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Use of rubber crumbs in cement concrete

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Abstract. Rubber crumb obtained from worn out tires has been increasingly used over the last 15-20 years, especially in manufacture of asphalt and cement concrete mixtures. This review pays principal attention to application of the rubber crumb to cement concrete mixtures. Use of the rubber crumb in cement concrete is not as successful as in asphalt concrete mixtures, due to incompatibility problems linked to chemical composition and a significant difference in rigidity between the rubber crumb and concrete mixture aggregates. Different methods are proposed and studied to mitigate the adverse influence and increase the beneficial effects of the rubber crumb when added to cement concrete.

1. Introduction

About 850 metric tonnes of worn-out tires appear in Russia every year; about 17% of them are milled into rubber crumb, 20% are burnt, 63% are buried in landfills [1]. Starting from 2019, the Russian Federation prohibits landfilling of worn-out tires [2]. In order to reduce unnecessary landfills and conserve the environment, the processed tires may be used as an alternative feed in the construction industry.

During the last 15-20 year the world, including Russia, saw a growing practice of using the rubber crumb in asphalt concrete mixtures, evident from a large number of publications dedicated to this matter [3,4,5]. This direction of research is explained by good compatibility and interaction between rubber particles and asphalt binder, leading to improvement of a number of attributes and characteristics of asphalt concrete mixtures. However, some problems were discovered, limiting applications of rubber-modified asphalt concrete. Due to increased viscosity following addition of the rubber crumb, preparation of rubber-modified asphalt concrete requires a higher temperature compared to common high-temperature mixtures. Increase in preparation temperature of the mixture leads to increased cost of production. Necessity to introduce changes and modifications into existing equipment of asphalt concrete plants is a significant obstacle on the path to large-scale use of rubber-modified asphalt concrete.

Due to certain complications in the rubber crumb use with asphalt concrete, there is a trend to apply the rubber crumb in cement concrete mixtures, during the recent years.

2. Rubber crumb in cement concrete mixtures

Rubber crumb of varied size (from 50mm to 0.075mm) is used in cement concrete instead of coarse and fine aggregate. Khalid and Hameed [6] studied influence of rubber crumb content and size on placeability of concrete mixtures. The researchers note improved rheological characteristics of concrete mixtures, but also point to reduced compression strength of concrete samples with higher



rubber crumb content.

Eldin and Senouci [7] conducted tests to determine strength and impact ductility of concretes with aggregate partially substituted with rubber crumb. The results had shown lower compression strength and tear strength, while impact ductility increased significantly. The authors presented an explanation of fracture mechanism of rubber-modified concretes, developed from the theoretical strength of materials. Papers [8,9] also note that size and content of rubber crumb have significant impact on compression strength of concrete samples. More recent research of Bisht and Ramana [10] has shown that when 4% of fine aggregate is substituted with rubber crumb, compression and bend strength of rubber-modified concrete, its density, water absorption, wear resistance changed insignificantly, compared to check samples without rubber crumb. In [11] the authors note increased corrosion resistance of rubber-modified concrete.

Analysis of literature shows that the most common negative commentary about use of rubber crumb in cement concrete is a notion of some degree of a reduction of compression, tension and bend strength. The authors explain the significant loss of strength with two factors:

a) hydrophobic character of untreated rubber creating weak interfacial bonding between the rubber particles and cement slurry;

b) significant difference in rigidity between the typical concrete aggregates and rubber crumb. Rubber components behave like pores inside the concrete. Such pores concentrate stress from different loads, thus impairing strength characteristics of cement concrete samples. Thus, the larger the rubber aggregate size, the higher the porosity of a concrete mixture, and strength of corresponding rubber-modified cement concrete.

However, some researchers note that rubber-infused concrete becomes more deformable, evident from its increased impact viscosity and plasticity, thus allowing preventing brittle failure of cement concrete structures.

Most researchers record increased freeze-thaw durability of rubber-modified concrete. However, some researchers note that increased rubber crumb content actually impairs freeze-thaw durability.

An unquestionable advantage of rubber crumb-modified cement concrete is its lower weight in comparison with cement concrete with common aggregates. Rubber has significantly lower specific density than road metal or sand, thus replacement of a part of common aggregates with rubber crumb leads to lower specific density of cement concrete.

The analyzed literature shows that due to insufficient compression and bend tension strength, the principal area of application for rubber-modified cement concrete lays in structures, which are not subjected to significant loads. There are reports of successful use of rubber crumb in walling materials, pedestrian path surfacing in residential areas, garage floors, etc.

Lower strength indicators of cement concretes due to introduction of rubber crumb makes researchers search for possible solutions of this problem. It was proposed that using a finer grade of rubber crumb may prevent from a significant loss of concrete strength. A significant increase in compression and bend tensile strength was obtained only when the rubber crumb grain size approached that of cement particles (about 20 micron). Processing rubber crumb to obtain such fineness would inevitably increase cost of modified concrete mixtures.

Another possible approach to improve strength of rubber-modified cement concrete is to subject rubber particles to some kind of chemical treatment. It is known that rubber in its natural form does not form stable bonds with concrete cement matrix. Chemical treatment changes surface properties of rubber particles and may potentially improve bonding between rubber and cement slurry.

Segre and Joeke [12] used sodium hydroxide (NaOH) solution to treat worn-out tires before their inclusion into concrete. Lee et al. [13] used nitric acid (HNO₃) and water-soluble esters of cellulose (METHOCEL). A number of works propose washing the rubber with water to improve bonding between the crumbs and cement slurry. There were also proposals for pretreatment of rubber crumb with cement paste before its introduction into a concrete mixture. Li et al [14] studied influence of several factors (grain size, treatment time with NaOH, physical fixation with drilled holes through the

center, use of hybrid crumb of rubber and polypropylene fiber) onto improvement of quality of rubber-modified concrete. All types of surface treatment showed some grade of success.

However, no effects of any surface treatment were significant enough to prevent the degree of loss of strength due to introduction of rubber crumb. While surface treatment may somewhat improve adhesion, it cannot change the fundamental fact of incompatibility between rubber and cement component of the concrete mixture.

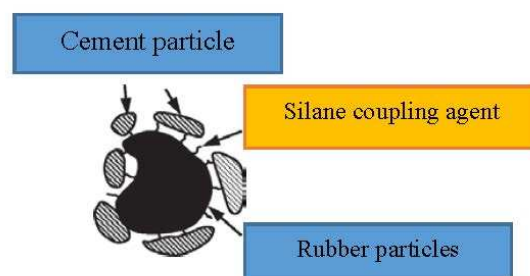
A combination of approaches in grain size reduction and surface treatment may help obtain modified cement concrete with desired strength characteristics. Lowering the production cost will be the key problem in resolving this issue.

The next trend having appeared recently in increasing strength characteristics of rubber-modified concrete is combined use of rubber crumb and steel fiber. Results obtained by Köroğlu [15] from testing rubber-modified concrete with addition of steel fiber showed significantly higher values when tested for compression strength, bending tension strength and fracturing tension strength in comparison with concrete containing only rubber crumb. However, the author notes that introduction of steel fiber in a ratio over 2% while providing high bending tension stress, may lead to mixture segregation thus having adverse effect on strength characteristics of rubber-and-steel-fiber-modified concrete.

Paper [16] presents an explanation for the role that rubber components play in properties of rubber-modified concrete. Its authors found out that rubber particles block diffusion of water in rubber-infused concrete, thus leading to insufficient hydration of cement in selected areas and reduction of strength properties of the concrete. To improve mechanical properties of rubber-modified concrete, the researchers proposed treating surface of rubber aggregates with organic sulfur or partially oxidizing them at high temperature. The proposed methods modified the rubber crumb surface, turning it from hydrophobic to hydrophilic, which led to improved compression and bending strength of the cement concrete.

Papers [17,18] propose two-stage treatment of rubber crumb surface, which is illustrated in Figure 1; such treatment allowed improving strength of modified cement concrete. The first state of the treatment is formation of chemical bonds between the rubber particles and cement paste due to action of silane binder; the second stage is increasing rubber crumb rigidity by creation of a solid envelope around the rubber particles bonded with cement materials. The results of the research show that compression strength of rubber-modified cement slurry may be improved by 110%. This method is also effective for improving the characteristics of rubber-modified concrete.

The methods, proposed for manufacture of strong and plastic rubber-modified concrete, significantly broaden its prospective area of application. Potential areas of application for rubber-modified cement concrete may be structures that are subjected to impact and dynamic loads (such as road surfacing, airport runways, railway sleepers, bridge superstructure slabs).



a

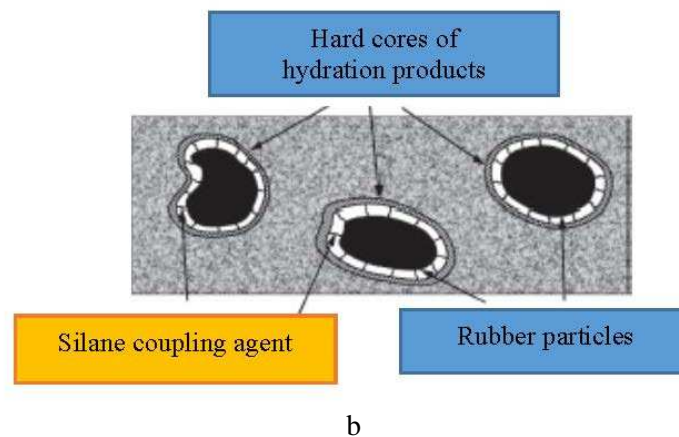


Figure 1: Two-stage treatment of rubber crumb surface: a – before treatment; b – after hydration.

3. Conclusion

The Russian Federation has a vast stock of worn-out rubber tires, which only grow with years. The limited area of their application forces to look for new areas of application for this type of waste. One of several prospective directions is use of rubber crumb in cement concrete. In comparison with application in asphalt concrete mixtures, use of rubber crumb in cement concrete is not so successful due to issues with incompatibility caused by chemical composition and significant difference in rigidity between common aggregates and rubber crumb.

Researchers proposed different methods to mitigate the adverse influence and increase the beneficial effects of the rubber crumb when added to cement concrete. Further studies in improvement of rubber-modified concrete characteristics will allow extending life cycle of cement concrete structures and improving environmental situation in the region of production.

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