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Technical Report

Physical and mechanical properties of foamed Portland cement composite containing crumb rubber from worn tires

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ABSTRACT

The management of worn tires is a concern in industrialized countries. The application of crumb rubber as lightweight aggregate in cement based materials is a green alternative for reusing this material. High replacements of natural sand by crumb rubber were studied and an air-entraining agent was employed to ensure a cellular structure in the cement-based composite. The obtained results from tests in fresh state reveal an improvement in workability. The tests conducted on hardened composite show promise for constructive applications where thermal and acoustic properties are required. The minimum requirement of mechanical strength for masonry units was achieved, since compressive strengths varied between 1 and 10 MPa. Finally, potential applications as a construction material have been highlighted.

1. Introduction

At the present time, the increase of worn tires in industrialized countries needs creative solutions to manage and reduce the volume that is generated year after year [1]. Rubber tires cannot be reprocessed and improper disposal of large amounts can seriously pollute the environment. The solutions adopted worldwide include: (i) reuse of re-treading tires and second-hand market, (ii) material recovery from whole, chopped, shredded and micronized tires, and (iii) energy recovering. Following this order, the well-known waste hierarchy is particularized for the management of worn tires. It reflects several ways of management of worn tires, prioritizing them from highest to lowest ecological quality. Nevertheless, the quantity of tires consumed in material recovery applications is lower than those generated at almost all industrialized countries, which already manage close to 100% of the generated tires each year [2]. The excess of tires that is not consumed by material valorization applications is used in energy recovery applications. For instance, in Spain, 42% of worn tires generated have been destined to energy recovery, mainly in cement kilns, 10% have been reused and 48% have been destined to material recovery in 2011 [3].

Waste reuse in concrete mixes is a feasible solution to waste reduction and it often achieves improved properties, turning concrete in a more versatile material [4–7]. In this study, material recovery of crumb rubber as lightweight aggregate in Portland cement mortar is approached. Material recovery of worn tires in cement based materials as aggregate has been broadly studied [8]. Observations made on rubberized concretes concluded that workability, fresh unit weight, and dry bulk density decrease as a measure that rubber contents increase [9,10]. In all cases, researchers have identified a loss of mechanical strength and static modulus, either flexural, compression, or tensile, even by using fibers [11–17]. This effect can be attributed to the lack of adherence between rubber and cement matrix [9]. Despite low mechanical strengths obtained, rubberized concretes have shown improved freezing-thawing resistance [18], chloride ion penetration [19], resistance to mechanical impact [20], depth damage against fire [21], and fracture toughness [14–16], when compared with plain concrete. More recently, the thermal [22–25], acoustic [24,25] and anti-vibration [26] properties have attracted the attention of many researchers.

In this study, the thermal and acoustic properties of mortar incorporating crumb rubber are strengthened by adding an air-entraining agent (AEA). Previous work conducted by Paine and Dhir [27] combined the use of rubber aggregates and AEA in concrete batches with a dual objective, (i) to accommodate the stresses generated by hydraulic pressure during freezing and thawing of water into the pore structure of concrete, and (ii) to obtain concrete with low thermal conductivity. The results reported therein showed improved durability against frost damage, and promise for applications were thermal insulation is required.

In the present paper, the acoustic properties were assessed: Ultrasonic pulse velocity and standard resonance vibration tests were conducted to assess the damping properties of rubberized

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mortars. Mechanical properties were also ascertained. Selected batches were produced to perform thermal conductivity tests. All properties observed were linked to microstructure observations with scanning electron microscopy (SEM). Finally, attending to physical and mechanical properties observed, practical applications as construction material were underlined.

2. Experimental details

2.1. Materials

Mortar samples with a water/cement ratio (w/c) of 0.5 by weight and aggregate/cement ratio (a/c) of 3.83 by volume were produced. Portland cement type CEM I 52.5R, with a density of 3.10 g/cm^3, was used. Rubberized mortars were produced combining crumb rubber (CR) from mechanical shredding of worn tires, and siliceous aggregate (natural sand). The density of CR and natural sand was determined with a pycnometer, using as working liquid acetone (density of 0.79 g/cm^3) and water, respectively. The density obtained for both aggregates were 1.15 g/cm^3 for CR, and 2.43 g/cm^3 for natural sand. Percentage contents of 40%, 50%, and 60% by volume of CR were studied. Rubberized mortars were targeted in function of the percentage content of CR as V4, V5, and V6 respectively. To further highlight the properties of rubberized mortars against plain mortar, a standard Portland cement mortar (MS) was produced according to EN-196-1 [28]. The particle size distributions for the aggregates used in this work are shown in Fig. 1.

For reference, the eigen-packing for CR and natural sand was determined experimentally. It was determined by packing of the aggregates in a graduated beaker of 250 cm^3. The eigen-packing (Φ) can be determined as,

$$\phi = \frac{m}{V \cdot \rho} \tag{1}$$

where m is the mass of the aggregate, V is the volume occupied by the aggregate, and ρ is the density of the aggregate. The eigen-packing was found to be 0.45 for CR and 0.68 for natural sand.

The air-entraining agent (AEA) was Genapol PF80 Powder, which is a low-foaming and non-ionic surfactant. It was added in amount of 0.125%, 0.250%, 0.500%, and 0.750% by weight of cement, to achieve a cellular structure (AEA levels: T1, T2, T5, and T7). Furthermore, control dosages without any AEA were prepared with a sulphonated melamine based superplasticizer Melment L10/40. It was added in amount of 1% by weight of cement, for all replacement levels of natural sand by CR (K series mortars: V4K, V5K, and V6K). In Table 1 are listed the working levels used in this study. A number of three samples per type of mortar were produced.

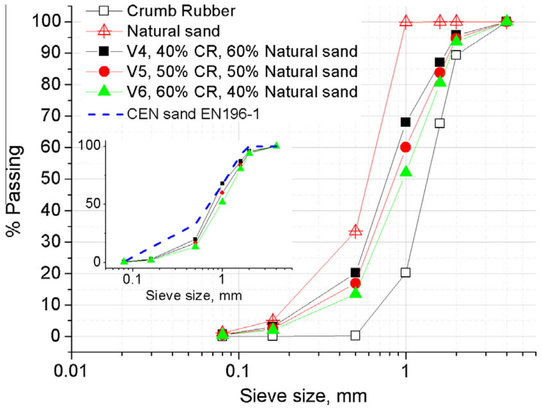

Fig. 1. Particle size distributions for CR and natural sand, and combinations of natural sand and CR studied (V4, V5, and V6). The inset shows particle size distribution of V4, V5, and V6 compared to CEN standard sand (EN 196-1).

Table 1
Working levels.

CR			V4	V5	V6
			40%	50%	60%
Superplasticizer		1.000%	V4K	V5K	V6K
AEA	T1	0.125%	V4T1	V5T1	V6T1
	T2	0.250%	V4T2	V5T2	V6T2
	T5	0.500%	V4T5	V5T5	V6T5
	T7	0.750%	V4T7	V5T7	V6T7

2.2. Tests procedures

The flow table test was performed on fresh batches in accordance with EN 1015-3 [29]. Prismatic 40 × 40 × 160 mm^3 test samples were produced and preserved in a moist chamber, at 20 °C and 95% of relative humidity for 28 days. After curing, the saturated mass was determined. The dry bulk density was also ascertained, after oven-drying the samples at 60 °C. Once the specimens reached constant mass, ultrasonic pulse velocity, in accordance with ASTM: C597, was determined with a TICO ultrasonic instrument, and 54 kHz transducers. The fundamental transverse frequency test, ASTM: C215, was also conducted. The excitation of resonance frequencies were achieved by dropping an alumina ball with mass of 12.5 g, from a distance of the sample of 10 cm. The excitation was sensed with an accelerometer (ICP model 352A21) with sensitivity of 0.956 mV/(m s^{-2}). A total of 8192 points were recorded with a sampling frequency of 25 kHz. Ten impacts per sample were recorded and transformed to the frequency domain with the FFT algorithm. Finally, the mechanical strength was obtained, in the displacement control environment at a rate of 1 mm/min, with a universal testing machine (INSTRON model 3382). Undisturbed fragments from mechanical tests were examined by scanning electron microscopy (SEM). Moreover, V4T5, V5T5 and V6T5 mortars were selected to prepare 150 × 150 × 20 mm^3 specimens, to determine their thermal conductivity with a thermal conductivity meter NEOTIM FP2C, based on hot-wire technique.

3. Results and discussion

3.1. Consistency of fresh mortar

The mortars were targeted in function of their slumped cone diameter as fluid, plastic or dry consistency in accordance with EN 1015-3 [29]. It was necessary to add superplasticizer in rubberized mortars without AEA, i.e. V4K, V5K and V6K, to obtain workable mortars. The batches classified as dry consistency mortars presented the formation of 0.5–1.5 mm balls during compaction. This phenomenon is not desirable in practice, and it can be avoided by increasing the w/c ratio, or by using superplasticizers. However, when the amount of water or superplasticizer dosage is increased, mortar segregation and bleeding can be caused. In particular, Turatsinze et al. [15] combined different superplasticizers and air entraining agents to prevent segregation and bleeding on rubberized concrete.

Fig. 2 shows the flow table test results, in function of the AEA content. The greater AEA content is added, the higher workability is obtained. All CR contents studied (40%, 50%, 60%) follow the same behavior regardless their CR content. The results have been fitted to the potential model