Mechanical properties and durability of crumb rubber concrete

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Abstract. This paper is focused on concrete with admixture of rubber powder, generally called crumb rubber concrete (CRC). The inspiration was found in Arizona, where one of the first CRCs has been created. However, Arizona has completely different climates than Central Europe. Could we use the crumb rubber concrete on construction applications in the Central European climate too? The paper evaluates the influence of the rubber powder on material characteristics and durability of CRC. CRCs with various contents of fine and coarse crumb powder were compared. The tested parameters were slump, air content, permeability, resistance of concrete to water with deicing chemicals, compressive and splitting tensile strength. The tests showed that workability, compressive strength and permeability decreased as the amount of rubber increased, but the air content increased as the rubber content increased. Photos of air voids in cement matrix from electron microscope were captured. The results of laboratory tests showed that admixture of rubber powder in concrete could have a positive impact on durability of concrete and concurrently contribute to sustainable development. Considering the lower compressive strength, CRC is recommended for use in applications where the high strength of concrete is not required.

1. Introduction
Increasing amount of waste materials in landfills has become a huge problem in the last decades. Fortunately, considerable amount of waste is recycled in developed countries. This includes for example glass, plastics, paper, electronic devices and worn tires. Constantly growing number of manufactured tires (1 billion in 2016, expected 1.2 billion in 2030) and permanently increasing number of worn tires in landfills created a problem of reuse of the worn tires.

Recycling is carried out in several ways. Worn tires can be incinerated at high temperatures or crushed to rubber powder. The difference between shredding at normal temperature and shredding at temperature below zero (cryogenic shredding) is in quality of rubber powder. Cryogenic shredding leads to higher grinding fineness, but it is more expensive.

The use of shredded tires as an additive to concrete can not only help to solve the problem of further exploitation of worn tires, it can also have positive effect on concrete properties. On this subject, several studies were created. The results of the tests showed that an additive of rubber powder could have a positive influence on deformability [1] and durability [2]. Frankowski [13] studied the influence of crumb rubber on reinforced concrete for structures. The results of his research showed that the addition of rubber powder in reinforced concrete improved the resistance to cracking, shock...
wave absorption and acoustic wave damping and lowered the weight and thermal conductivity of the material.

This paper is focused on workability, air content, compressive strength and splitting tensile strength of concrete with different amounts of added rubber powder and on the resistance of crumb rubber concrete to water with deicing chemicals. The values of concrete with an additive of rubber powder (crumb rubber concrete, abbreviated as CRC) were compared with concrete mixture without an additive (control mix).

2. Experimental program
Concrete mixtures with various amounts and particle sizes of crumb rubber were tested. Rubber powder used in this research was obtained by mechanical shredding at normal temperature. Basic content of rubber powder was 40 kilograms per cubic meter and supplementary content of rubber powder was 80 and 120 kilograms per cubic meter. Concrete mixture contained fine (0-1 mm) and coarse (1-3 mm) rubber particles in several ratios. Rubber powder was not used as a replacement of aggregate, it was added to the basic compounds. Concrete mix compositions are shown in Table 1.

### Table 1. Mix compositions.

| Compound              | Quantity in control mix (kg/m³) | Quantity in CRC mix (kg/m³) |
|-----------------------|---------------------------------|-----------------------------|
| Cement CEM I 42,5 R   | 410.0                           | 410.0                       |
| Water                 | 200.0                           | 200.0                       |
| Fine aggregate 0-4    | 840.0                           | 840.0                       |
| Coarse aggregate 4-8  | 340.0                           | 340.0                       |
| Coarse aggregate 8-16 | 620.0                           | 620.0                       |
| Stachement 2180       | 0.82                            | 0.82                        |
| Shredded rubber       | 0.0                             | 40.0 (80.0, 120.0)          |

All tests were performed with basic content of rubber powder, test of air content, compressive strength and splitting tensile strength were also performed with supplementary content.

Example of designation of concrete mixes: 40 - RUB - 0/100 = 40 kg/m³ of rubber powder, 0 % of fine rubber / 100 % of coarse rubber.

3. Tests of fresh concrete

3.1. Slump test
The tests were performed according to [10] for content of rubber powder 40 kg/m³. Ratios of fine and coarse rubber are shown in Table 2.

3.2. Air content
The tests were performed according to [11] for content of rubber powder 40, 80 and 120 kg/m³. Ratios of fine and coarse rubber are shown in Table 2.
3.3. Results
The tests showed that incorporation of rubber powder in concrete mix caused lower workability and higher air content in fresh concrete. The surface of rubber particles caught molecules of the air which entered the fresh concrete. Fine rubber has higher specific surface, therefore the fine rubber caught more air molecules than the coarse rubber. This is the reason why mix 40-RUB-100/0 had higher air content than other mixes containing 40 kg/m$^3$ of rubber. The surface of the rubber particles can catch molecules of water too. Higher amount of the fine rubber particles caught more water and therefore reduced the workability.

4. Mechanical properties of hardened concrete
The compressive strength of concrete specimens was determined according to [8] after 7, 28 and 45 days for 40 kg/m$^3$ (Figure 1) and after 7 days for 80 and 120 kg/m$^3$ of rubber powder in concrete mixes. Measurements were performed on 150 mm cubes. Measured values are shown in Table 3.

| Table 3. Compressive strength. |
|--------------------------------|
| Mix               | 7 days [MPa] | 28 days [MPa] | 45 days [MPa] |
|-------------------|--------------|---------------|---------------|
| REF               | 38.6         | 48.6          | 49.3          |
| 40 – RUB - 0/100  | 30.4         | 34.2          | 34.0          |
| 40 – RUB - 20/80  | 30.9         | 33.8          | 34.8          |
| 40 – RUB - 40/60  | 27.8         | 34.8          | 32.1          |
| 40 – RUB - 60/40  | 28.3         | 31.7          | 32.2          |
| 40 – RUB - 80/20  | 26.6         | 31.4          | 35.6          |
| 40 – RUB - 100/0  | 25.7         | 31.8          | 30.4          |
| 80 – RUB - 0/100  | 23.6         | ---           | ---           |
| 80 – RUB - 100/0  | 20.8         | ---           | ---           |
| 120 – RUB - 0/100 | 16.5         | ---           | ---           |
| 120 – RUB - 100/0 | 20.2         | ---           | ---           |

This research confirmed the results of other works focused on added rubber powder to concrete mixes [3] and [4]. Decrease of mechanical resistance has several reasons. The first one is the lower...
adherence between the cement matrix and the particles of rubber. This effect could be eliminated by chemical treatment of rubber particles before the mixing, as recommended by [5] and [6]. Chemical pretreatment of rubber improves adherence and mechanical resistance compared with rubber concrete without pretreatment. The next reason is higher content of air voids in cement matrix.

The splitting tensile strength was determined according to [9] for different amounts of rubber powder and only for 0/100 and 100/0 ratios of fine and coarse rubber. Measurements were performed on 150 mm cubes. Measured values are shown in Table 4 and Figure 2.

| Mix                  | Strength [MPa] |
|----------------------|----------------|
| REF                  | 2.5            |
| 40 – RUB - 0/100     | 1.9            |
| 40 – RUB - 100/0     | 1.8            |
| 80 – RUB - 0/100     | 1.7            |
| 80 – RUB - 100/0     | 1.5            |
| 120 – RUB - 0/100    | 1.3            |
| 120 – RUB - 100/0    | 1.2            |

The results showed that rubber powder has the same influence on the splitting tensile strength as on the compressive strength. The lower adherence and higher air content caused the decrease of the splitting tensile strength of concrete mixes containing rubber powder. Compressive strength and splitting tensile strength of concrete containing rubber powder has been investigated by several authors [3, 4] with similar results.

5. Resistance of concrete to water with deicing chemicals

Having in mind the influence of rubber powder to content of air voids in fresh concrete mixes, it was expected that the rubber will also influence the resistance to water with deicing chemicals. Previous studies have confirmed positive effect of added rubber powder to freezing and thawing durability [7]. A part of this research was focused on freezing and thawing combined with the effect of deicing chemicals.

![Figure 1. Compressive strength for 40 kg/m³ of rubber powder.](image1)

![Figure 2. Splitting tensile strength.](image2)

The tests were performed for mixes containing 40 kg/m³ of rubber powder in ratios 20/80 and 100/0. Measurements were conducted according to [12] on 150 mm cubes. Figures 3 and 4 show the
mass of scaled material after certain numbers of freezing and thawing cycles. The limits were reached after 32 cycles for mix 40-RUB-20/80 and after 129 cycles for mix 40-RUB-100/0.

The limit value of the mass of scaled material was 1000 g/m$^2$. This value was determined for exposure class XF4. Both tests were performed for 100 freezing and thawing cycles. For mix 40-RUB-100/0, the limit value was not achieved even after 100 cycles. Therefore the limit value was calculated by linear extrapolation.

The results indicated that incorporation of fine rubber powder to concrete mixes had a highly positive influence on the resistance to water with deicing chemicals. The air voids created additional space for expansion of ice and salt crystals. Optimum size and spacing of voids was confirmed by microscopic analysis.

6. Microscopic analysis

The photos from electron microscope were created for mixes 40-RUB-0/100, 40-RUB-100/0. The images were captured by primary electrons for all mixes, and also by secondary electrons for mixes with additive of rubber powder. The photos proved that the sizes and spacing of pores were better in the mix containing finer rubber particles; this corresponds with the results of the tests of resistance to water with deicing chemicals.

Figure 3. The result for mix 40-RUB-20/80.

Figure 4. The result for mix 40-RUB-100/0.

Figure 5. The photo of coarse rubber particle in cement filler by secondary electrons. Zoom - 50x.

Figure 6. The photo of coarse rubber particle in cement filler by primary electrons. Zoom - 50x.
7. Conclusion

Several tests of concrete with admixture of rubber powder were performed. The results indicated that the incorporation of rubber powder to concrete mixes had significant effect on the properties of fresh and hardened concrete. Laboratory tests included slump test, air content test, compressive strength, splitting tensile strength tests and test of resistance to water with deicing chemicals.

The results of macroscopic properties showed the following:

- As the content of rubber powder increased, compressive strength and splitting tensile strength decreased.
- In mixes containing 40 kg/m³ of rubber powder, the compressive strength generally decreased with increasing ratio of fine rubber powder to coarse rubber powder in earlier stages. After 45 days, the strength of all the mixes was almost the same.
- Fine rubber particles were significantly more efficient in increasing the air content than the coarse ones. The effect of the total amount of added rubber powder was less significant than the effect of fineness.
- Incorporating of rubber powder to concrete mix has also influence on workability. Workability decreased, as the amount of fine rubber increased.

Microscopic analysis performed for two selected mixes confirmed that fine rubber particles contributed more efficiently than coarse rubber particles to creation of optimal size and spacing of air voids in hardened concrete. This is a reason why the mix containing fine rubber particles had better resistance to water with deicing chemicals.

Acknowledgements

This paper was prepared thanks to the support of the Science Foundation of the Czech Republic (GAČR), project “Analysis of the relations between the microstructure and macroscopic properties of ultra-high performance concretes” (no. 17-19463S).

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