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Influence of fibers partially coated with rubber from tire recycling as aggregate on the acoustical properties of rubberized concrete

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HIGHLIGHTS

- An experimental acoustical characterization of rubberized concrete with and without fibers was carried out.
- Concrete with fibers partially coated with rubber can be used for sound absorption.
- Rubberized concrete with fibers have a better NRC than rubberized concrete.
- Concrete with 80–100% of FCR have an absorption coefficient similar to other EPC.
- High volumes of recycled rubber can be revalorized in non-structural concrete panels for sound barriers.

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ABSTRACT

The aim of this study is to analyze the main parameters that influence the acoustic properties of lightweight concrete containing high volume of recycled rubber aggregates. To that end, the sound absorption and the sound insulation on rubberized concrete are tested under different frequencies. Concrete specimens were designed with 0–100% substitution of its coarse aggregate by two different rubber aggregates from recycled tires, which is up to a 60% of the overall concrete volume fraction. Moreover, to evaluate the influence of the external texture and the direct contact of rubber, concrete panels with different surface finishes (rough and smooth face) were casted. Crumb rubber (CR) and fibers partially coated with crumb rubber (FCR) have been studied for sound barriers. FCR are composed of steel and plastic fibers mixed with small rubber particles from recycled tires and obtained during the granulation process, before the complete rubber separation. The results of this research indicate that the combination of steel and textile fibers contaminated with rubber powder increase sound absorption when compared to ordinary or rubberized concrete. The addition of CR or FCR reduces concrete density and increases its open porosity. However, concrete with large VF of FCR presents an even larger volume of open pores than concrete with CR admixtures, which increases the sound absorption. In addition, the results obtained for sound insulation in high frequencies are also improved with CR and FCR, even when the concrete becomes lighter, because damping of CR and FCR concrete is enhanced. As a consequence, high VF of FCR (80–100%) can be incorporated to concrete for non-structural uses to increase sound absorption.

1. Introduction

Annually, end-of-life tires are accumulated on landfill sites. The storage control, elimination and recycling becomes a problem for the different State administrations. In Europe 300 million car tires and 17 million truck tires were produced in 2014 in European plants [1]. The elimination of tires by burning has been a common disposal undertaken using them as fuel for cement kilns, reducing energy costs but expelling large amounts of CO_2 into the atmosphere.

Nowadays, tires are commonly recycled through mechanical, cryogenical, chemical processes, or a combination of them, in order to obtain rubber granulates and fibers separately to be used in construction and engineering products [2]. These processes to recycle tires into rubber granulates are expensive, because the tires are resistant composites, made of a binder based on a cross-linked

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polymer with fillers (black carbon, silica, clay, etc.) with the addition of different types of fibers, designed in several layers [1].

The characteristics of rubber derivatives are modified depending on the process of tire recycling. The rubber derivates used in this work were obtained through a mechanical process that can be summarized as follows:

1 Tire pre-crushing for the production of shreds or chips (about 50×50 mm).
2 Granulation process using the flat die press/pan grinder mill for crushing the chips before a further processing.
3 Iron separation through magnets and classification into different rubber fractions. Crumb Rubber (CR) (commercialized sizes from 0.2 to 0.8 mm, 0.8 mm to 2 mm, 2 to 4 mm).
4 Cleaning of granulate to separate textile fibers from rubber through vacuums. Some plastic and steel fibers cannot be cleaned because they are partially coated with crumb rubber (FCR).

Two derivates from the mechanical process to recycle tires have been used in this work in high volume fractions as aggregate in concrete: crumb rubber (CR) containing only rubber, and fibers partially coated with crumb rubber (FCR). These two rubber aggregates have been studied by different authors previously, and the mechanical properties of the rubberized concrete obtained were published in their research works [3]. Meanwhile CR is well known, whereas FCR has not been so widely studied. CR and FCR used as aggregates reduce the static mechanical properties of concrete, but FCR show a better behavior than CR [4]. Papakonstantinou has worked earlier with a rubber aggregate from Tire recycling made of rubber and steel fibers such as FCR, called rubber beads [5]. However, the shape of the rubber beads is different from that of FCR, because the length of the steel fiber of the rubber bead is larger than those found in FCR, and also the size of the rubber component is bigger too [5].

In the last two decades, the different uses of rubber derivate products from end-of-life tires (ELT) in concrete have been studied, and the knowledge of its mechanical behavior has been developed [6–10]. These research works have concluded that the use of rubber as aggregate in concrete for structural uses has to be limited to low volume fractions, mainly in high strength concrete, because their mechanical strengths are reduced with the addition of rubber aggregates. The mechanical results may be different depending on the size of the rubber aggregate, whether the surface has been treated to improve the interface transition zone (ITZ) or whether the concrete is confined with special transverse reinforcement [10]. Same results were presented for concrete with rubber beads [5] or FCR [4], although industrial steel fibers slightly improved some mechanical properties in rubberized concrete [11]. The problem is that when rubber is used as aggregate in concrete for structural purposes a very low volume can be added, and this does not reduce the ELT stock problem. However, concrete with ELT derivate products might be used in non-structural construction products, allowing the addition of higher rubber volume from recycled tires [12–15].

Shredded rubber and chips of rubber with a planar shape are not appropriate in concrete, but they can be used in landfill sites as a lightweight filling for drainage in roofing and for thermal insulation control [16]. Granulate and powders from rubber tires are used as aggregate in concrete paving blocks, pillars, slabs and as rubberized bitumen aggregate for roads, which result in a good impact energy absorber [6].

Steel fibers recovered from waste tires have been previously used in concrete researches due to their pull-out behavior and compressive and flexural strength [17]. Plastic fibers recovered from waste tires have been used in recycled soundproofing materials [13].

Concrete is a dense material that insulates mainly by reflection, and its sound absorption coefficient is less than 0.05 [18]. Some researchers have made efforts to increase the sound absorbing properties of building materials in urban areas to reduce the noise, but keeping the insulation properties [18]. Sound absorbing materials with a porous structure absorb most of the energy allowing the sound wave to enter through the material while the wave energy is dissipated as energy [19,20]. Cavities, channels and interstices provide absorption properties depending on the frequency, composition [21], thickness and surface finishing.

Obtaining a porous concrete (EPC) is possible by using only one aggregate fraction, and usually a 2-to-6 mm gap grading [22]. EPC with 15–25% interconnected porosity has a good sound absorption behavior. Designs with 25% target void ratio for porous concrete, and a 50% target void ratio for porous concrete with recycled aggregates, are adequate for a good sound absorption [23]. It has been reported that in concrete the greater the target opened ratio the bigger the sound absorption coefficient (α) [24]. Openings generated in boards made of concrete and other porous materials are used to improve sound absorption property [25]. Besides, other authors have state that CR as aggregate increases the porosity of concrete in a similar proportion to rubber VF [26]. The absorption coefficient of concrete can range up to 0.7–1.0 in concretes for 40–150 Hz and up to 0.2 for 1 kHz frequencies, through foaming additives, but the mechanical resistances limit the possible use in building construction [27].

However, due to this mixture modification, concrete density and strength is reduced. As the material density is reduced, its sound insulation properties are reduced as well, because higher porosity makes a dense material become lighter and it reduces the mass per area decreased [28]. This fact can be corrected with an increase of concrete damping through the use of rubber as aggregate. The damping of rubberized concrete can be a 230% greater than in plain concrete. Moreover, rubberized concrete also has a greater ductility than plain concrete, with a 90% of enhanced energy dissipation [18,28].

The importance of porosity in asphalts used for road surfaces as sound absorber can be found in current scientific literature [29,30]. Porous asphalts with coarse aggregates and porous asphalts with CR reduce the noise generated by traffic on a frequency range around 900 Hz [31]. They reduce the noise because of the effect of muffling the vibrations caused by the tires on the pavement and because of the macrotexture of the road surface acting as sound absorber [32]. Rubberized concrete can be used also in noise control of highways when used as absorbing panel [12,14,33]. The sound absorbing properties of concretes with CR as aggregate have been studied, and although in the 125–250 Hz frequency range rubberized concrete was not a sound absorber, in a range over 500 Hz, the α were overall 0.37 with 20% of crumb rubber. Moreover, the noise reduction coefficient (NRC) obtained was 0.19 [16]. A different research work, nevertheless, displayed that the sound absorption of rubberized concrete with glass fiber was lower than 5% under the 1 kHz frequency and nearly 50% over the 1250 frequencies band [34]. Due to its good thermal absorption and sound properties, CR has also been studied as aggregate in concrete blocks [16] and as roofing material [20]. In addition, rubber has been studied as concrete aggregate in noise panels [12–14] and asphalts for acoustic proposes [18]. CR has been also used to increase the thermal and sound insulation in gypsum based composites [35].

However, the sound absorbing properties of rubberized concrete with fibers or with FCR as aggregate have not been found in the literature, and the research published works concerning sound properties of rubberized concrete are scarce.

The research presented here is of interest concerning specifically two facts: