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Crushed rubber waste impact of concrete basic properties

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HIGHLIGHTS

- Waste tire crumb rubber classified into fractions 2/4 and 4/6.
- Sand in concrete mixes was replaced by crumb rubber at the proportion from 5 to 20%.
- Crumb rubber increase the predicted exploitation freeze-thaw resistance.

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ABSTRACT

Cement CEM I 42.5 N was used for the investigation. Waste tire crumb rubber classified into fractions 2/4 and 4/6 was used for the tests. Sand in concrete mixes was replaced by crumb rubber at the proportion from 5% to 20%. Compressive strength, water absorption, ultrasonic pulse velocity in concrete modified with crumb rubber were measured in the tests. Structural performance indicators of concrete specimens were calculated. The tests results revealed that compressive strength dropped 68–61.3%. The calculation of structural performance indicators showed that higher content of crumb rubber in the mix reduces the relative pore and capillary wall thickness and the spare pore space. With higher content of crumb rubber in the specimens the spatial inhomogeneity indicator gradually increases because the bigger amount of coarser rubber granule causes uneven distribution of pores and capillaries by their length. When up to 20% of fine aggregate in concrete mixes is replaced by crumb rubber the predicted freeze-thaw resistance increases.

1. Introduction

Nowadays waste handling and utilization has become a serious economic problem. Economic activities have a negative effect on nature. Therefore, the testing of the possibilities to utilise household and technological waste, such as furnace slag, agloporite, perlite, wood chippings and sawdust, crushed glass, shredded tire rubber, zeolites, small polystyrene granules (1–3 mm), polypropylene fibres, etc. is very important [1–6]. Almost all kinds of rock and a lot of industrial waste as well as organic raw materials are used in the production of construction materials. Natural fillers are obtained by means of processing natural rocks or from natural materials, for example wood, straw, flax etc. Some specific products or industrial waste, the structure of which was modified in the manufacturing process, are classified as artificial fillers, such as expanded clay, slag, polymers and others.

Waste tires have become a serious global problem. Every year almost 1000 million tires are disposed and 50% of them are not recycled. In 2030 the annual accumulation of tires will reach 1200 million. It is a very important ecological issue that needs an immediate solution [7–13]. Besides, waste tires present a fire hazard, especially in hot summers [19]. Decomposition of tires in the natural environment takes a long time as they are weatherproof and non-biodegradable. Obviously, the utilization of waste tire rubber will remain a problematic issue in the future. Vehicle tires are the main product of rubber industry. It is necessary to recycle used tires by separating the metal, textile and rubber that may be further used as reclaimed raw materials in the manufacturing of other products [7].

In mechanical-pressurised destruction of waste tires one technological line can recycle from 6 to 11 thousand tons of tires per year and from one ton produce approx. 550 kg crumb rubber, 270 kg metal scrap and 180 kg textile fibre. The diameter of rubber granules may range from 0.1 mm to 3.0 mm, according to the needs. The following fractions can be separated by means of sieving: 0.1–0.4 mm; 0.5–1.0 mm; 1.1–1.5 mm; 1.6–2.0 mm;

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2.1–3.0 mm and so on. Most of the properties that are important in using tires for their intended purpose are also essential in the use of tire waste as a raw material. Recycled tires maintain the following characteristics: slow growth of bacteria; resistance to mould, heat and moisture; resistance to sunlight or UV radiation, oil products, most thinners, acids and other chemical agents. In terms of physical characteristics tires are non-toxic and non-biodegradable; their weight and plasticity enable to use them uncut, shredded, granulated or powdered.

In the last decade the variety of materials and products manufactured from recycled tires has significantly increased. In civil engineering uncut or cut tires are used for the building of noise screens, insulation, light fillers, bridge supports, erection of landfills [7,12,13,15]. Product manufacturers use smaller fractions obtained by means of modern recycling technologies in the production of vehicle spare parts, coating, pigments [16–18]. The fine fraction of shredded tires is used in road building and repair [14,27].

Waste tire recycling technologies have also developed from simple mechanical machines used for tire pressing and cutting to complex multistage mechanical-chemical and/or thermal processing equipment [20]. Crumb rubber of certain fractions is used as an additive (up to 10–15%) in the manufacturing of new tires; as an additive (up to 25%) in the manufacturing of technical rubber products; manufacturing of rubber pipes (added up to 40%); roofing materials (up to 40%); track sleeper spacing (up to 60%) (from 14–15 to 60–70 tons per track kilometre); floor mats (10–100%); footwear soles (10–100%); wagon wheels (10–100%); tennis court flooring; road building; additive in construction concrete.

American researchers analysed the possibilities of using steel scrap from waste tires in Portland cement concrete. The use of crumb rubber and tire shreds in Portland cement concrete was among the main goals of the scientific research. The study, however, mainly focused on the use of steel granules in concrete mixes. The main variable of calculations in the study was the percentage of steel granules by volume. The test results showed that with the use of steel granules the compressive strengths reduces, but the hardness of the material significantly increases. Besides, there were no significant changes in the performance of prepared concrete mixes [21].

Researchers from Venezuela investigated concrete specimens by non-destructive methods. They tested the ultrasonic pulse velocity in concrete specimens with and without rubber admix. They found that in specimens where 5 wt% of fine aggregate was replaced with 0.59 mm fraction rubber admix the ultrasonic pulse velocity dropped 19%, and in specimens with 10 wt% of the same fraction rubber admix the ultrasonic pulse velocity dropped 41% compared to the control specimen. In tests with rubber admix of smaller fraction, i.e. 0.29 mm, the ultrasonic pulse velocity dropped 23% and 56% in the samples with 5 wt% and 10 wt% rubber admix respectively [22].

Chinese researchers also tested shrinkage, freeze-thaw resistance and thermal conductivity of rubber modified concretes. The test results showed that the softness of rubber particles from waste tires helps to reduce the shrinkage of concrete mixes. Rubber powder admix in cement concrete can significantly improve the freeze-thaw resistance of concrete products. However 3/4 fraction rubber particles with coarse surface have a very little positive effect on freeze-thaw resistance properties. The appropriate amount of rubber admixtures may significantly reduce the thermal conductivity of concrete, however too high content of rubber admix can cause a negative effect [30].

Good practice examples in Singapore and Asian countries prove that recycled tyre rubber may be used to manufacture both normal and high-performance concrete in tropical conditions. Tests with fresh concrete included slump, weight and air entrainment measuring. Hardened concrete was tested by non-destructive methods including density and ultrasonic pulse velocity measuring, as well as destructive methods to measure the compressive strength and axial destruction of concrete cylinders and obtain the stress-deformation curves. Modifications of water-cement ratio (W/C), aggregate substitution with rubber, rubber type, cement substitution with mineral admixtures and the change in the properties of rubber modified concrete were evaluated at different setting times and compared. Forecasts were done for normal and high-performance concrete modified with recycled rubber taking into consideration the characteristics of the mix and hardened concrete [23].

Crumb rubber may be used to replace a weight fraction of sand in the manufacturing of concrete products. Rubber granules tend to adhere well to Portland cement binder (cement paste) and bond well with the matrix. Mechanical properties (compressive and splitting strength) and density of concrete modified with crumb rubber depends not only on the rubber content but also and W/C ratio [24–26].

2. Materials and composition of the mixes

Cement CEM I 42.5 N was used for the tests. Plysical, chemical and mechanical properties of Portland cement CEM I 42.5 N presented in Table 1. It is a classical hydraulic binder. 0/4 fraction sand and 4/16 fraction gravel were used for the production of specimens. Physical characteristics of sand and physical – mechanical characteristics of gravel as well as particle-size distribution of fine aggregates were laboratory tested according to the methodology specified in the following standard EN 1097 series: EN 1097 – 7, EN 1097 – 6, EN 1097 – 5, EN 1097 – 3, EN 933 – 1, EN 1476 – 7. The characteristics of the fine aggregate are listed in Table 2.

Crumb rubber obtained from mechanical grinding of waste tires and divided into fractions 2/4 and 4/6 were used for the test. 7 batches of specimens were made. The control batch of specimens without rubber admixture was marked 0. Two fractions of different granule size 2/4 and 4/6 were used. Different weight percentages of crumb rubber substituting the fine aggregate were used: 5%, 10% and 20%. The selected polycarboxylate ether-based superplasticizer was added at 0.5% by weight of cement. Water and cement ratio was 0.35. The compositions of mixes with rubber additive are presented in Table 3. The mixes were designed in order to evaluate the effect of the rubber admixture on the characteristics of the specimens and their Structural performance indicators.

3. Test methods

The quality and durability of concrete depends on compressive strength, which is described as the ability to resist the destructive internal strains caused by external compressive loads. $100 \times 100 \times 100$ mm cubes were used to evaluate this property according to the methodology described in the Standard EN 12390-3. The density of concrete was measured according to EN

Table 1
Physical, chemical and mechanical properties of Portland cement CEM I 42.5 N.

Characteristics	Results
Specific density	2750–3200 kg/m^3
Bulk density	900–1500 kg/m^3
Melting point	>1250 °C
pH (when water temperature T = 20 °C)	11–13.5
Volume stability at curing	<10 mm
Initial setting time	>60 min
Compressive strength after 2 days	22 ± 3 Mpa
Compressive strength after 28 days	50 ± 3 Mpa