Substitution of aeration additive with recycled rubber and its effect on compressive strength and modulus of elasticity

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Abstract. The article follows on previous research by authors dealing with the properties of concrete with the addition of recycled rubber. This paper describes the substitution of aeration additives with rubber recycled material and the effect of this substitution on strength and modulus of elasticity. For concrete mixes containing 40 kg/m³ of recycled rubber, the air content of the fresh concrete was measured. Concrete with the same amount of fresh air was made using an aeration additive. Compressive strength and modulus of elasticity were compared.

1. Introduction
Humans consistently exhaust the planet's natural resources and produce a large amount of waste that can not be recycled. The 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 an issue of reuse of the worn tires. Fortunately, used tires have found several ways of reuses.

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.

One of the ways how to use a shredded tire is to add rubber powder to concrete. 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 [3] 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 the substitution of an aeration additive by recycled crumb rubber. Different concrete mixes with defined amount of air in fresh concrete were performed. The values of concrete with an additive of rubber powder (crumb rubber concrete, abbreviated as CRC) were compared with concrete mixture with an aeration additive (control mix). The effect of substitution of an aeration additive by recycled rubber powder on compressive strength and modulus of elasticity has been investigated.

Protecting the environment, using waste material and conserve natural resources. This is a task for our and future generation. Especially, in civil engineering, there are many opportunities to save natural resources and reuse of waste material of other industries. The use of secondary raw materials can also positively affect the mechanical properties of concrete.
This article explores the possibility of using recycled tires as a replacement for aeration additives and the effect of this substitution on the strength and the modulus of elasticity of concrete.

2. Mixture composition
According to previous research by the authors, the addition of rubber powder has a positive effect on freezing and thawing durability [4].

At first, the content of the air in fresh concrete was measured for mixes contain 40 kg/m$^3$ of recycled rubber powder. Normal strength concrete with the defined amount of air in fresh concrete as FCRC was made. Values of air content are presented in table 1.

The tests were carried out in accordance with a valid European Committee for Standardization (CEN) 2009 Testing fresh concrete; Air content – Pressure methods Part 7 (EN 12350-7) [7]. The final compounds of concrete are shown in table 2.

| Concrete mix | Air content (%) |
|--------------|-----------------|
| CCRC         | 2.7             |
| FCRC         | 7.2             |
| AA           | 7.2             |

FCRC – crumb rubber concrete with finely (0-1 mm) crushed rubber powder
CCRC – crumb rubber concrete with coarsely (1-3 mm) crushed rubber powder
AA – Normal strength concrete with an aeration additive

| Quantity in FCRC (kg/m$^3$) | Quantity in AA (kg/m$^3$) |
|-----------------------------|---------------------------|
| Cement CEM I 42,5 R         | 410.0                      |
| Water                       | 200.0                      |
| Fine aggregate 0-4 mm       | 840.0                      |
| Coarse aggregate 4-8 mm     | 340.0                      |
| Coarse aggregate 8-16 mm    | 620.0                      |
| Shredded rubber             | 40.0                       |
| Water reducer               | 0.8                        |
| Aeration additives          | 0.0                        |

3. Results
3.1. Compressive strength
The compressive strength of concrete specimens was determined according to European Committee for Standardization (CEN) 2009 Testing hardened concrete; Compressive strength of test specimens Part 3 (EN 12390) [8] after 28 days. Measurements were performed on cylindrical specimens with 150 mm diameter and 300 mm height. Measured values are shown in table 3.
### Table 3. Compressive strength (MPa).

|         | Density (kg/m³) | Average force (kN) | Average strength (MPa) |
|---------|----------------|--------------------|------------------------|
| FCRC 1  | 2270           | 617.8              | 34.3                   |
| FCRC 2  | 2262           | 595.3              | 33.7                   |
| FCRC 3  | 2258           | 595.0              | 33.6                   |
| CCRC 1  | 2210           | 601.3              | 33.2                   |
| CCRC 2  | 2267           | 594.7              | 33.7                   |
| CCRC 3  | 2245           | 607.7              | 34.1                   |
| AA 1    | 2208           | 552.7              | 31.3                   |
| AA 2    | 2241           | 563.8              | 31.9                   |
| AA 3    | 2226           | 547.5              | 31.0                   |

#### 3.2. Modulus of elasticity

The modulus of elasticity is the ratio of stress and deformation. Materials with a higher modulus of elasticity require higher stresses to achieve the same deformation. In conventional construction, a higher modulus of elasticity is usually advantageous, but in particular cases material with a lower modulus of elasticity may be advantageous. These specific cases include load by shock-impacted or explosive. The explosive load of construction is treacherous, except that the pressure waves are dangerous as well as flying pieces of concrete released from the structure.

There is a relationship between the strength and the modulus of elasticity of concrete. If we produce a structural element that is capable of withstanding of load by explosion from high-strength concrete
with a higher modulus of elasticity, the overall damage rate will be smaller, but the speed of flying parts of concrete from the structure will be greater. This could be dangerous as well as the explosion.

The solution to this problem could be to use a material with sufficient strength but a lower value of the modulus of elasticity. The modulus of elasticity of the concrete depends on the composition of the recipe. If we want to reduce the modulus of elasticity of concrete, we need to add a compound with low modulus of elasticity to the concrete mixture.

The modulus of elasticity of concrete specimens was determined according to [9]. Measurements were performed on cylindrical specimens with 150 mm diameter and 300 mm height. Measured values are shown in tables 4.

### Table 4. Modulus of elasticity (GPa).

| Modulus of elasticity (GPa) |
|-----------------------------|
| FCRC 1 | 26.6 |
| FCRC 2 | 36.8 |
| FCRC 3 | 30.1 |
| CCRC 1 | 33.0 |
| CCRC 2 | 32.8 |
| CCRC 3 | 30.4 |
| AA 1 | 30.1 |
| AA 2 | 27.6 |
| AA3 | 28.5 |

### 4. Discussion

Nowadays, there are quite a number of different studies dealing with the addition of recycled rubber in various forms to the concrete mix.

For example, Zheng et al. [5] investigated the effect of replacing coarse aggregate with crushed rubber. In their study, among other things, they confirmed the indirect relationship between the amount of rubber added and the compressive strength and value of the modulus of elasticity.

Gerges et al. [6] observed the mechanical and dynamic properties of concrete with the addition of a variable amount of crushed rubber. They confirmed the assumption of a negative effect of rubber recycled material on strength, but also a favorable effect of rubber recycled material on the resistance of the material against dynamic loading.

The findings of the above and other studies are consistent with the author's review [4]. The aim of this paper was to understand whether the negative effect of adding rubber recycled material on strength and modulus of elasticity is primarily due to the recycled rubber and its low strength, or is due to increased air content in fresh concrete.

In the case of concrete containing coarsely crushed rubber recycled material (CCRC), the reduction in strength and modulus of elasticity is exclusively attributable to rubber recycled as the difference in fresh air content from the reference mixture is 0.6% and coarse rubber recycled can be considered as partial aggregate replacement.

Concrete containing finely ground rubber recycled material had comparable strength and modulus of elasticity to concrete with coarse rubber recycled material, but the air content was significantly higher than CCRC and REF. The reduction in strength and modulus of elasticity can be attributed to the increased of air content of fresh concrete since on the surface of rubber powder is more air and pores are situated around rubber powder.

The AA mixture tests which contained the same amount of fresh air as the FCRC mixture confirmed the relative compliance of the compressive strength. The modulus of elasticity was slightly lower than the FCRC and CCRC mixture.
5. Conclusion
Several tests of concrete with substitution of aerating additive by crushed rubber powder were performed. At first, concretes with the admixture of 40 kg/m³ of finely (FCRC) and coarsely (CCRC) crushed rubber were performed and the air content in fresh concrete was measured. Thereafter, concrete with the same air content as FCRC was made using aeration additive (AA). On these concretes compressive strength and modulus of elasticity were investigated. The results of tests showed the following:

- Finely crushed rubber powder is more efficient than coarsely crushed rubber powder as aerating additives.
- Using finely crushed rubber powder as substitution of aerating additive has a low positive influence on compressive strength and modulus of elasticity.
- Concrete made by aerating additive is more homogenous compared with finely and coarsely crumb rubber concrete.
- Shredded rubber powder can be used as a full replacement aeration additive without a negative influence on the strength and modulus of elasticity.

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