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Mechanical and thermal properties of concrete incorporating rubber and fibres from tyre recycling

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HIGHLIGHTS

- Fibers fixed to crumb rubber (FCR) from tyre recycling are successfully used as aggregate in rubberized concrete.
- Toughness and impact energy of rubberized concretes are increased when recycled steel fibres are added.
- FCR is cheaper than CR and enhances the energy absorption of rubberized concretes.
- Thermal conductivity of rubberized concretes is reduced with FCR aggregates.
- Concretes CR and FCR with low thermal conductivity and light weight can be used in rehabilitation of traditional flat-roofs.

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ABSTRACT

In this paper, an analysis of the mechanical and thermal properties of a sustainable concrete incorporating crumb rubber (CR) and steel or plastic fibres partially coated with rubber (FCR) is presented. Whereas CR is normally used as aggregate in concrete, FCR is a new aggregate. FCR consists of fibres partially coated with crumb rubber recovered from the tyre recycling process, during granulation and before the total separation of rubber. The mechanical properties of concrete with rubber getting up to 100% volume substitution of stone aggregate have been obtained through compressive, bending, impact and wear resistance tests. Young's modulus, toughness, toughness index and impact energy absorption are also studied. Concrete with FCR aggregate presents the same or even better mechanical behaviour than conventional rubberized concrete. The thermal conductivity (k) of concrete with FCR as aggregate is comparable to the k of concrete with CR, and it is also lower than the reference concrete. Finally, some proposals of constructive systems with rubberized concrete for thermal rehabilitation of buildings are analysed using pseudotime-dependent software, for which a significant reduction of the thermal fluxes can be observed.

1. Introduction

Nowadays, end-of-life tyres are valorised as material. Mechanical and chemical processes to obtain rubber granulate for construction and engineering derivatives have already been developed [1]. Many of the tyre recycling industries shred a mixture of tyres from cars and trucks, which are composed of different types of fibres. However the great majority are tyres from cars. This fact is important because the type of fibres is quite different depending on their origin: coming from car tyres or from truck tyres [3]. Tyres from trucks have steel beads formed by a cord of steel fibres of 0.15–0.32 mm diameter, but the fibres in the cars tyres are simple and randomly placed in the tyre. Tyres for trucks have a higher amount of steel fibres by weight: 15% cars-25% trucks, but a smaller amount of textile fibres than passenger tyres: 8% cars-1% trucks.

Crumb Rubber (CR) is commercialized and used as aggregate in plasters, mortars, concrete and asphalts. CR is good as an aggregate because it dissipates impact energy [2,3], it reduces the risk of high-strength concrete (HSC) spalling with fire. On the other hand, it reduces concrete stiffness without a high strength loss, because the volume fraction of rubber needed is only of a 2%. [4]. CR presents a good thermal and sound absorption in concrete, so it can be also used in many construction composites [5–7]. Rubber

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additives have also been studied in concrete for acoustic absorption, increasing the noise reduction coefficient from 0.1 for plain concrete to 0.5 for rubberized concrete [8]. Nevertheless, CR reduces the mechanical strength of concrete when replacing stone aggregates. Some authors have indicated strength reductions by up to 90% when sand is replaced completely, or by up to 80% when coarse aggregate is replaced by 60% of rubber [9–11].

On the other hand, steel fibres recovered from waste tyres are used as reinforcement in concrete, due to their good bonding to concrete matrix and tensile strength. Recycled fibre reinforced concrete presents increased toughness or fracture energy in comparison with plain concrete [12,13].

Fibers coated with rubber (FCR) is a new sustainable derivative obtained from tyres with less energy because they can be obtained by only processing with a granulator or cracker mill, before the components of the tyre are separated. FCR consists of steel and plastic fibres coated with crumb rubber recovered from the tyre recycling process, obtained during mechanical granulation, without other thermal or chemical treatments. Papakonstantinou has worked before with rubber beads, a recycled composite of rubber and fibres obtained from shredded tyres with a 50–300 mm length and 5-15 mm thickness [14]. However, when these composite aggregates were used, the concrete mechanical properties were drastically reduced due to its shape and size [14]. On the other hand, FCR has been studied by the authors in a previous work, as an aggregate with lower strength reductions than with rubber beads [11]. It was found, that higher compressive strengths can be obtained in concrete with FCR than with conventional CR as aggregate, up to amounts of 80% volume fraction (VF) [11]. However, when higher amounts of FCR (100%) are used, the balling-up effect of the fibres reduced the final concrete strength.

Nevertheless, a big effort to use rubberized concrete in structural elements has been done by the scientific community in the last decade. Some of the works focus on the improvement of the rubber aggregate interface with the concrete matrix, through the treatment of the rubber surface before it is added to the concrete [15,16]. Other research works use manufactured fibres as reinforcement, achieving an increase of the energy of fracture and impact energy of the rubberized concrete [17]. However, according to the literature, the VF of rubber aggregate has to be limited to around a 20%, and hence the amount of recycled rubber that can be reclaimed for structural concrete is small [18].

On the other hand, when mass concrete is used in external walls, thermal insulation is needed. The thermal conductivity of plain concrete is mainly dependent on the moisture content in the pores and on the VF of the aggregate, as well as on the water cement ratio and the admixture types [19–21]. The thermal conductivity of concrete can be reduced through the addition of an air-entraining admixture (aerated concrete) [22,23], or through lightweight aggregates (lightweight concrete).

These lightweight aggregates can be natural [24] or synthetic [25], or also polymers such as wood-derivatives [26–28], expanded polystyrene [29–32], rubber [7–9,19], PET [33–35]... etc., combined [32] or not. Some of these aggregates, as CR, come from recycling processes [36–38]. Moreover, CR also may have a significant effect on concrete mix air entrapment, which also reduces the thermal conductivity of concrete [19].

The goal of this research is to develop a sustainable non-structural concrete with a high amount of recycled rubber. Meanwhile, rubber is used for thermal conductivity reduction; recycled steel fibre is added to improve the mechanical properties of rubberized concrete. To that end, toughness, abrasion resistance, impact energy and thermal conductivity of concrete with CR and FCR are studied. Also, the relationship between thermal conductivity and bulk porosity are analysed. The results obtained are compared with those of previous published literature. However, further research needs to be done, because the amount of pores and their distribution is critical for explaining the thermal behaviour. Finally, some constructive systems used for covers are analysed and proposals for thermal rehabilitation in buildings with traditional systems for flat roofs and covers are offered.

Promoting FCR as aggregate with low thermal conductivity, as it contains rubber and the fibre is partially covered, will also reduce environmental impact, increasing tyre recycling possibilities. Besides, concrete with FCR aggregate can have a lower cost than rubberized concrete with CR.

2. Materials and methods

2.1. Materials

A 42,5 MPa cement from Portland Valderrivas™ (CEM I 42,5 R) has been used in concrete mixtures. It presents a density of 3180 kg/m^3 and a Blaine fineness of 3750 cm^2/g. Siliceous sand and coarse aggregate from riversides have been used. Fig. 1 shows the particle size distribution of the aggregates used (cumulative finer fraction). Two types of rubber aggregates, CR and FCR, were used. The nominal densities of the stone aggregate, CR and FCR were 2.61 g/cm^3, 0.90 g/cm^3 and 1.10 g/cm^3, respectively. The composition of the rubber aggregates has been summarized in Table 1. Particles of rubber from FCR, were separated and their gradation studied later. The length and diameter distribution of steel fibres based on weight fraction are represented in Fig. 2.

2.2. Experimental work

2.2.1. Physical and mechanical tests

Concrete with compressive strength of 45 MPa, w/c ratio of 0.5 and without water reducer was used as reference. As the mixtures presented dry consistency, due to the fibres and rubber content, the mixing of the batches was done following a previous work [12]. The consistency of the fresh mixtures was determined using the Vebe test UNE-EN 12350-2:2009 [40], instead of the slump test UNE-EN 12350-3:2009 [41], as to compare samples with fibres to those without fibres.

Proportions of concrete series are presented in Table 2. Reference concrete was modified by volume substitution of stone aggregates by rubber aggregates, from 20% to 100%, according to a previous work done by the authors [12].

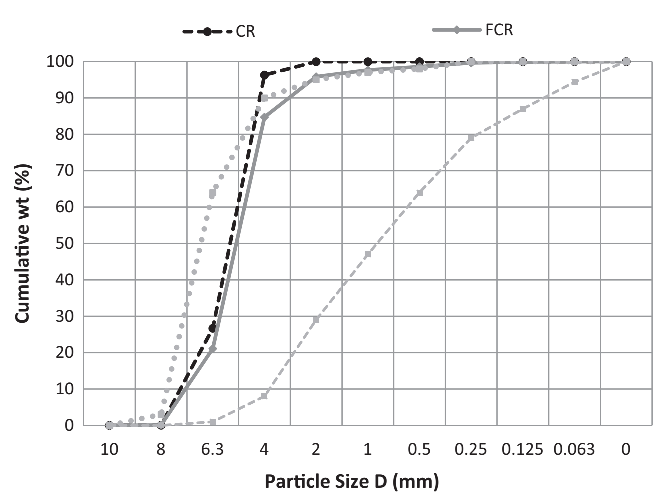

Fig. 1. Particle size distribution of rubber parts of the aggregates used (cumulative finer fraction).