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THE PROPERTIES OF RECYCLED RUBBER FROM WASTE TIRES IN THE PRODUCTION OF CEMENT COMPOSITES

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ABSTRACT

This article presents the results of a study dealing with the use of a combination of recycled rubber from waste tires as a 100% substitute in the production of cement composites. Aggregate was replaced with recycled rubber in two ratios, namely the ratio of 50/50 and the ratio of 40/60 of the share of fraction 0/1 mm and fraction 1/3 mm. The designed formulas of cement composites were subjected to the tests of their physical and mechanical properties in order to determine the properties of the used recycled rubber combination. The tests included the consistency of the grain curve, mixing water properties, consistency of cement mortar, and strength characteristics (tensile flexural strength and compressive strength). The study presents results that are fundamentally different from the comparative samples and their use in the building industry; however, at the same time, they open up new possibilities of their utilization as a building material.

Keywords: Composite; Concrete; Mixing water; Recycled rubber granulate; Waste tire

1 INTRODUCTION

The development of the society and transportation is accompanied by an exponential increase in the production of tires. It is also associated with the production of waste tires [1]. In 2017, the global tire production exceeded 2.9 billion units. In the EU alone, more than 300 million tires are scrapped every year [2]. International organizations, such as the European Union, impose binding and pivotal targets on waste management, such as Directive 2018/851 on waste of the European Parliament and the Council [3]. The building industry has been trying to face the challenge of improving the environment for several years. Even here, there is a demand for environmentally friendly materials and a decrease in the ecological footprint. The building materials whose components have been modified or replaced with waste components, such as concrete fillers, contribute to the sustainability of the ecosystem and give a new perspective on waste materials as secondary raw materials. Cement and concrete waste materials from demolitions of buildings or structures have been used as sources of new building materials for many years. Many studies have focused on the use of fly ash, slag, glass waste, paper fibres and other materials used in the building industry [4-7].

A study focusing on the mechanical properties of high-strength concrete with the addition of rubber particles up to 30% volume replacement showed that the concrete-rubber mixture had higher mechanical damping properties compared to conventional concrete [8]. The addition of rubber particles in concrete increases its durability and crack resistance. The addition of 20% of rubber particles in concrete revealed an increase in frost resistance of concrete products by 89% with 2/4 fraction [9, 10]. Reinforcing concrete containing recycled rubber with synthetic polypropylene fibres increases the loading capacity and deformation of residual flexural strength, thereby increasing the overall toughness while reducing brittleness [11].

The utilization of waste materials as secondary raw materials and hence their recycling are being considered due to their great benefit in terms of the reduction of waste disposal and the environmental protection costs. Their practical use as new construction materials requires a thorough understanding and reliable prediction of their effects.

2 MATERIALS AND METHODS

Recycling of tires enables the recovery of precious materials, energy savings in relation to the primary production, and a reduction of the amount of waste. Recycled materials are obtained using a conventional method where the tires are mechanically separated into steel and textile at normal temperature. Other possibilities include cryogenic process (freezing resulting in tire decomposition) or pyrolysis, either taking advantage of conventional methods or a new one using microwaves or plasma. However, the way of recycled material utilization is essential for the economic success of recycling. A worn tire contains a number of chemicals with energy potential, but it is also a source of secondary raw materials. Tires are made of flexible rubber material whose construction is reinforced with textile and metal materials. Figure 1 shows the percentage composition of tires used for passenger and freight transport [12, 13].

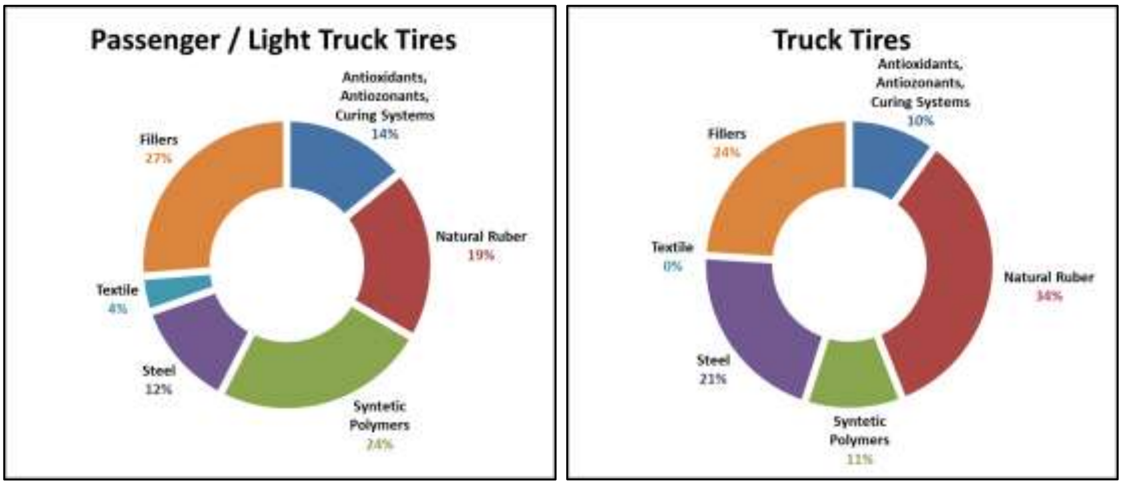

Figure 1. Composition of tires for personal and freight transport [14]

New formulas of cement composites based on volumetric aggregate replacement with recycled rubber have been designed. Two formulas containing different ratios of rubber granulate were selected. Z2 mixture contains a 50/50 ratio of the fine and coarse fractions, while Z3 mixture contains a 40/60 ratio of the fine and coarse fractions. The prepared test specimens were subjected to the tests of their physical and mechanical properties described below.

Cement

Blast furnace cement CEM III/A 32.5 N from Považská cementárna, a.s. EN 197-1 [15] was used as the mixture binder.

Mixing water

Drinking water from the water supply network was used as the mixing water for the production of the test specimens. The mixing water was tested according to ČSN EN 1008 [16].

Filler – recycled rubber

The aggregate was replaced with rubber granulate from waste tires with fractions of 0/1 mm and 1/3 mm, and it was used as the filler for the production of the test specimens based on the designed formulas. The rubber granulate was subjected to a grain size test - sieve analysis according to ČSN EN 933-1 [17].

Cement composite formulas

Two formulas were designed for the production of cement composites in order to determine the effect of a complete replacement of aggregate with recycled rubber. Their composition is presented in Table 1. 100% volume of aggregate was replaced, and the standardized aggregate weight (PG1, PG2, PG3) of 1350 g corresponds to the volume of 820 ml. In Z2 mixture, the replacement consisted of a 50/50 ratio of the fine and coarse fractions and, in Z3 mixture it was a 40/60 ratio of the fine and coarse fractions. Due to the partial compressibility of rubber granulate, the total volume of the input aggregate replacement with the recycled rubber was increased from 820 ml to 1100 ml. All the other input raw materials were recalculated.

Table 1. Composition of experimental formulas of cement composites

Formula	Comp.	Z2	Z3
CEM III 32,5 N [g]	450	604	604
Pure mixing water [g]	225	302	302
Sand [ml]	820	-	-
Granulate fr. 0/1 [ml]	-	550	440
Granulate fr. 1/3 [ml]	-	550	660

Volume 66 (2020), No. 1
p. 33–39, ISSN 1802-5420
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Determination of consistency of fresh cement mortar – diffusion test using a flow table

The consistency of fresh mortar was determined by means of a diffusion test carried out according to ČSN EN 1015-3 [18] using a flow table.

Determination of tensile flexural strength and compressive strength

The determination of tensile flexural and compressive strengths was performed after 3, 7 and 28 days of age of the test specimens according to EN 196-1 standard [19]. The testing was carried out using the prepared test specimens with the dimensions of 40x40x160 mm, which were stored in a water bath prior to the test. Formtest instrument with a compressive force of 100KN and 300KN was used as the testing equipment.

Determination of hardened mortar density

The test specimens prepared according to formulas Z2 and Z3 were dried to a stable weight and subsequently tested to determine the density of hardened mortar according to ČSN EN 1015-10 standard [20].

3 RESULTS AND DISCUSSION

Determination of grain-size curve of recycled rubber

Sieves with mesh sizes of 0.063, 0.125, 0.25, 0.5, 1.0, 1.6, 2.0, 2.5, 3.0, 4.0, and 5.0 mm were used to determine the grain-size curve of rubber granulate with the fractions of 0/1 and 1/3 mm. The resulting grain-size curves are shown in Figure 2.

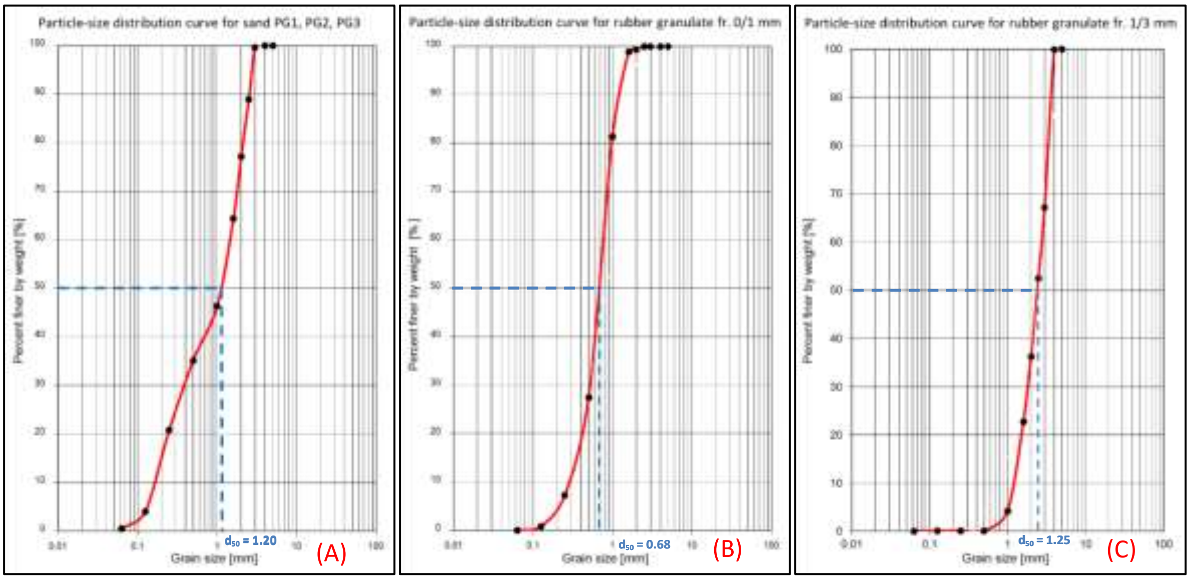

Figure 2. Results of grain-size curve determination: (A) comparative sample of standard aggregates PG1, PG2, PG3; (B) rubber granulate sample with the grain-size of 0/1 mm; (C) rubber granulate sample with the grain-size of 1/3 mm

The mean grain size was determined for the individual material types in the diagrams. In the comparative sample of standardized aggregate, the mean grain size is d_{50}=1.20 mm, for 0/1 fraction rubber granulate d_{50}=0.68 mm, and for 1/3 fraction rubber granulate the mean grain size is d_{50}=1.25 mm. The results clearly show that the mean grain sizes for the comparative standardized aggregate and 1/3 fraction rubber granulate are almost identical, but in 1/3 fraction rubber granulate, there is an almost negligible amount of fine fraction. These missing fine particles are replaced with rubber granulate with the fraction of 0/1.

Determination of consistency of fresh mortar

Manual shaking table with a metal cone was used to determine the consistency of fresh mortar. The resulting values are presented in Table 2.

Volume 66 (2020), No. 1
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Table 2. Values of fresh mortar diffusion

	Sample		
	Comp.	Z2	Z3
Diffusion ø [mm]	170.5	121.0	123.0

It is clear from the results of the diffusion test of fresh mortar that the addition of recycled rubber in cement mortar impairs its workability. The change in workability is directly proportional to the amount of added coarse fraction of recycled rubber. With a higher content of coarse fraction of rubber granulate, the workability is worse. Workability can be influenced by plasticizing and super-plasticizing additives.

Determination of cement composite strengths

The strength of cement composites was determined according to ČSN EN 196-1 - Methods for testing cement - Part 1: Determination of strength [19]. The test specimens were subjected to tensile flexural and compressive strength tests. Formtest testing instrument with a compressive force of 100 KN and 300 KN was used as the testing device. The individual strengths were determined on cement composites which had been stored in a water bath for 3, 7, 14, 28 and 90 days.

Figure 3 and 4 clearly show the course of the individual measurements of tensile flexural strength and compressive strength. The graph shows the individual strengths of the test specimens stored in a water bath after 3, 7, 14, 28 and 90 days compared to comparative sample. It can be clearly seen from the dependencies that, with increasing storage time, the experimental specimens can withstand higher loads, both in terms of compression and in tensile flexural strength.

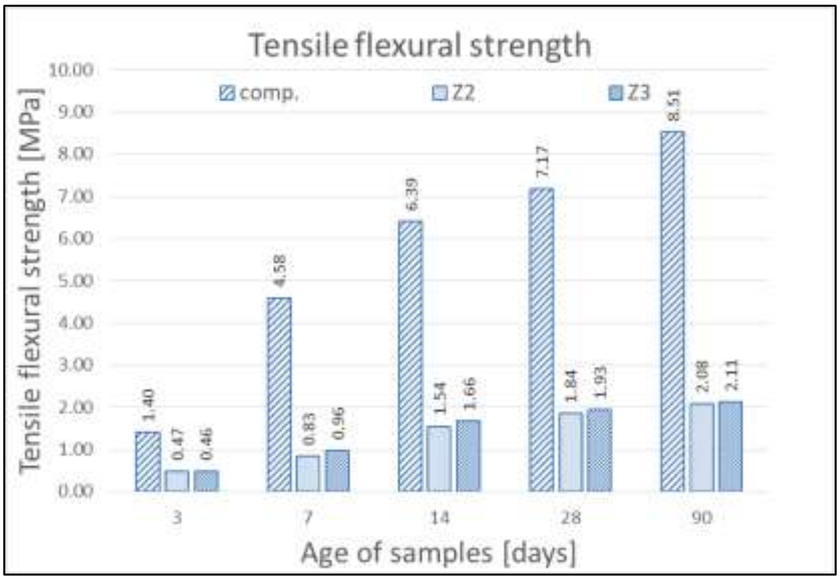

Figure 1. Graphic representation of tensile flexural strength

Volume 66 (2020), No. 1
p. 33–39, ISSN 1802-5420
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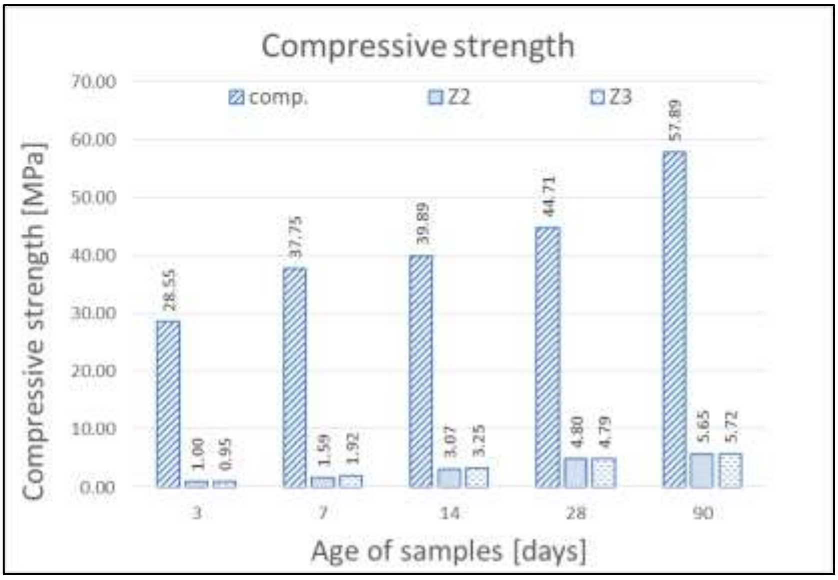

Figure 4. Graphic representation of compressive strength

Based on the results of the strength determination, a significant drop in both tensile flexural (Figure 3) and compressive strength (Figure 4) is visible in all samples containing recycled rubber when compared to comparative sample.

After 28 days, all samples of Z2 mixture, containing a 50/50 recycled rubber ratio of fine and coarse fractions, showed a 74.4% decrease in tensile flexural strength. The samples of Z3 mixture containing a 40/60 recycled rubber ratio of the fine to coarse fractions showed a 28.1% decrease in tensile flexural strength compared to the comparative sample after 28 days.

The compressive strength of both samples (Z2, Z3) after 28 days was lower by 89.3% in comparison to comparative sample. The decrease in the tensile flexural and compressive strength values is due to the high elasticity of rubber compared to the comparative sample with aggregate, which has no elastic properties. This results in lower tensile flexural and compressive strengths. The cohesion of the rubber particles with the cementing compound is significantly lower than the cohesion of the cementing compound with aggregate.

Density

The test specimens prepared according to formulas in Table 3 were dried to a steady weight and subsequently tested to determine the density of hardened mortar according to ČSN EN 1015-10 standard [20].

Table 3. Determination of density of hardened mortar

	Mixture		
	Comp.	Z2	Z3
Density [kg/m^3]	2150	1260	1250

The results of the determination of density (Table 3) clearly show that all the tested samples with recycled rubber belong to the category of lightweight concrete, namely class LC 1.4, with density within the range of 1200–1400 kg/m^3 according to EN 206-1 [21].

4 CONCLUSION

The results of the experimental research show that it is possible to replace aggregate with recycled rubber. The performed tests prove that replacing aggregate with rubber granulate may impair the workability of cement mortar, however, it can be influenced and controlled using a suitable plasticizer or superplasticizer. The test results further show that the use of recycled rubber significantly reduces the tensile flexural strength and compressive strength. The decrease in the tensile flexural and compressive strength values is due to the high elasticity of rubber compared to the comparative sample with aggregate, which has no elastic properties. The elasticity of rubber results in lower tensile flexural and compressive strengths, but the density values also have a great effect on the lower strengths of the tested samples. The results of the density values indicate that the samples belong to the LC 1.4 lightweight concrete category. This study presents results that are fundamentally different from the comparative samples and their possible use in the building industry. Some properties can be corrected or improved by using admixtures (e.g. plasticizers). At the same time, these results open up new possibilities for the utilization of this material as an environmentally friendly building material. The modifications of this cement compound and further testing of its physical and mechanical properties will be the subject of further research.

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