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Utilization of waste rubber in non-structural applications

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HIGHLIGHTS

- Graded crumb rubber was used as fine aggregate replacement up to 100%.
- Composites of rubber–cement and rubber–epoxy were proposed.
- Surface treatment of rubber particles by polyvinyl acetate (PVA).
- Thermal and sound insulation properties were evaluated.
- Rubber composites have distinguished thermal and sound insulation properties.

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ABSTRACT

The main focus in this investigation is to study the availability of using waste rubber particles in non-structural applications. In fact, from the previous investigations, the implementation of waste rubber particles in concrete has a negative effect on the mechanical properties. This study aims to benefit from the high insulation properties of rubber to enhance the thermal and acoustical insulation properties of concrete. Furthermore, the properties of rubber–cement and rubber–epoxy composites were evaluated in this investigation, especially in terms of thermal and acoustical insulation. The concept in these composites is to use cement or epoxy as a binder for the waste rubber particles without any other additives.

The experimental program is divided into two parts. The first part focuses on the thermal and acoustical insulation properties of rubberized concrete at high rubber volume fractions. Also, the physical and mechanical properties of rubberized concrete were evaluated in terms of density, absorption, compressive strength, impact resistance, ductility and flexural strength. The second part is about the rubber–cement and rubber–epoxy composites. Three series of tests were conducted to determine the thermal and acoustical insulation properties in addition to stress–strain relations and the related properties for these composites.

1. Introduction

Solid waste management is one of the major environmental concerns in the world. Each year millions of tires are generated worldwide. In fact, tires are extremely durable and not naturally biodegradable. Also, waste tires stock piles are dangerous and considered a potential environmental threat due to the fire hazards and creating a breeding ground for rats, mice and mosquitoes. According to Rubber Manufacture Association (RMA) [1], about 265.8 million scrap tires were produced in the United States in 2011 and more than 80 million tires are currently in stock piles.

In the United Kingdom, it is estimated that 37 millions car and truck tires are being discarded annually and this number is set to increase with the growth in road traffic by 63% by 2021, as reported by Cairns [2]. According to the European Tire and RMA, over 3.2 million tons of used tires, about 220 million tires, were generated in 2010. Maciej Sienkiewicz [3] reported that, the annual global production of tires is about 1.4 billion tires, which corresponds to an estimated 17 million ton of used tires each year. The total worldwide production of waste tires represents 2% of total annual solid waste.

Topcu [4] studied the properties of rubberized concrete. Two sizes of rubber particles were used in Topcu's study; 0–1 mm as a replacement of fine aggregate and 1–4 mm as a replacement to coarse aggregate. The study stated that, all specimens withstood measurable post-failure compression load and underwent significant displacement. Also, displacement and deformations were

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partially recoverable upon loading. Topcu related this behavior to the fact that rubber particles have low modulus of elasticity, so high internal tensile stresses are produced perpendicular to the direction of the compression load applied. Thus, cement paste shows early failure because its weakness against tension, while rubber particles behave like springs which delay the widening of the existing cracks. Topcu suggested that rubberized concrete can be used in various applications such as; architectural applications as nailing concrete, in road constructions where high strength is not necessary, in wall panels that require low unit weight, in construction elements and jersey barriers that subjected to impact, in sound barriers as sound absorbers and in rail ways to fix the rails to the ground.

Khatib and Bayomy [5] reported that, two types of rubber aggregate were used, crumb rubber as fine aggregate replacement and tire chips as coarse aggregate replacement. From this work, compressive strength was reduced by 93% when coarse aggregate was fully replaced by tire chips. Also, crumb rubber caused compressive strength loss about 90% when fully fine aggregate replacement. For flexural strength, the initial rate of reduction was more pronounced than compressive strength. The same trend of reduction in the mechanical strength for rubberized concrete was reported by Toutanji [8].

Rubberized concrete exhibits ductile mode of failure as reported by previous investigations [4–6]. Moreover, rubberized concrete shows enhancement in toughness. Gideon Momanyi Siringi [7] stated that, at 7.5% replacement of fine aggregate, crumb rubber improves the modulus of toughness by 54%. Also, at 15% replacement of fine aggregate, the modulus of toughness for crumb rubber concrete is 15% higher than that of control concrete. Therefore, the addition of crumb rubber into concrete improves toughness and affect resistance. In addition, Gideon reported that, crumb rubber modified concrete has a lower elastic modulus, splitting tensile strength and modulus of rupture when compared with that of control concrete.

Tantala et al. [9] used rubber chips as a replacement of coarse aggregates by 5% and 10%. Tantala found that toughness of concrete increases significantly when rubber aggregate is used. Concrete mixture with 5% rubber content obtained higher toughness than rubberized concrete with 10% rubber content, which is due to the large reduction in concrete compressive strength as the result of usage at 10% rubber content. Moreover, Fibrous rubber was used in the study by Hernandez-Olivares et al. [10]. The study stated that fibrous rubber improves some properties of the mortar comparing to rubber granules. In particular, the crack width and crack length due to plastic shrinkage were reduced.

The bond between rubber surface and cement paste is the main parameter that control the reduction in mechanical concrete properties. Rubber surface texture is responsible for the week bond with cement paste, so improving the bond with cement paste can be achieved by using surface treatment of rubber particles before placing in the concrete mix [11].

Damping ratio of concrete was also studied by various investigations. The damping ratio of the materials is used to measure the ability of the material to decrease the amplitude of free vibrations on its body. Ching-Yao Lin et al. [12] studied the damping ratio of rubberized concrete containing 2 mm and #40 (0.42 mm) rubber powder. The results revealed that, at 2.5% replacement of fine aggregate by #40 rubber powder, the damping ratio of concrete increased by 94%. Also, the damping ratio of concrete increased by 56% when #10 rubber powders is used as a replacement of fine aggregate by 2.5%. Furthermore, Goulias and Ali [13] reported a large decrease in concrete damping ratio of rubberized concrete with the increase in rubber content increase.

Topcu [4] and Fatuhi and Clark [14] recommended the usage of rubberized concrete in application where damping capacity of concrete is required like railways stations and machinery foundations. Topcu [4] and Ali [15] indicated that, the impact resistance of concrete increases when rubber aggregate is used in concrete mixtures.

Most of the previous studies investigated the utilization of waste rubber in concrete for structural applications, but the results indicated a significant reduction in almost all the mechanical properties of concrete. Thus, the present study evaluates the use of rubberized concrete in non structural applications, which seems to be very promising. Furthermore, different types of rubber particles were used in the present study like crumb and fibrous rubber. Also, some of the previous studies [2,4,14,16,21,22,24,27,30,31] recommended that the thermal and sound insulation properties of rubberized concrete are considered a research need. In addition, new composites (products) were suggested in the research work. These composites were rubber–cement and rubber–epoxy composites.

2. Experimental program

2.1. Materials and studied parameters

2.1.1. Rubberized concrete

Type I Ordinary Portland cement according to ASTM C 150 was used in this research for all mixes. Natural siliceous sand and pink limestone of 3/8 inch nominal maximum size, were used as natural aggregates. Also, high range water reducer admixture Type F (synthetic polymers base) was used in the mixtures. Table 1, Figs. 1 and 2 present the physical properties and sieve analysis of the aggregates used.

Crumb rubber was used as a replacement of sand by volume. It was decided to use crumb rubber with the same gradation as natural sand. Three different sizes of rubber particles were used to provide that gradation. Mesh 40 (0.42 mm), mesh 20 (1 mm) and 2 mm rubber particles were mixes in portion 1:1:1. The physical properties and sieve analysis of the used crumb rubber is shown in Tables 2 and 3.

2.1.2. Rubber–cement and rubber–epoxy composites

Three types of rubber particles are presented in this part of the investigation as shown in Fig. 3. The first type is 4 mm crumb rubber from mechanically cutting process of waste truck tires. The sieve analysis of crumb rubber is presented in Table 4. The other two types are fibrous rubber. Fibrous rubber is a by-product from truck tires retreading process. Two types of rubber fibers are separated by sieving using standard sieves (ASTM E11). These two types are named Fiber 8 and Fiber 4 according to fiber size. Rubber fiber that passed through 2.36 mm (No. 8) sieve and retained on 1.18 mm (No. 16) sieve is called Fiber 8, while the rubber fiber that passed through 4.75 mm (No. 4) sieve and retained on 2.36 mm (No. 8) sieve is called Fiber 4.

Rubber particles were exposed to surface treatment to enhance the interface interaction between rubber particles and the used binder. The rubber particles were treated with polyvinyl acetate (PVA) for 30 min just before mixing with the binder [16].

Type I Ordinary Portland cement according to ASTM C 150 was used in the rubber–cement composites as a binder material. For rubber–epoxy composites, polyurethane epoxy resin was used in this study as an adhesion, which complies with BS EN 12004, ES 4118. This epoxy is a solvent free and slow drying adhesive. The physical properties of the used polyurethane epoxy are shown in Table 5.

Table 1
Properties of the used aggregates in rubberized concrete.

Properties	Natural aggregate		Limits (according to Egyptian standard specifications)
	Coarse agg. crushed pink limestone (N.M.S = 3/8″)	Fine agg. sand	
Specific gravity (SSD)	2.57	2.65	
Water absorption (%)	1.92	1	⩽2.5 for coarse agg. and ⩽2.0 for fine agg.
Materials finer than 200 sieve by washing (%)	1.4	2.5	⩽3.0
Finesse modulus	–	2.67	