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Effects of spheroid and fiber-like waste-tire rubbers on interrelation of strength-to-porosity in rubberized cement and mortars

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HIGHLIGHTS

- Fiber-like waste-tire rubber has affected mechanical behavior and slump flow.
- Mechanical behavior and porosity relation was compared with previous models.
- Specific strengths of mortars have revealed an inverse effect with rubber content.

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ABSTRACT

The waste tire rubber represents a serious pollution and waste disposal problem. The aim of this experimental investigation is focused on the interrelation of strength/porosity in the rubberized cement and mortars as a function of distinctive rubber morphologies. Experimental results show the interrelation of flexural (FS), compressive (CS) and specific (SS) strengths with porosity (*P*) and water absorption (WA) of the control and four distinctive rubberized cement pastes and mortars. It is found that the fiber-like rubber particles provide distinctive both the slump flow tendency and mechanical behavior. A bimodal distribution of the pore sizing between irregular and spheroidal morphologies is observed. Models of the compressive, flexural and specific strengths as a function of both the rubber content and porosity are also proposed. When a 5% (volume) of sand is replaced with rubber particles, a number of alternative applications (e.g. flexible pavement, building facades and water purification systems) can be induced.

1. Introduction

The increase of waste tires persuades to a serious pollution problem in terms of waste disposal [1–5]. A great problem in terms of ecological, environmental aspects and renewable resource energy is clearly evidenced. Alternative recycling procedures and reuse of tires [6] have been proposed in order to solve the mentioned problem. From new motor vehicles, a great number of their tires will be discarded contributing the ecological and disposal problems [6–8]. The rubber content into concrete for non-critical structures (e.g. building exterior wall, pedestrian blocks and sidewalks, partition walls, paving, crash barriers, lightweight aggregate, flexible pavement, building facades, etc) has widely been investigated [1,8–10]. For instance, a porous rubberized mortar improves a water purification system. It can potentially be used in a vertical barrier in order to catalyze the bacteria elimination treatment. It is also remarkable that the rubberized mortars are used in several applications, which requires ductility. Gupta et al. [11] have reported that the waste rubber fiber can be used as a sustainable material to improve the impact resistance and ductility of concrete. They have also demonstrated that the impact resistance of concrete improved on replacement of fine aggregate by rubber fibers and on replacement of cement by silica fume.

Reda Taha et al. [12] have also been declared that the tire rubber denotes a large volume of solid waste. Additionally, they have also reported that the choice of the optimal replacement ratio of the tire rubber particles with desirable strength and fracture toughness criteria can be attained.

Mechanical behavior of rubberized concrete using distinctive sizes and morphologies of waste tire has widely been reported [1–3,9–18]. During last 20 years, a great number of investigations

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[1–5,9–22] has been reported the rubber content affecting the properties of the cement mortars and concretes. In a recent investigation [1], it was reported a considerable decrease of both the compressive and flexural strengths in distinctive cement mixtures containing rubber particles. These authors have also demonstrated that the decrease in modulus of elasticity has increased the flexibility [1].

Other recent studies [2,23–29] have summarized and demonstrated the mechanical behavior and fresh properties of rubberized cement and concrete. Various investigations [1–5,9–22] have indicated the improvement on mechanical properties using refined rubber particles. On the other hand, some studies have indicated opposite tendency [1]. A counterbalance between the compressive and flexural strengths of a cement mortar and their hydration kinetic, pore structure, and morphology of hydration products has been reported [21]. Limitations concern to water-to-cement mass (w/c) ratio, type of cement, hydration degree, and the morphology and size are evidenced [21].

A study developed by Khatib and Bayomy [14] reveals that a w/c ratio of 0.55 without superplasticizer (water-reducer) with the sand being partially replaced with a 30% of rubber content provides results of the compressive (CS) and flexural (FS) strengths after 7 days of curing time of about 5 MPa and 2 MPa, respectively. Khaloo et al. [28] using a 0.45 w/c ratio associated with superplasticizer have shown that 25% and 37.5% of rubber contents shown the CS values of about 1.22 MPa and 0.81 MPa, respectively. Two recent studies [2,24] have shown that 25% of fine aggregate replaced with rubber particles have generated the results of the CS of about 5 MPa [24] and 30 MPa [2] when 0.30 and 0.45 w/c ratios were respectively used.

Experimental investigations provided by Nacif et al. [6] after 28 days of curing have shown the CS measurements of about 6 MPa and 10.5 MPa when 0.5 and 0.35 w/c ratios were respectively used. Using a 0.55 w/c ratio and after 7 days of curing, the study provided by Boudaoud and Beddar [25] has revealed the results for the CS and FS of ~15 MPa and ~1.5 MPa, respectively.

Nacif et al. [6] shown that a more finely distributed rubber particles (i.e. between 0.28/0.18 mm) has provided lower density and apparent porosity. They have also evidenced an increase of about 30% in the CS for a same w/c ratio (i.e. 0.35) when the distinctive rubber particles were considered (i.e. from 0.84/0.58 mm to 0.28/0.18 mm). On the other hand, an increasing of the rubber content from 5% to 30% with 0.35 and 0.5 w/c ratios and coarse rubber particles (0.84/0.58 mm) has induced to the CS of about 11 MPa and 6 MPa, respectively. With similar w/c ratios, the CS results were very similar when fine rubber particles were used (0.28/0.18 mm). It was also shown that the w/c ratio significantly affects the mechanical strength [6]. It was stated that a more refined rubber particle into cement improved the CS results due to the effect of water content on cement pore formation. It was also found that rubberized cement with 15% (w/w) of coarse rubber particles and a 0.35 w/c ratio (0.84/0.58 mm) has provided the CS about 20 MPa [6]. This represents a viable and economical recycling alternative for construction application [6].

Kong et al. [21] have also reported that the rubber content decreased the density and compressive strength. The silane acts as a coupling agent and it effectively contributes to the chemical bonding between the rubber and cement mortar [21].

In literature has been reported a great number of very important investigations concern to the effects of the waste tire rubber on the performance of mortars and concretes. However, those investigation concern to the cement pastes and mortars with rubber content using a HES cement is scarce. In this sense, one of the novelty of this proposed paper is focused on the effects of the pore morphology in the properties of hardened and fresh HES cement mixtures with distinctive rubber contents. Besides, a rubberized HES cement commonly attains their highest mechanical resistance and mixing cohesion after 7 days of curing. Based on the characterized morphology of a commercial rubber particle, it can be understood both the fresh and hardened properties of these proposed cement pastes and mortars. Additionally, the strength-to-porosity relation of the cement mortar is also scarcely reported. The present investigation shows the effect of distinctive porosity/water absorption levels for the rubberized mortars (i.e. 5%, 10%, 15% and 30%) on the flexural, compressive and specific strengths. The mechanical behavior of the rubberized mortar is associated with the rubber content. The specific strength as a function of the porosity and water absorption are also discussed.

2. Experimental procedure

2.1. Materials and cement mixture preparation

In order to evaluate the properties of fresh and hardened cement pastes and mortars a HES (High Early Strength) Portland cement was used. This HES cement has been selected based on their highest mechanical behavior (i.e. their highest strength), which is achieved at 7 days of curing. This is associated with their lower grains than other conventional cements. A HES cement has a more rapid water reaction (hydration) decreasing their curing. Additionally, it also has a higher mixing cohesion due to silicon compounds content than conventional cement. It is known that a more homogeneous cement paste induces to the rubber powder envelopment.

The cement composition and mechanical behavior are compliant with Brazilian standard ABNT NBR 5733:1991. Both chemical and physical characteristics after 7 days of curing are similar to CEM-I 42.5 HES (NBN EN 197–1), type I (ASTM C150) and AS 3972 type HE. Table 1 shows the chemical composition of the HES cement with their density of about 3.15 g × cm^{-3}. The fine aggregate is constituted by a natural quartzitic sand. Their fineness modulus and density are 1.64 and 2.65 g × cm^{-3}, respectively. The saturated dry density and the absorption of the sand are 1.52 g × cm^{-3} and 1.5 (±0.3)%, respectively. The sieve analysis of the used fine aggregate is shown in Table 2.

A carboxylated polyether-based high-range water reducer was used as superplasticizer in order to reach the flowability. Accordingly to those prescribed requirements at ASTM C494 and C1017, the superplasticizer depicts a density of about 1.19 g × cm^{-3}, pH = 6 and a viscosity lower than 150 cps (centipoise). It should be remembered that the cement mortars are absent of silane coupling agent, coarse aggregate (gravel) and viscosity-modifier admixture.

A sieve analysis of the recycled waste tire rubber is also shown in Table 2. The rubber particles have density of 1.16 g × cm^{-3} and they are ranged between finer and coarser particles, which are distributed in two distinctive morphologies, i.e. fiber and spheroid-like rubber particles. It is very important to remark that a company, which has requested their anonymous description, supplied the waste tire rubber particles. The as-received rubber powder is that commercialized into the market to be used in remolded tires, rubberized components, asphaltic application, etc. When the volume of the as-received material was characterized, the spheroidal and fiber-like rubber powders were determined. A bimodal distribution between fiber and spheroid-like rubber particles was determined. From the used volume of the rubber particles, the spheroid-like rubber constitutes of about 72% with 23% of their particles ranging between >0.06 mm and 0.1 mm. The fiber-like rubber particles constitute of about 28% from the total volume of rubber, with their sizes between >0.1 mm and 1.3 mm.

A 0.48 water–cement (w/c) ratio of the HES cement was designed as the control mixture. Table 3 shows the cement mixture proportions. A mechanical mixer with a rotation ~125 rpm was used in the mixing. Deionized water (pH = ~6) was used to constitute the cement paste mixtures. The cement and sand proportions were firstly mixed during approximately 1 min and before specific water volume was added and mixed during 1 min. The superplasticizer was sequentially added and mixed during 2 min. The rubberized cement mortars have their sand proportion partially replaced with rubber particles (containing 5%, 10%, 15% and 30%).

The control mixture (0% rubber) and cement mortars (with 5%, 10%, 15% and 30% of rubber content) were poured into low-carbon steel molds with dimensions of 40 × 40 × 160 (±0.8) mm. All desired mixtures were self-flowed into each selected mold. These samples were cured at 25 °C under a 60% of RH (relative humidity). At least three distinctive specimens were produced for each cement mortar. During a period of 24 h a polymeric thin film covered the specimens in order to avoid the water loss. After 24 h the specimens were removed from the steel molds and they were immediately immersed in water (environmental temperature) during 7 days before the mechanical tests.

2.2. The slump flow and water absorption tests

The slump flow test was carried out based on the ASTM C1437-07. A slump cone of 125 × 80 mm and with a height of 65 mm was used. The resulting spread diameters of each prepared cement mixture were carefully measured. The spread diameters were obtained from the averages between two perpendicular cross diameters.