexural and compressive strengths. The cohesion of rubber particles with cementing compound is significantly lower than the cohesion of cementing compound with aggregate. For clarity of the graphs, the standard deviations of the values of tensile flexural strength and compressive strength are given separately in Table 2.

Table 2. The standard deviation of tensile flexural strength and compressive strength of experimental mixtures.

Mixture	The magnitude of the standard deviation of tensile flexural strength [MPa]				
	3 days	**7 days**	**14 days**	**28 days**	**90 days**
Z2	0.08	0.04	0.04	0.09	0.05
Z3	0.05	0.02	0.02	0.05	0.03
Comparative	0.04	0.02	0.05	1.20	0.07
	The magnitude of the standard deviation of compressive strength [MPa]				
Z2	0.06	0.03	0.03	0.42	0.07
Z3	0.04	0.02	0.02	0.09	0.03
Comparative	0.09	0.07	0.05	0.74	1.21

3.3. Density of Hardened Mortar

The density of cement composites based on recycled rubber did not exceed the value of 1300 Kg·m^{-3}, more precisely the samples prepared according to mixture Z2 reached the density of 1260 Kg·m^{-3} and the samples of mixture Z3 of 1250 Kg·m^{-3}. For the purpose of comparison, a test using cement composites based on natural aggregate (standardized sand) was performed as well. The value of the density of hardened mortar was 2150 Kg·m^{-3}. The results of the test determining the density of hardened mortar have confirmed the assumption that the resulting cement composites prepared according to mixtures Z2 and Z3 belong to the category of lightweight concrete LC 1.4 as far as their density is concerned according to CSN EN 206-1 [50]. Their density does not exceed 1400 Kg·m^{-3}.

3.4. Outcomes of the Determination of Sound Absorption of Cement Composites

The results of the measurement of the sound absorption coefficient α of the examined cement composites are presented in tabular form (Table 3) and graphically (Figures 6–11).

Table 3. Determination of sound absorption of cement composites.

Frequency [Hz]	Z2			Z3			Comp.		
	10 mm	30 mm	50 mm	10 mm	30 mm	50 mm	10 mm	30 mm	50 mm
125	0.36	0.31	0.27	0.37	0.32	0.28	0.26	0.21	0.22
250	0.06	0.06	0.07	0.05	0.06	0.07	0.13	0.09	0.11
500	0.26	0.42	0.30	0.28	0.43	0.28	0.37	0.25	0.27
1000	0.09	0.20	0.23	0.06	0.17	0.23	0.27	0.26	0.23
2000	0.52	0.42	0.35	0.52	0.45	0.34	0.34	0.30	0.32

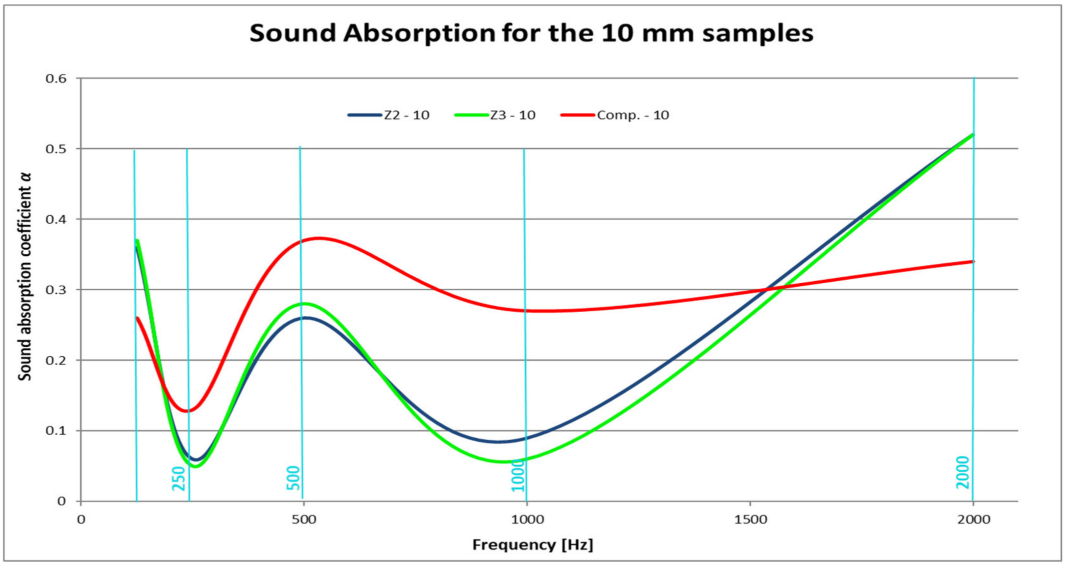

Figure 6. Sound absorption of cement composites th. 10 mm.

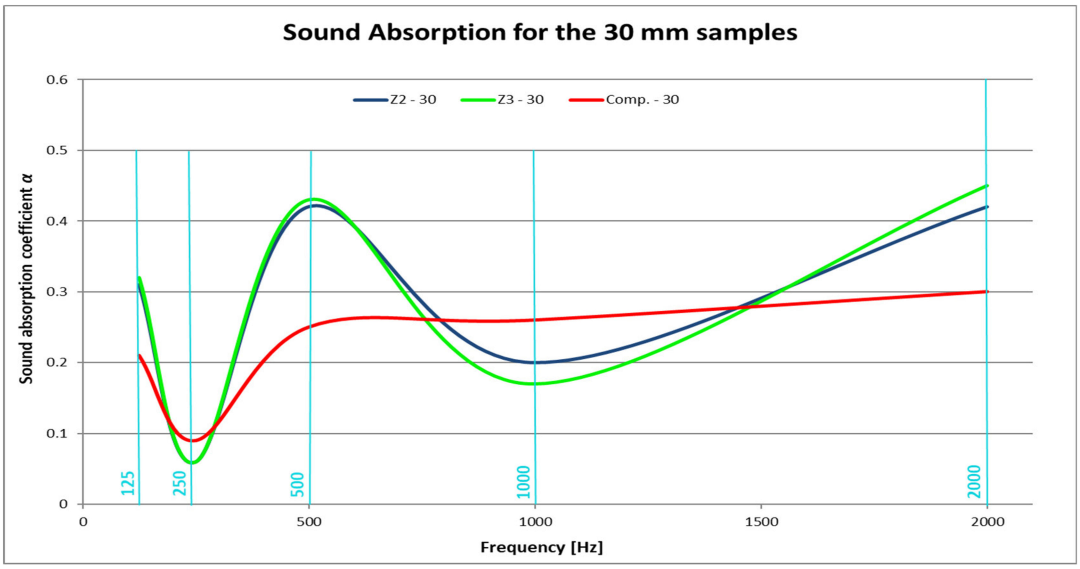

Figure 7. Sound absorption of cement composites (thickness 30 mm).

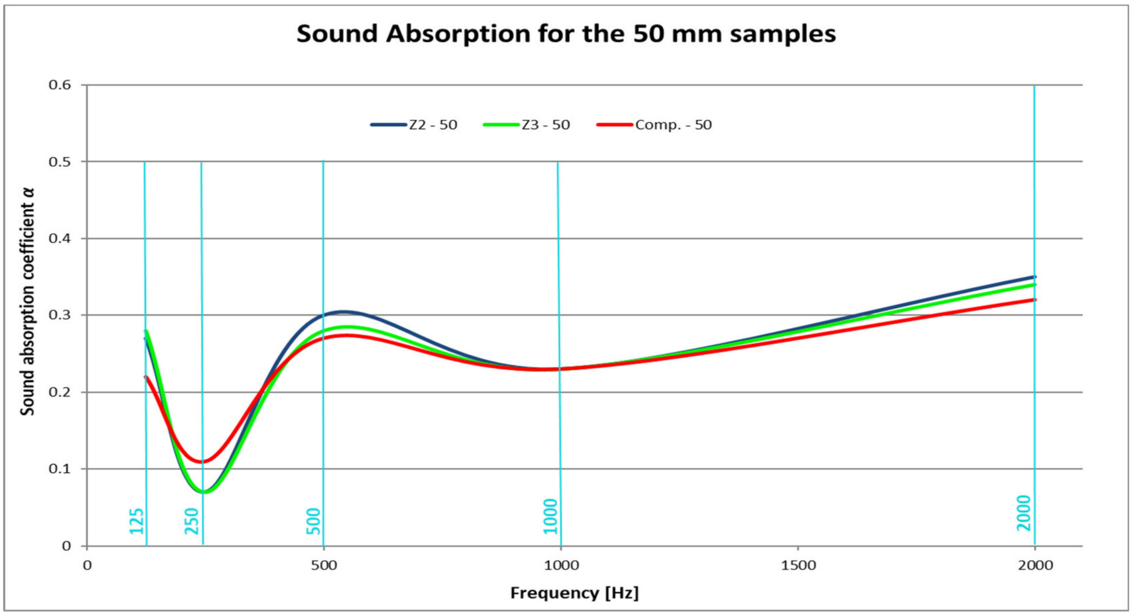

Figure 8. Sound absorption of cement composites (thickness 50 mm).

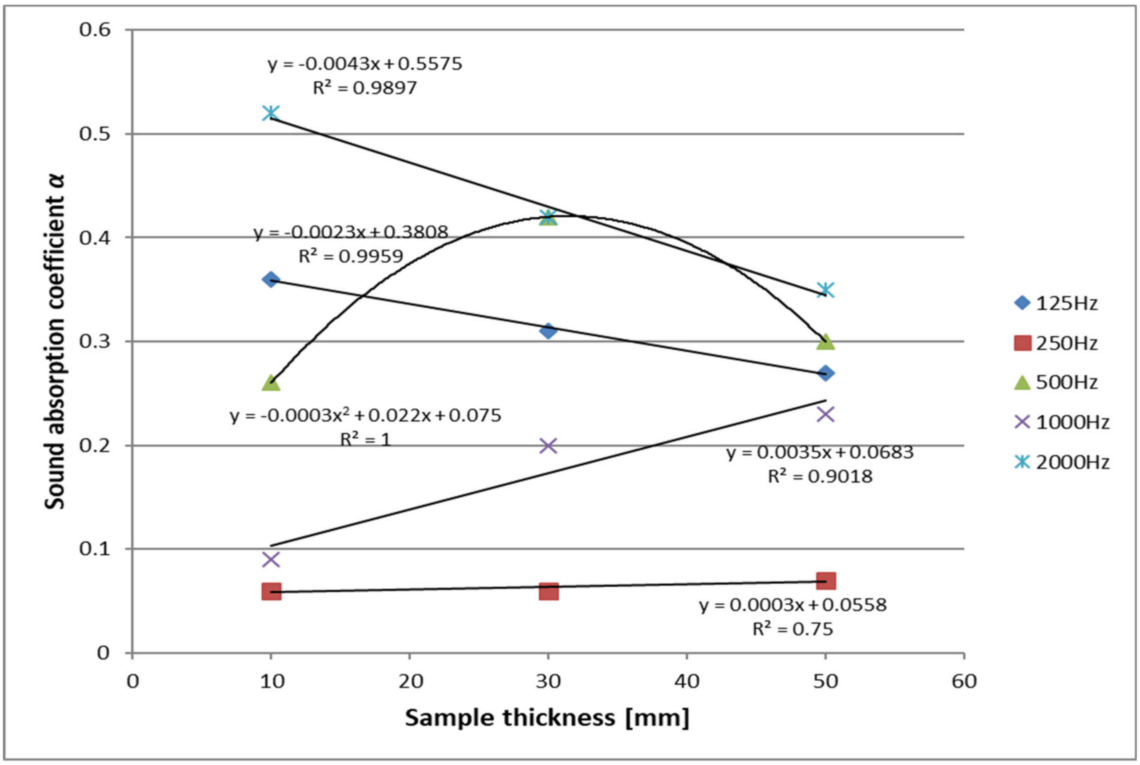

Figure 9. Sound absorption coefficient dependence on the thickness of the sample of mixture Z2 (the trendline is reported for each set of measurements).

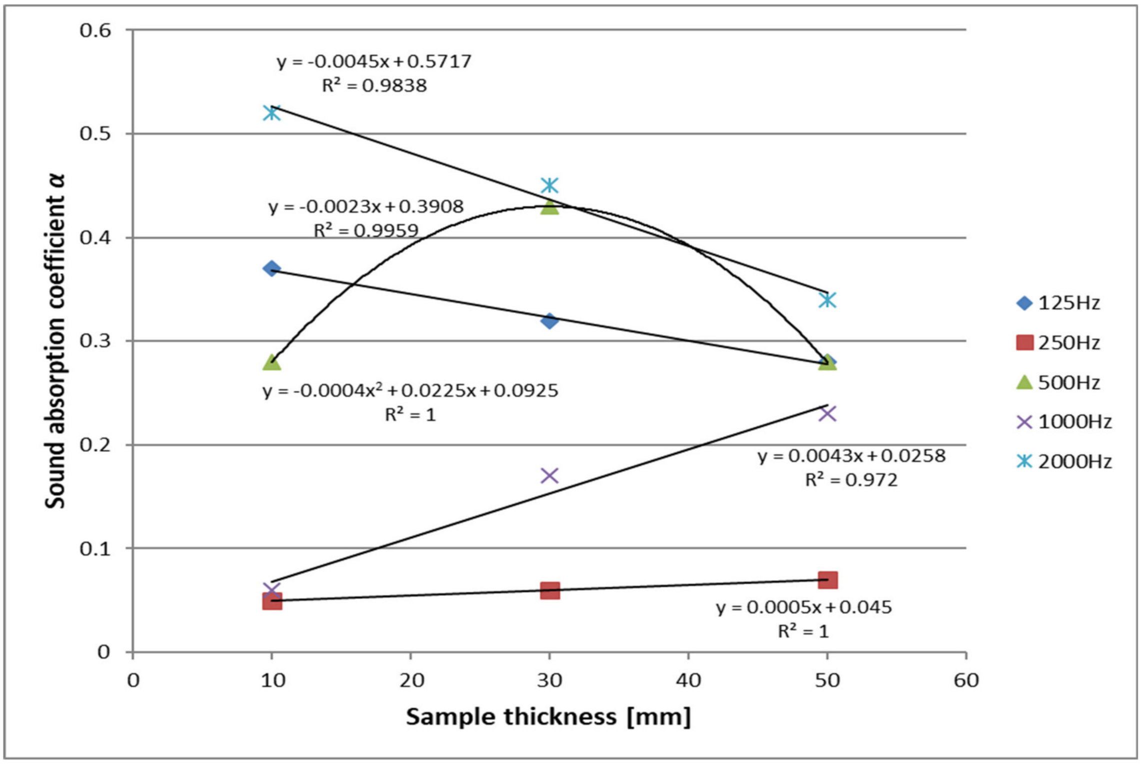

Figure 10. Sound absorption coefficient dependence on the thickness of the sample of mixture Z3 (the trendline is reported for each set of measurements).

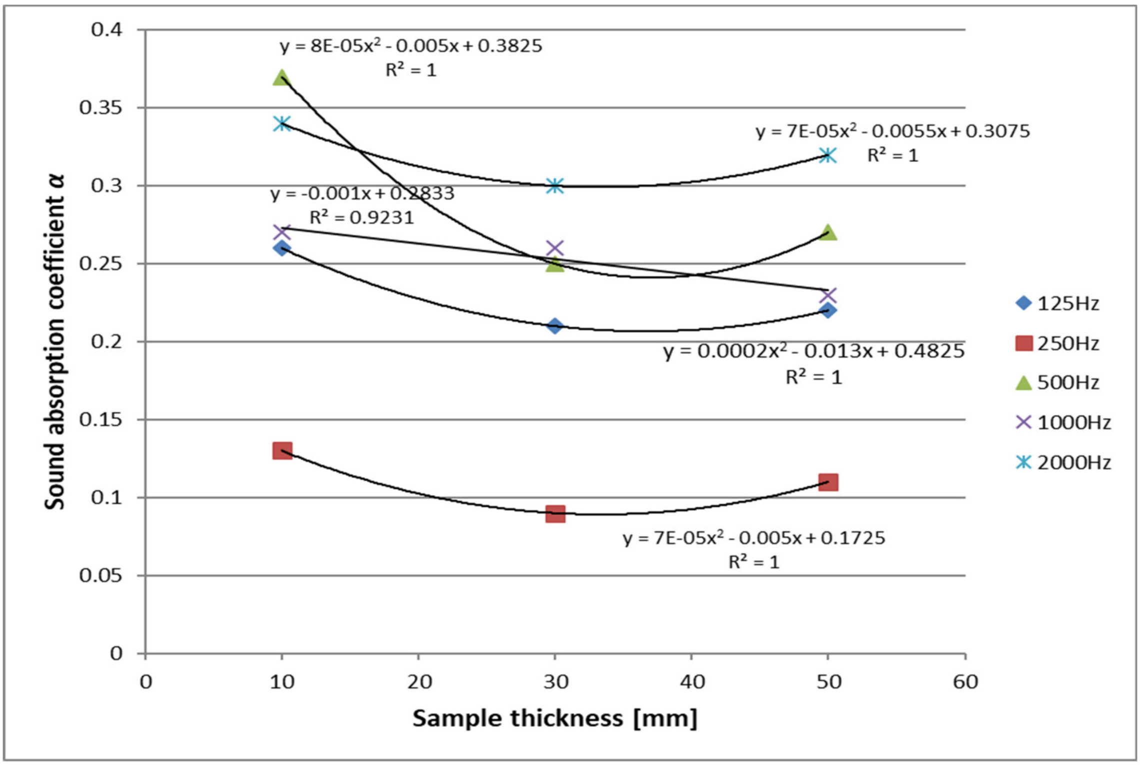

Figure 11. Sound absorption coefficient dependence on the thickness of the sample of comparative mixture (the trendline is reported for each set of measurements).

The sound absorption capacity of Z2 mixture with the test specimen thickness of 10 mm is higher by 27.8% at a frequency of 125 Hz and by 34.6% at a frequency of 2000 Hz in comparison with the comparative mixture. The sound absorption capacity of Z3 mixture with the test specimen thickness of 10 mm is higher by 29.7% at a frequency of 125 Hz and by 34.6% at a frequency of 2000 Hz in comparison with the comparative mixture. At the other examined frequencies of 250, 500 and 1000 Hz, the comparative mixture showed better sound absorption.

The sound absorption capacity of Z2 mixture with the test specimen thickness of 30 mm is higher by 32.3% at a frequency of 125 Hz, by 40.5% at a frequency of 500 Hz and by 28.6% at a frequency of 2000 Hz in comparison with the comparative mixture. The sound absorption capacity of Z3 mixture with the test specimen thickness of 30 mm is higher by 34.4% at a frequency of 125 Hz, by 10.7% at a frequency of 500 Hz and by 33.3% at a frequency of 2000 Hz in comparison with the comparative mixture. At the other examined frequencies of 250 and 1000 Hz, the comparative mixture showed better sound absorption.

The sound absorption capacity of Z2 mixture with the test specimen thickness of 50 mm is higher by 18.5% at a frequency of 125 Hz, by 10.0% at a frequency of 500 Hz and by 8.6% at a frequency of 2000 Hz in comparison with the comparative mixture. The sound absorption capacity of Z3 mixture with the test specimen thickness of 50 mm is higher by 21.4% at a frequency of 125 Hz, by 3.6% at a frequency of 500 Hz and by 5.9% at a frequency of 2000 Hz in comparison with the comparative mixture. At the other examined frequencies of 250 and 1000 Hz, the comparative mixture showed better or comparable sound absorption.

The charts in Figure 6, Figure 7, and Figure 8 shows that the rubber granulate samples have better sound insulation properties at a certain width of the test specimen and at certain sound frequencies than the comparative sample with aggregate and vary to a similar extent as the researches already performed in the past. [18,39,51]

Figure 9 clearly shows that the cement composite prepared according to mixture Z2 follows a linear dependence of the decrease of the sound absorption coefficient α for the frequencies of 125 and 2000 Hz, which is confirmed by the value of reliability R = 0.998 Hz (for 125 Hz) and R = 0.995 (for 2000 Hz). A linear increasing dependence is evident for frequencies of 250 and 1000 Hz. The reliability value for 250 Hz is R = 0.866 and for 1000 Hz, it is R = 0.950. The above presented facts also apply to the cement composite prepared according to mixture Z3 (see Table 1), while the reliability value for the frequency of 125 Hz is R = 0.998, for 2000 Hz R = 0.992, for 250 Hz R = 1 and for 1000 Hz R = 0.986 (Figure 10).

The linear dependence of the decrease and increase in the value of the sound absorption coefficient for cement composite prepared on the basis of natural aggregate is no longer apparent from Figure 11.

The value of the sound absorption coefficient is within the range of 0–1. If $\alpha = 1$, it expresses a complete sound absorption (100% effect), if $\alpha = 0$, it expresses a complete sound reflection (0% effect). On the measurements of the authors, it was found that the highest value of sound absorption for the material prepared according to mixtures Z2 and Z3 is $\alpha = 52$ (52% attenuation). The increasing thickness of the materials goes hand in hand with the decreasing sound absorption value (this applies to sound frequencies of 125 and 200 Hz). For sound frequencies of 250 and 1000 Hz, the highest value of absorption was found at the material thickness of 50 mm. The results presented by us correlate with the results of experimental research projects dealing with the issue of acoustic properties of building materials [52,53].

3.5. Outcomes of the Determination of Thermal Properties of Cement Composites

Thermal properties of the cement composites have been determined for all the prepared mixtures, i.e., comparative mixture, mixture Z2 and mixture Z3. The results of non-stationary measurements using the ISOMET 2114 instrument are presented in Table 4.

Table 4. Determination of thermal properties of comparative mixture.

Measurement Mixtures	Thermal Conductivity Coefficient λ [$W \cdot m^{-1} \cdot K^{-1}$]	Specific Volume Thermal Capacity c_p 10^6 [$J \cdot m^{-3} \cdot K^{-1}$]	Thermal Conductivity $a \cdot 10^{-6}$ [$m^2 \cdot s^{-1}$]
Comparative	2.9706	2.0568	1.4487
Z2	0.3120	1.5079	0.2069
Z3	0.3547	1.5508	0.2287

The thermal conductivity measurement results clearly show that a 100% replacement of aggregate with recycled rubber in cement composites significantly affects the thermal conductivity coefficient. Mixture Z2 shows a decrease in the coefficient of thermal conductivity from 2.97 to 0.31, which corresponds to a decrease of 89.5% compared to the comparative mixture. Mixture Z3 shows a decrease in the coefficient of thermal conductivity from 2.97 to 0.35, which is a decrease of 88.1% compared to the comparative mixture. Furthermore, the results of thermal properties of the prepared composites based on recycled rubber show that mixture Z2, with 100% replacement of aggregate with recycled rubber of fractions 0/1 and 1/3 in the ratio of 50:50, have better thermal conductivity result than mixture Z3 with the ratio of recycled rubber fractions of 40:60. This improvement of 11.4% is influenced by a larger share of the finer fraction of recycled rubber, which has positive effect on thermal conductivity [54,55].

4. Conclusions

The research results show that:

- Lightening of the concrete mixture was achieved by replacing aggregate with rubber granulate from waste tires in cement composites, which places this mixture in the category of lightweight concrete class LC 1.4 according to CSN EN 206-1 [50]. The workability of this mixture containing rubber granulate can be controlled using plasticizing or super-plasticizing additive.
- Cement composites containing recycled rubber from waste tires show better sound insulation properties at a layer thickness of 10 mm—at frequencies of 125 and 2000 Hz, at a sample thickness of 30 mm—at frequencies of 125, 500 and 2000 Hz, and at a sample thickness of 50 mm—at frequencies of 125, 500 and 2000 Hz when compared to the comparative sample containing natural aggregate.
- 100% replacement of natural aggregate with recycled rubber will significantly reduce the coefficient of thermal conductivity, which will significantly improve the thermal insulation properties of the cement composite.
- 100% replacement of natural aggregate with recycled rubber results in a significant reduction in the strength characteristics of the prepared cement composites. This reduction is caused by the lower cohesion of the cementing compound with rubber particles and the high elasticity of the rubber compared to natural aggregates.
- Based on the acoustic and thermal properties, mixture Z2 can be selected as the optimal mixture of cement composite based on recycled rubber. This mixture contains fr. 0/1 mm in the amount of 50% and fr. 1/3 in an amount of 50% as well.

In this study, the authors were looking for a new type of sustainable material that will use a tire recycling product at the end of the life cycle in its structure. Natural aggregate as a clean source was replaced with a secondary raw material in the form of recycled rubber fraction 0/1 and 1/3 mm. Since natural aggregate was completely replaced with recycled rubber as the filler in cement composites within the scope of this research, a decrease in the strength characteristics of the prepared composites was expected due to the high elasticity of rubber and the different density of both materials. The potential of the newly developed material is not heading towards the segment of structural concrete, but the application of this material will be directed to the segment of lightweight concrete fillers, thermal and sound insulating concrete.

In the future, the expected focus of further research will be the use of this composite based on recycled rubber as part of a sandwich panel. The main supporting element of the panel will be designed from concrete based on natural aggregate and the sound-absorbing layer will be made of a cement composite based on recycled rubber. Based on the presented results, 30–50 mm seems to be the optimal thickness of the absorbing layer. This panel should find subsequent use in the construction of noise barriers in busy line structures.

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