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The influence of the use of recycled rubber in concrete on its selected properties

Radoslav Gandel[1*], *Jan* Jerabek[1], and *Jaromir* Varak[1]

[1]VSB – Technical University of Ostrava, Faculty of Civil Engineering, Department of Building Materials and Diagnostics of Structures, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic

Abstract. The paper deals with the area of the use of recycled materials with regard to the potential of sustainable development of the construction industry. The need for recycling and new solutions in materials engineering is constantly growing. Potential sources of recycled raw materials also include rubber recyclate, where two mixtures with different proportions of recycled rubber are compared within the proposed experimental program. The researched mixtures reflect the need for local resources, which also reflects the needs of the circular economy. The experimental program is focused on typical mechanical properties, which are supplemented by specialized tests. Among the results of the experimental program is that with significant proportions of rubber granulate, not only the mechanical properties are affected, but also the durability is significantly affected with regard to the action of the external environment.

1 Introduction

It is very difficult to imagine current and future building structures without concrete. However, the very essence of concrete will be significantly innovated with regard to current possibilities and needs. All the basic parts of concrete, which include binder, filler and water, are limited by available raw material and energy resources [1, 2]. Among the important properties of concrete is that it is a quasi-brittle material that has different properties in compression and tension. Much attention is paid to the determination of properties and experiments with concrete in our country and in the world. Possible interesting solutions include, for example, the replacement of cement with alternative binders [3-5], which are usually alkali-activated materials, hybrid concrete or, generally speaking, composites [6-8]. Alkali-activated materials have great potential, where the main obstacle is the technological and rheological aspects of the materials. It is also advisable to find special application solutions for the mentioned materials, which may include, for example, hybrid beams. In any case, however, it is necessary to carefully handle the mentioned materials not only with respect to their basic mechanical properties, but above all with specialized tests and tests focused on durability. An alternative approach to new solutions for concrete is high-performance concrete (HPC), which still uses cement. However, the technical and useful

* Corresponding author: radoslav.gandel@vsb.cz

properties of HPC significantly exceed the application possibilities of concrete, where at the same time, excellent properties with regard to durability in the overall assessment of lifetime and environmental impact are an effective solution [9]. Interesting solutions include use in bridge structures or the possibility of combining concrete with fibers, resulting in fiber concrete [10-12]. From the point of view of the use of recycling in the design of concrete mixtures, there is the possibility of using recycled rubber, which replaces part of the aggregate [13, 14]. Despite some advantages of partially replacing aggregates with tyre rubber recyclate in concrete, such as sound absorption [15], most studies point to a significant reduction in the material characteristics and strength-mechanical properties of the resulting rubberized composite [16-18]. The application of tyre rubber recyclate in concrete appears to be ineffective at this point in the context of sustainability in the construction industry, as there are many other more appropriate uses for waste tyre rubber. This case is dealt with in the aforementioned article , which deals with the presentation of an experimental program for two mixtures with different dosages of rubber recyclates.

2 Methodology

The research presents a comprehensive experimental program, which in the first part was focused on the basic strength-mechanical properties of concrete. In the second part, specialized durability tests are performed. In the case of the first mixture, 70 kg/m^3 of rubber granulate was used, and for the second variant, 140 kg/m^3 of granulate was used as a partial substitute of aggregate. The manufacturer declares the granularity of the rubber granulate 1-3 mm with a bulk density of 448 kg/m^3 ± 5% [19]. The corresponding photo documentation is in **Fig. 1.**

Fig. 1. Used rubber granulate.

The composition of the mixture consisted in both cases (per m^3 of fresh mix) of: cement CEM I 42.5 R, Hranice (I - 410 kg, II - 380 kg), water (I - 185 kg, II - 172 kg), plasticizer Glenium 300 (I - 2.7 kg, II - 2.5 kg), aggregate Tovačov 0-4 mm (I - 930 kg, II - 700 kg), aggregate Litice 4-8 mm (I - 500 kg, II - 470 kg), recycled rubber (I - 70 kg, II - 140 kg). In the case of mixture II, the amount of recycled rubber was doubled. The water ratio of both mixtures was 0.45, average bulk density of the hardened samples of the first mixture reached the value of 2194.6 kg/m^3, the second one 2091 kg/m^3.

Compressive strength tests according to standard *ČSN EN 12390-3. Testing hardened concrete – Part 3: Compressive strength of test specimens* [20], tensile splitting strength due to standard *ČSN EN 12390-6. Testing hardened concrete - Part 6: Tensile splitting strength of test specimens* [21] and flexural strength tests (standard *ČSN EN 196-1 Methods of testing cement - Part 1: Determination of strength* [22]) were performed on samples of both mixtures. In addition, the presented experiment also included durability tests, namely determination of frost resistance due to standard *ČSN 73 1371 Determination of frost resistance of concrete* [23] and resistance to water and defrosting chemicals according to standard ČSN 73 1326 Resistance of cement concrete surface to water and defrosting chemicals [24]. The dynamic modulus of elasticity (measured by the ultrasonic pulse method) of the samples subjected to frost and the reference samples according to standard *ČSN 73 1371 Non-destructive testing of concrete – Method of ultrasonic pulse testing of concrete* [25] were also compared. The results from experimental program [26] are presented in the following chapter.

3 The results of the experiment

The following **Table 1** contains the values of the average compressive strengths and tensile splitting strength after 28 days, performed on cubes with an edge length of 150 mm. Each test series contained 5 samples.

Table 1. Strength characteristics and their respective variability indicators.

Mixture	Compressive strength [MPa]	Unbiased sample standard deviation [MPa]	Coefficient of variation [%]	Tensile splitting strength [MPa]	Unbiased sample standard deviation [MPa]	Coefficient of variation [%]
M. I	38.0	2.09	5.49	2.40	0.33	13.86
M. II	22.1	0.96	4.37	1.55	0.05	3

From the values in **Table 1**, it can be seen that both compressive strength and tensile splitting strength decrease with an increase in the content of rubber granules in the mixture. Doubling the amount of rubber granules resulted in a nearly 42% reduction in compressive strength compared to Mixture I and a 35% reduction in tensile splitting strength, also compared to Mixture I. In addition, a greater dispersion of the statistical dataset was recorded in the tensile splitting strength test of mixture I. The coefficient of variation reached a value of approx. 13.9%. The dispersion of compressive strength values was similar and relatively low for both mixtures. The coefficient of variation ranged from 4.4 to 5.5%.

In the following graphs in **Fig. 2** and **3,** it is possible to see the development of flexural strength and compressive strength over time, carried out on beams with dimensions 160x40x40 mm (6 pieces for one-day and seven-day strengths and 12 pieces for seventeen and twenty-eight-day strengths).

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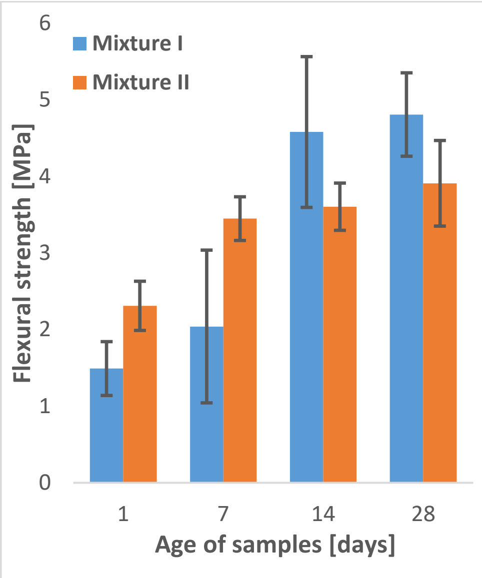

Fig. 2. Development of flexural strength.

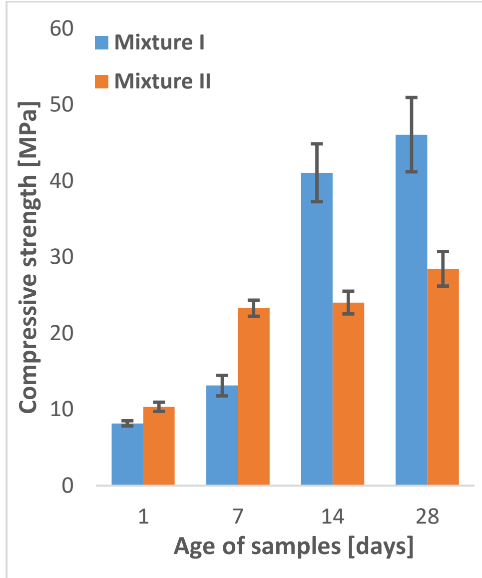

Fig. 3. Development of compressive strength.

As you can see in **Fig. 2** and **3** above, for both flexural and compressive strength, mixture 2 reached higher values in the first 7 days, after 14 days they increased only negligibly. Between 7 and 14 days, a high increase in both strengths was noted for mixture 1, but with a higher dispersion of values than for mixture 2. After 28 days, samples of mixture 1 reached a flexural strength of 4.8 MPa and a compressive strength of 46.1 MPa. Mixture 2 at this time acquired flexural strength of 3.9 MPa and compressive strength of 28.5 MPa. **Fig. 4** and **5** show the progress of the given tests.

Fig. 4. Test of flexural strength.

Fig. 5. Test of compressive strength.

Among other things, the listed mixtures were subjected to the test of frost resistance, tested on samples of 6 beams, for each mixture and given cycle interval, with dimension 160x40x40 mm and resistance to water and chemical de-icing agents, tested on 3 cubes, for each mixture, with an edge length of 100 mm. **Table 2** shows the coefficient of frost resistance after individual cycles.

Table 2. Coefficient of frost resistance.

Number of cycles	50	125	250
Mixture I	90%	109%	41%
Mixture II	49%	53%	39%

From the results of **Table 2** and due to the relevant [23], it follows that mixture I is frost-resistant for 125 cycles, mixture II is not frost-resistant.

Graphs in **Fig. 6** and **7** compare flexural strength and in compressive strength of both mixtures before and after a given number of freezing cycles.

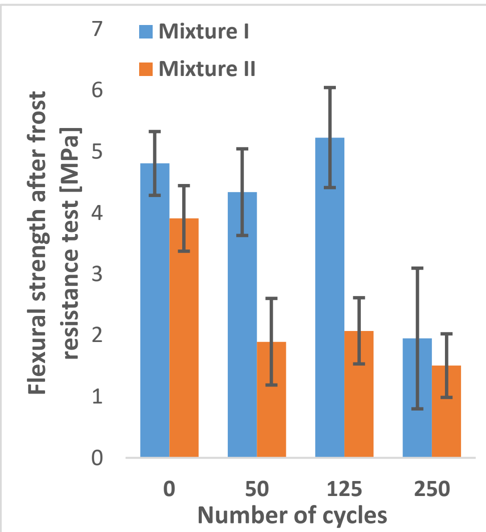

Fig. 6. Development of flexural strength after frost resistance test.

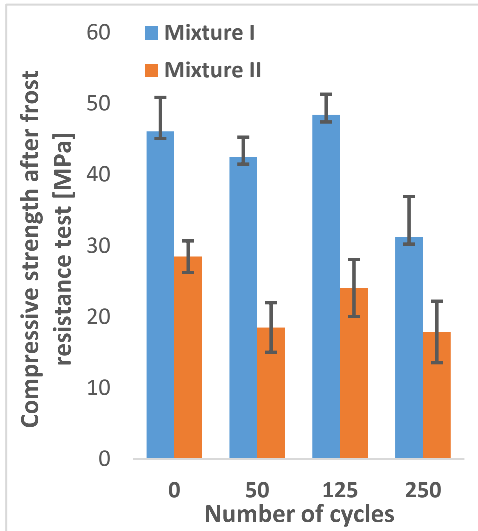

Fig. 7. Development of compressive strength after frost resistance test.

From the frost resistance coefficients in **Table 2** and from the graphs in **Fig. 6** and **7**, it is clearly seen that mixture I always achieved better flexural strength and compressive strength than mixture II after individual cycles. On the samples tested for flexural strength, a greater dispersion of values was also noticed than on the samples tested for compressive strength. The values of the compressive strength of both mixtures had a similar development as in the case of the flexural strength.

Another monitored characteristic during the frost resistance test was the change in the dynamic modulus of elasticity, also tested on beams with dimensions 160x40x40 mm, results are shown in **Fig. 8**.

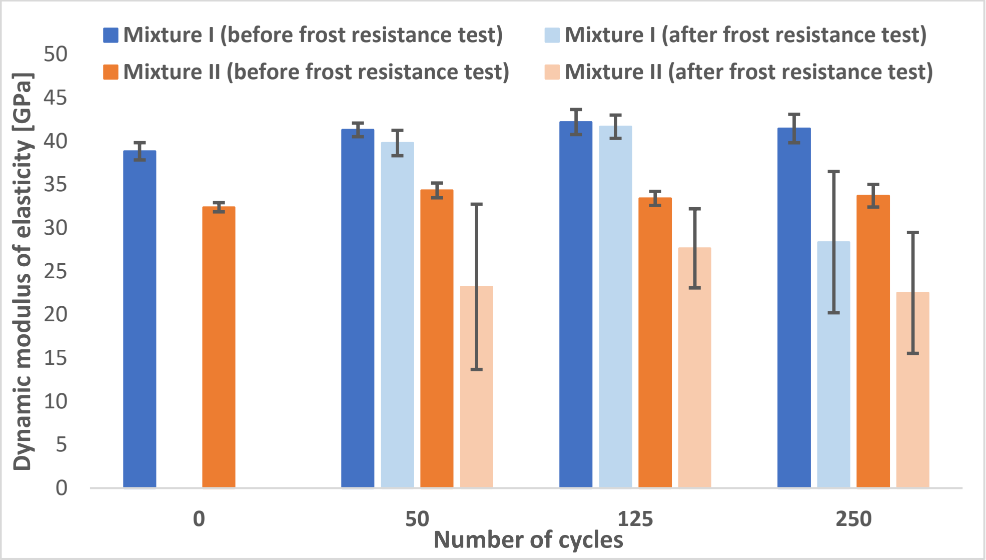

Fig. 8. Development of dynamic modulus of elasticity after frost resistance test.

Graph in **Fig. 8** shows a significant drop in the dynamic modulus of elasticity of mixture I after 250 cycles, with significant dispersion of values. Dynamic modulus of elasticity of mixture II decreased significantly after 50 cycles due to low frost resistance. The dispersion of values of the dynamic modulus of elasticity of mixture II fluctuated during the entire test period.

The last durability test was testing resistance to water and chemical de-icing agent on samples of cubes with an edge length of 100 mm (see the **Fig. 9**).

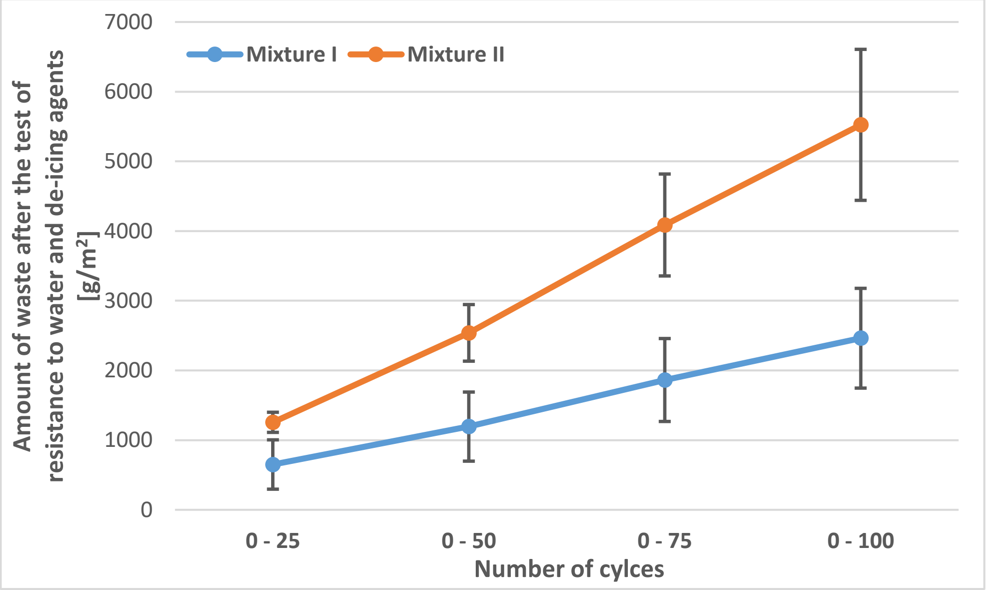

Fig. 9. Results of the test of resistance to water and de-icing agents

According to standard [24] mixture I with a waste of 2462.3 g/m^2, after 100 cycles, reached a level of disturbance of 3 (disturbed). Mixture II after the same number of cycles with waste of 3062.0 g/m^2 reached disturbance level 4 (strongly disturbed).

4 Conclusion

The presented research investigated the possibility of using rubber recycled from old tires as a partial substitute for filler in concrete. The strength-mechanical and durable properties of two mixtures with partial replacement of aggregates with rubber granules were observed.

Doubling the rubber granulate content from 70 kg to 140 kg (per cubic meter) reduced the 28-day compressive strength by approximately 42% and the tensile splitting strength by approximately 35%. The development of compressive and flexural strength was the same in the first 7 days: mixture II achieved higher strength characteristics, which could be used for structural elements requiring higher initial strengths. From the 14th day, a higher increase in strength was recorded for the mixture with half the content of rubber granulate. As with the cube specimens, the 28-day compressive strength of mixture 2 was approximately 40% lower than that of mixture 1. The 28-day flexural strength of mixture 2 was approximately 19% lower than that of mixture 1. Rubber recyclate provides strength and stiffness to the concrete composite, which is higher in the early stages of hydration than that of the cement matrix and fillers. Further investigation is worth testing rubber granules with rapid-setting cement, or as a partial replacement for filler in HPC.

Mixture I also performed better in durability tests. The frost resistance of this mixture was determined for 125 cycles, mixture II was evaluated as not frost-resistant. the development of compressive and flexural strength for both mixtures fluctuated, with mixture I it significantly decreased after 250 cycles from a value of 5.2 MPa to 1.2 MPa. With mixture II, a significant decrease was recorded after 50 cycles from a value of 3.9 to 1.9 MPa. The compressive strength increased and decreased moderately with the flexural strength. The frost resistance of mixtures also affected their dynamic modulus of elasticity, which, like the strength characteristics of mixture I, significantly decreased after 250 cycles and of mixture II after 50 cycles.

The test of resistance to water and chemical de-icing agents determined after 100 cycles a greater level of disturbance (4) in mixture II, where the waste reached a 50% increase compared to mixture. The more porous structure of the material with a higher content of rubber recyclate therefore limits the use of this mixture in environments with alternating freezing and thawing and environments in which defrosting chemicals are present.

Overall, mixture I achieved better results in all respects (except for compressive strength and flexural strength in the first 7 days, which could be used in structural elements requiring faster initial strength). Another interesting point is that increasing the content of rubber granules in the mixture affected the flexural strength less than the compressive strength, which could be tested in combination with reinforced concrete. However, the increase in rubber granulate adversely affects the durability of the resulting composite. The use of granulate within the framework of the circular economy appears to be one of the possibilities of recycling, but the effectiveness depends on the assessment with regard to the requirements for structural elements. The use of rubber recyclate as a partial replacement for aggregate is certainly cannot be condemned, but determining the optimal mixture is still in the early stages.

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