The effect of CO$_2$ on the strength characteristics of cement composites based on recycled rubber from waste tires

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Abstract. This paper presents the results of a research into the use of a combination of recycled rubber from waste tires as a 100% aggregate replacement in the production of cement composites. The aggregate was replaced with rubber recycled material in two ratios. At a ratio of 50/50 and a ratio of 40/60 fraction 0/1 mm and fraction 1/3 mm. The test specimens were further subjected to CO$_2$ effect in a Lamart laboratory chamber, where CO$_2$ effect was simulated as equivalent to an aging period of 50 years. The presented results show that the effect of CO$_2$ reduces the strength characteristics of the composite compared to the comparative samples.

1. Introduction
The boom in the automotive industry has been accompanied by a proportional increase in the production of waste tires, resulting in high environmental burden, because these tires are not properly stored and disposed of [1-3]. Following the example of the use of other waste materials as a secondary raw material [4-7], a potential research can also focus on the incorporation of recycled rubber material in cement composites [8,9]. In recent decades, great emphasis has been placed on the specification of the resistance of concrete structures. Along with a better understanding of the individual factors affecting the durability of concrete and reinforced concrete structures, many research teams are dedicated to improving the resistance of concrete [10]. The corrosion of concrete and steel reinforcement is the dominant cause of the deterioration in the properties of concrete structures, which leads to concrete degradation and a reduction in the effective reinforcement cross-sectional area [11-13]. Corrosion occurs as the result of carbonation of the surrounding concrete or the penetration of chloride ions [14]. Carbonation is a process during which carbon dioxide (CO$_2$) from the atmosphere diffuses the porous concrete microstructure and reacts with hydroxides, such as calcium hydroxide released from the hydration process, to form carbonates, thereby neutralizing the alkalinity of the concrete, leading to the degradation effects of the cement matrix [15-18]. At present, most research projects dealing with the effects of CO$_2$ on cement composites are concerned with the effect of CO$_2$ as the solidification and hardening accelerator in the early stages of composite formation [19-21] or as a possible CO$_2$ absorbent used to reduce its concentration in the atmosphere [22-24]. There are also researches focused on the influence of CO$_2$ on the resistance of cement composites depending on the individual components of the composite [25-27]. This article pays attention to the use of a combination of recycled waste rubber from waste tires as a 100% aggregate replacement in the production of cement composites and their resistance to carbonatation.
2. Materials and Methods

Two formulas with the designations of Z2 and Z3 (table 1) were designed on the basis of the properties already established before. The designed formulas had been exposed to CO₂ effects equal to 50 years and their strength characteristics were examined afterwards.

2.1. Cement

One type of cement was used for the designed formulas, namely CEM III/A 32.5 N Blast Furnace Cement. The amount of the cement used is presented in table 1.

2.2. Mixing water

Water from the water supply system according to ČSN EN 1008 was used as the mixing water [28]. The amount of mixing water used is presented in table 1.

2.3. Rubber granulate

Rubber granulate from waste tires with two fractions of 0/1 mm and 1/3 mm was used as the filler to fully replace standardized sand. The amount of granulate used is shown in table 1. Figure 1 shows the rubber granulate particle size analysis of fr. 0/1 mm and 1/3 mm compared to standard aggregates.

![Figure 1](image)

Figure 1. 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.

2.4. Formula design

Two formulas with the designations of Z2 and Z3 were designed in order to manufacture the test specimens from concrete based on recycled rubber. The compositions of the individual formulas per 1m³ of mixture are presented in table 1.
Table 1. Composition of experimental cement composite formulas containing rubber granulate and pure mixing water per 1m$^3$ of mixture.

| Formula                        | Comp. | Z2 | Z3 |
|-------------------------------|-------|----|----|
| CEM III/A 32,5 N [kg]         | 502   | 674| 674|
| Pure mixing water [kg]        | 251   | 337| 337|
| Standardized sand [L]         | 915   | -  | -  |
| Rubber granulate fr. 0/1 [L]  | -     | 614| 491|
| Rubber granulate fr. 1/3 [L]  | -     | 614| 737|

2.5. Strength characteristics
Tensile flexural strength and compressive strength tests were carried out in accordance with CSN EN 196-1 [29]. Beams with the dimensions of 40×40×160 mm were used as the test specimens. Form test instrument with a compressive force of 100 kN and 300 kN was used as the test equipment.

3. Results and Discussion

3.1. Surface carbonation
The comparative samples were cured for 90 days in a humid environment and subsequently exposed to CO$_2$ imitating a period of 50 years and then they were broken. A phenolphthalein indicator was applied to the fracture surface of the sample, and the area not affected by carbonation turns pink (figure 2).

![Figure 2](image_url)

Figure 2. Cement composite samples after the application of phenolphthalein of fracture surface: (a) Comp., (b) Z2, (c) Z3.
| Mixture | Total sample area [mm$^2$] | Carbonation area [mm$^2$] | Area affected by carbonation [%] |
|---------|-----------------|-----------------|------------------|
| Comp.   | 1613.1          | 715.2           | 44.4             |
| Z2      | 1648.6          | 731.6           | 44.4             |
| Z3      | 1632.1          | 709.4           | 43.5             |

Table 2. Carbonation area.

Table 2 presents the area affected by carbonation. It shows that the mixtures Z2 and Z3 have an area affected by carbonation of about 44%. The difference from the comparison sample is negligible. It is therefore clear that the use of recycled rubber did not affect the carbonation properties of the cement composites either in a positive or in a negative way.

3.2. Strength characteristics

Test specimens with dimensions of 40×40×160 mm were used for testing the tensile flexural strength and compressive strength. The determination of tensile flexural strength and compressive strength was performed on samples after 90 days of age and on samples subjected to CO$_2$ effect imitating a period of 50 years. The measured values of tensile flexural strength and compressive strength are presented in figure 3 and 4.

![Figure 3](image1.png)

**Figure 3.** Graphical expression of tensile flexural strength of cement composites exposed to accelerated carbonatation.

![Figure 4](image2.png)

**Figure 4.** Graphical expression of compressive strength of cement composites exposed to accelerated carbonatation.
It is clear from the results shown in figure 3 and 4 that the samples exposed to CO$_2$ have reduced tensile flexural strength as well as compressive strength. The comparative sample exposed to accelerated carbonation showed lower tensile flexural strength by 9.5% and compressive strength by 5.5% compared to the comparative sample not exposed to accelerated carbonation. The sample of the Z2 formula exposed to accelerated carbonation showed lower tensile flexural strength by 18.8% and compressive strength by 9.4% compared to the comparative sample not exposed to accelerated carbonation. The sample of the Z3 formula exposed to accelerated carbonation showed lower tensile flexural strength by 17.1% and a compressive strength by 8.6% compared to the comparative sample not exposed to accelerated carbonation.

4. Conclusion
This article presents the results of an experimental research of the use of recycled rubber from waste tires in the production of cement composites. The research was focused on the physical-mechanical properties of cement composites exposed to the effects of CO$_2$ representing the period of exposure of 50 years.

The results of the tests show that:
- the area of cement composite with recycled rubber affected by carbonation is comparable to that of the comparative sample, which means that the addition of the recycled rubber did not have any positive or negative effect of the composite to withstand the impact of CO$_2$.
- the comparative sample exposed to accelerated carbonation showed lower tensile flexural strength by 9.5% and compressive strength by 5.5% compared to the comparative sample not subjected to accelerated carbonation.
- both mixtures containing 100% replacement of natural aggregate with recycled rubber showed a decrease in strength compared to composites not exposed to accelerated carbonation. This decrease was almost double compared to the cement composites based on natural aggregate.
- the formula Z3 containing 100% aggregate replacement with recycled rubber in the ratio of 40% fraction 0/1mm and 60% fraction 1/3mm was rated as the most suitable formula containing rubber granulate.

5. References
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