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Sound absorbing materials made by embedding crumb rubber waste in a concrete matrix

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HIGHLIGHTS

- Sound absorbing concrete composites with embedded crumb rubber were made.
- Various analysis techniques helped to identify the best mixture.
- Sound absorbing coefficient α was higher than 0.5 for 9 of 12 samples.
- α reached top values of 0.82 and 0.93 when favorable conditions existed.
- SOM and PCA techniques were used to identify correlations and similarities.

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ABSTRACT

The aim of this study is to characterize the acoustical behavior of concrete made with crumb rubber waste from sport fields. Concrete mixes with different water to cement ratio (0.45, 0.50 and 0.55) and crumb rubber dosages (0%, 5.0% and 7.5% by weight) were prepared. Properties examined for the nine mixes included compressive strength, apparent density, apparent porosity and acoustic tests. Four additional samples with a modeled intrinsic porosity were subjected to acoustic tests in the frequency range 200–3000 Hz. Some samples with high crumb rubber dosage were selected to study the interaction between crumb rubber wastes and cement matrix. Self-organizing maps (SOM) and Principal Component Analysis (PCA) methods were implemented to generate visual clustering and to find out the correlations between experimental data.

1. Introduction

The increased level of traffic noise calls for appropriate methods for protection. Records of the sound level, for different types of vehicles and roads showed that, for a frequency range 150–3000 Hz, the maximum allowed sound level is exceeded to up to 20 dB [1]. This noise is mainly caused by the contact of tyres on the road, especially for speeds exceeding 40 km/h [2]. Therefore, the need for appropriate countermeasures has appeared. One of these methods consists in placing sound absorbing panels as a noise barrier. Such panels can be made out of plastic composite materials [3,4] or materials containing recycled rubber [5].

According to the last published Eurostat data, approximately 3 million tonnes of rubber and 17 million tonnes of plastic wastes were discarded in European Union in 2012 [6]. Plastic waste has several impacts on the health of ecosystems and humans through water and soil pollution. In recent years there has been considerable interest in using crumb rubber, produced in different shape [7], to replace a portion of natural aggregates in concrete mixes [8–10]. Concrete is a dense material with a very low absorption capacity of sound waves. Thus, for a standard composition, the absorption coefficient has a very low value, well below the limit which defines a sound absorbing material (which is 0.5). A review of the literature on rubberized concrete topic [11] found that rubber concrete has the advantages of absorbing of shock and earthquake shock-wave, besides an effective mean for sound control. A major drawback of rubberized concrete is the drop of compressive strength and permeability compared to non-rubberized concrete mixture [12]. Among the advantages of the composite material used in this paper, i.e. concrete – recycled rubber, are the creation of materials that lacked toxicity, uses waste in their manufacturing process, reduces both noise pollution and costs of raw materials.

Researchers have explored approaches such as chemical pretreatment of crumb rubber as a mean of reducing the mechanical

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strength loss in rubberized cement composites. Rubber pre-treated with sodium hydroxide (1M NaOH) and silica fume addition to improve the mechanical properties of the concrete was used by Pelisser et al. [13]. Chou et al. [14] studied the influence of treating waste tyre aggregate with waste organic sulphur compounds from a petroleum refining factory to modify surface properties of crumb tyres. Colom et al. [15] notes that by treating tyre waste with H_2SO_4 and HNO_3 the ability of rubber to interact with the high-density polyethylene (HDPE) was improved and material's stiffness increased. Despite the limited mechanical strength of crumb rubber concrete (CRC), its property of absorbing and reflecting sound [16] made this material suitable to mitigate ambient noise.

Discarded tyre rubber was extensively used as aggregate or cement replacement [17,18], particularly for sound absorption reasons [5] or road construction [19]. In contrast to previous studies, this paper investigates the potential of using the styrene butadiene rubber (SBR) as aggregate replacement. This rubber comes from sport fields and does not need to be grinded, its grain shape and size being statistically ideal. This approach offers an environmental friendly solution comparing with composites made with resins.

The main objective of this study is to obtain a material for noise protection, consisting of SBR modified concrete using NaOH-treated crumbs. The resulted composites were investigated by various tests. Altogether, a number of 94 samples of SBR modified concrete, including the specimens used to determine the compressive strength at 2, 7 and 28 days, were analyzed and characterized. The experimental results of apparent density and porosity, compressive strength, sound absorption property and characterization of microstructure by means of optical microscopy are presented. Within the obtained set of materials, it was aimed the identification of the best solution concerning the sound absorption coefficient. In the end, all experimental values for evaluated properties were analyzed by Self Organizing Maps (SOM) and Principal Component Analysis (PCA) to uncover patterns of correlations [20]. SOM is a useful technique that can transform the information related to a highly dimensional set of data into an intuitive two-dimensional map, in which it can be visualized the possible clusters of the initial data [21]. PCA is frequently employed to reduce the dimension of input space [22,23] as an aid-technique in various applications, especially those that use artificial intelligence [24,25], i.e. neural networks models dealing with a large number of inputs.

2. Materials and methods

2.1. Materials

The cement used in this investigation was CEM II/A-V 42.5R. Physical and chemical properties of the cement are given in Table 1. Type of cement choice was aimed at getting an enhanced SBR crumb - cement paste interface. A fine aggregate with size ranging

Table 1
Physical properties and chemical composition of the cement.

Physical properties	CEM II/A-V 42.5R cement
Apparent density (g/cm^3)	2.94
Specific surface (m^2/kg)	430
Residue on 90 μm sieve (%)	1.1
Water requirement of normal consistence (%)	32.9
Setting time (min)	
Initial	170
Compressive strength (MPa)	
2d	24.4
28d	55.6
Chemical analysis (%)	
SO_3	2.68
Cl^-	0.0068
Loss on ignition	2.84

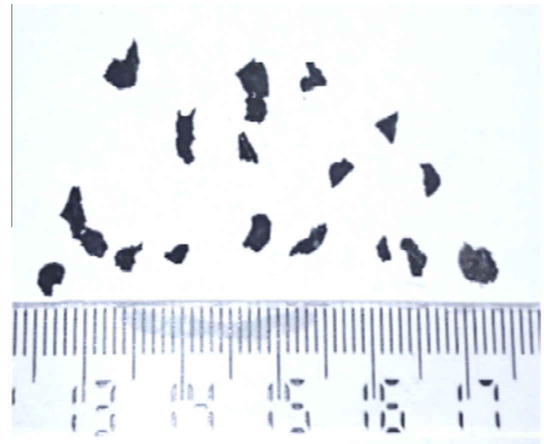

Fig. 1. Size and shape of SBR crumbs.

from 0.063 to 2 mm, and a coarse aggregate with size ranging from 2 to 16 mm were used in this paper, their grading being according to EN 933-2. The size of SBR crumbs varied from 0.5 to 4 mm (see the photographic view in Fig. 1). A polycarboxylate ether additive was used as superplasticizer.

2.2. Concrete mixture proportioning and casting

It was prepared one basic mixture, designated with code 1. In the basic mixture, 5%, and 7.5% by weight of fine aggregates were replaced by SBR crumbs. The mixtures were designated with code 2 and 3, respectively. The water/cement ratio (*w/c*) was considered 0.45, 0.50 and 0.55, and superplasticizer 0.8% by weight. The mixtures were designated A, B and C, codes that correspond to the three values of *w/c* ratio. Mixture proportioning specifications are detailed in Table 2.

Considering the above variables, nine different mixes were obtained according to the following procedure. The aggregate constituents were introduced into the mixer and homogenized for 30 s with a minimum amount of water added. Then the cement powder was added to the wet mix of aggregate and homogenization restarted. Subsequently, the remaining water and the additive were gradually added and stirring continued for 10 min. In case of rubberized concrete mixtures, SBR crumbs were added to the mixer immediately after the aggregates to have a distribution as homogeneous as possible. Our experimental set up was based on the adaptations of the conventional mixing procedures reviewed by Najim and Hall [26]. The steps of the workflow were carried out precisely as in the case of control samples (A1, B1 and C1). Since SBR crumbs does not present a rough surface, necessary for the cement to anchor the rubber granules, it was treated with a 1 M solution of sodium hydroxide (NaOH) for 20 min. Another reason for this treatment was to increase the hydrophilicity of the rubber particle surface. In order not to influence the material composition, the rubber crumbs were washed, dried and then introduced into the mixer.

Additionally, four samples had a special treatment in order to observe the influence of the sample surface on the acoustic absorption property. Thus, taking into consideration the most promising results of sound absorption coefficient previously determined, was chosen the sample with w/c ratio of 0.5 and 7.5% added SBR crumbs. On this sample it was intervened on the intrinsic porosity by inserting objects of various shape and size, as shown in Fig. 2. Three types of macroscopic pores were produced in the samples, namely cylindrical (P1), rectangular (P2) and squared (P3). The fourth sample (P4) contained all three types of macroscopic pores.