Laboratory Investigation on the Effects of Natural Fine Aggregates and Recycled Waste Tire Rubber in Pervious Concrete to Develop More Sustainable Pavement Materials

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Abstract. Pervious concrete pavement is a recognized sustainable solution for urban roads. To enhance mechanical properties of pervious concrete material, in order to allow wider use of this technology, a lot of studies are going on all over the world. The use of a little percentage of fine aggregates is proven to increase the material resistance without an excessive reduction of permeability. This study aimed to evaluate the effect of replacing the fine virgin aggregates with recycled tire rubber. 14 different mixes were analysed in terms of indirect tensile strength resistance, void content and density. Two different dimensions of crumb rubber were studied, as well as two different dosages, which were applied to different no-fine control mixes. All results were compared with the same control mixes containing natural fine aggregate. The mixes had a fixed granulometric curve but varied in water/cement ratio; this in order to evaluate the effect of recycled rubber depending to w/c ratio of the mix. An image analysis was also conducted to verify the rubber distribution in the mixture and the cracking surfaces. The experimental analysis showed that a correct proportioning of fine sand significantly increased the strength of the material. Moreover, the use of recycled waste tire rubber, gave interesting improvements respect to the no-fine control mixes, even though the developed resistance was lower respect to mixes containing mineral sand. This result was expected because of the cementing property of mineral sand. Although, the important result was that it was possible to use waste tire rubber in pervious concrete, with an appropriate dosage and granular dimension, for increasing the performance of traditional mix design, in order to achieve pavement materials more and more sustainable.

1. Introduction

Pervious concrete, as a pavement material, was developed as an alternative to traditional pavements in order to reduce the environmentally negative effects deriving from large impermeable surfaces in urban areas. Its porous structure allows water to percolate and naturally recharge the subsoil and to mitigate the climate of the surroundings after evaporating [1]. At same time, its clear colour permit a reduction of urban heating effect [2]. The great void content produces noise adsorption [3] and made the pavement a natural filter for contaminants [4]. Moreover, the elimination of water runoff, lead to a more comfortable infrastructure for all the type of users and generally higher safety.

To achieve the appropriate porous structure, gap graded granulometric curves are used in the mixes. Void content generally ranges between 15%- 30% [5] with correspondent densities varying between 1750 kg/m³ and 2100 kg/m³ depending on compaction and mix design characteristics [6]. Small w/c,
between 0.2 and 0.4, is designed and a cement content ranging between 0.18 and 0.23 is generally adopted to produce a reduced-volume mortar and preventing, this way, voids to be filled with cement paste [1]. Despite of the wider and wider use of pervious concrete, standardization of mix design, construction procedures and laboratory testing are still limited. A lot of researches are going on, all over the world, studying how to enhance mechanical properties of pervious concrete without an excessive reduction of permeability.

Recent investigations showed that a small portion of sand in pervious concrete mixes can enhance freeze-thawing durability, friction, resistance to ravelling and indirect tensile strength although an increase of mechanical properties, due to fine particles in the mix, correspond to higher densities and reduction of permeability [7, 8].

Fly ashes, polymers, latex emulsion, and reinforcing fibers have been included to improve strength and durability enhancing particle links [7, 9, 10, 11, 12, 13].

Some studies, are going on about the use of recycled fine aggregates in substitution of the virgin sand. One of the most innovative areas of research is the one of the re-use of recycled tire rubber in pervious concrete. In fact, during last few years many investigators are trying to analyze the effects of recycled tire rubber in civil engineering applications in particular in asphalt mixtures and Portland concrete. Typical amount of rubber used in substitution of mineral aggregate in pervious concrete mixture ranges between 5%-20% [14, 15, 16, 17]. Researches demonstrated that the use of rubber can enhance abrasion and freezing–thawing resistance [14, 15]. The same researches demonstrated a reduction in flexural strength, compression and other mechanical properties, but at same time a preservation of permeability and ductility of the material. The use of scrap waste tire rubbers produces environmental benefits deriving from the use of a waste material and from preserving raw materials. Good permeability and volumetric properties are usually guaranteed but mechanical properties can be reduced depending on rubber particle size and rubber proportioning [14, 15, 16].

2. Investigation method

The present research, focused on the effect of the addition of both natural and recycled fine aggregates to different pervious concrete mixtures. Both mechanical and volumetric properties were evaluated. In fact, pervious concrete cannot be designed with the only purpose of achieving the greater mechanical performances. In order to guarantee drainability and environmental qualities of the material, the optimal balance between strength and permeability is to be researched. The present study could be a starting point for further deeper investigations on pervious concrete containing fine recycled aggregates. Mixes, that showed better behaviour, could be furthermore tested on other mechanical, durability and volumetric properties.

2.1. Experimental plan

A total amount of fourteen different mixtures were texted. Two different no-fine control mixes were considered, varying in water to cement ratio (of 0.35 and 0.30) and characterized by the same coarse aggregate granulometric curve and a fixed cement to aggregate ratio of 0.20. Two different proportions of fine aggregates were considered: 5% and 10% in substitution of the correspondent volume of the coarse aggregate. Natural sand was considered as well as two differently gradated scrap rubbers. The investigation matrix, containing all the texted mixtures and the respective identification code are listed in table 1.
Table 1. The investigation matrix of all the studied mixtures and their code.

| w/c\(^1\) | c/a\(^2\) | Control | 5% sand | 10% sand | 5% coarse rubber | 10% coarse rubber | 5% fine rubber | 10% fine rubber |
|------------|-----------|---------|---------|---------|-----------------|------------------|----------------|----------------|
| 0.35       | 0.2       | Mixa0   | MixaS5  | MixaS10 | MixaCR5         | MixaCR10         | MixaFR5        | MixaFR10       |
| 0.3        | 0.2       | Mixb0   | MixbS5  | MixbS10 | MixbCR5         | MixbCR10         | MixbFR5        | MixbFR10       |

\(^1\) water/cement ratio; \(^2\) cement/aggregate ratio

2.2. Materials

A standard Portland limestone cement, with a minimum compressive strength at 28 days of 28.8 MPa, was selected for this study according to ASTM C 1157 [18].

The sieve size distribution curves of all the granular materials, used in this research, are reported in figure 1, according to EN 933-1 [19].

Figure 1. Sieve size distribution curves of (a) Coarse aggregates, (b) fine aggregate/sand, (c) Coarse rubber, CR and (d) fine rubber, FR

The two different rubber gradations were studied in order to evaluate the influence of particle dimension on the properties of pervious concrete. Size gradation of natural sand located between coarse rubber one (CR) and the one of the finer rubber (FR), respectively shown in figure 2(a) and 2(b).

Figure 2. The two gradation of the studied scrap rubber. (a) Coarse rubber (CR) and (b) fine rubber (FR)
2.3. Specimen preparation
Texted specimens were mixed with a standard drum mixer, and compacted according to EN 12697-30 [20] by mean of Marshall compactor hammer. Indeed, it has been demonstrated that the impulsive compaction is suitable for laboratory production of pervious-concrete specimens to obtain similar particle distributions than real scale applications [21, 22]. In the present research, ten Marshall compaction blows were applied, in order to obtain the “optimal” strength-permeability balance according to author previous investigations [6, 22, 23]. The cylindrical specimen had 100 mm diameter and around 60 mm thickness. Specimen cured seven days under thermal and moisture controlled condition, before been tested.

2.4. Laboratory tests
In the present research considered two main properties of the material. From the mechanical point of view, specimens were tested in terms of Indirect Tensile Strength resistance (ITS). ITS represented the ultimate tensile strength, registered at the bottom surface of a pavement layer submitted to traffic loads. Tests were conducted according to the standard EN 12697-23 [24], at 20°C.

The ITS was calculated according to the formula identified by the standard (Eq. 1):

\[
ITS = \frac{2P}{\pi DH}
\]  

Material volumetric properties were studied in terms of density. Density was calculated according to UNI EN 12697-6 [25], procedure D. Masses of the dry specimens as well as dimensions (average diameter “d” and thickness “h”) were determined following to the standard EN 12697-29 [26]. Densities were calculated according to the formula (Eq. 2):

\[
\rho_b = \frac{m_1}{\pi h^2 d^2}
\]  

Previous researches demonstrated a street relationship between density and permeability of pervious concrete mixes identifying density parameter as a good predictor for drainability capacity [22].

3. Results and discussions
In this section laboratory results of the fourteen mixtures are reported with a brief discussion. Volumetric properties were measured in terms of density and registered values are presented in figure 3.

![Figure 3. Density values of the studied mixtures*](image_url)

*All the reported values are average of three laboratory made specimens*
From result analysis emerged that all mixtures type “mix a” (characterized by a w/c ratio of 0.35), generally presented higher densities respect to “mix b” mixtures (which had w/c ratio equal to 0.30), probably depending on the thicker volume of cement past around the aggregates, that partially filled the inter-particles voids. The addition of fine rubber (FR) produced the same effect in both the base mixes: this type of admixture sensibly increased densities. This was probably due to the extremely fine matrix of the scrap rubber type “FR”, which no more behaved like an aggregate but as a filler, increasing cement paste volume inside the voids of aggregate structure. Commonly, increasing density of pervious concrete is not a desired result. In fact, previous studies demonstrated that a reduction of density corresponded to a decrease in permeability [8, 22, 23]. Higher permeability mixes (with permeability around 30 mm/s) were characterized by densities lower than 1800 kg/m\(^3\); while the maximum admissible densities for pervious concrete mixtures, in order to guarantee drainability purposes (permeability greater than 6 mm/s), stated close to 2050 kg/m\(^3\), depending on several mix design parameters [22].

Moreover, for a comprehensive analysis of material performance, it is important to evaluate ITS as mechanical parameter, results are reported in figure 4.

![Figure 4. Indirect Tensile Strength (ITS) values of the studied mixtures*](image)

*All the reported values are average of three laboratory made specimens

Higher ITS values were measured for mixes containing natural sand, for both the considered w/c ratios. The cementing property of sand that collaborate with cement in forming cement paste is a possible explanation. The thicker cement paste produce a stronger bonding among the aggregates and higher strength. A surprising result is that even though rubber is not a cementing material, the addition of crumb rubber type “CR” allowed to increase ITS values respect to the control mixes.

In table 2, all the measured values of ITS and density are resumed with the respective standard deviation.

Although, mixtures that registered higher densities (the ones containing rubber FR) did not present greater strength. The lowest ITS values were measured for these mixes. For this reason it is possible to affirm that rubber “FR” is not appropriate for pervious concrete with the described mix-design characteristic.

The fine rubber type “FR” had a negative effect, because it diffusely distributed in the cement paste producing discontinuity points and weakening the cement chemical bonds. In figure 5, the specimens containing rubber are shown in comparison with the two control mixes.
**Table 2.** ITS and Density average value of three samples for each texted mixture and correspondent standard deviation.

| MIX TYPE | ITS  | St.Dev. | Density | St.Dev. | MIX TYPE | ITS  | St.Dev. | Density | St.Dev. |
|----------|------|---------|---------|---------|----------|------|---------|---------|---------|
| Mixa0    | 0.67 | 0.06    | 1900    | 26      | Mixb0    | 0.53 | 0.06    | 1815    | 10      |
| MixaCR5  | 0.69 | 0.06    | 1841    | 9       | MixbCR5  | 0.51 | 0.05    | 1842    | 50      |
| MixaCR10 | 0.64 | 0.07    | 1829    | 32      | MixbCR10 | 0.55 | 0.02    | 1846    | 105     |
| MixaFR5  | 0.60 | 0.04    | 1915    | 10      | MixbFR5  | 0.32 | 0.07    | 1855    | 24      |
| MixaFR10 | 0.34 | 0.07    | 1926    | 22      | MixbFR10 | 0.06 | 0.01    | 1929    | 35      |
| MixaS5   | 0.79 | 0.12    | 1787    | 6       | MixbS5   | 0.65 | 0.11    | 1742    | 48      |
| MixaS10  | 0.94 | 0.07    | 1840    | 34      | MixbS10  | 0.75 | 0.07    | 1786    | 14      |

In the image it is possible to perceive that crumb rubber is enclosed by cement paste if w/c ratio is adequate (mix type “a”, characterized by w/c ratio of 0.35) while in mix b, with w/c ratio of 0.30, rubber remains exposed, because cement paste has not a sufficient volume to cover it. Dark colour, associated with not covered rubber, is more evident for rubber “FR”.

Mixtures, where rubber particles were more observable, presented irregular fracture surfaces and, as expected, lower ITS.

**4. Conclusions**

The study aimed to evaluate the effect of fine aggregates in pervious concrete mixtures. Two control mixes, characterized by different w/c ratios, were modified by adding natural and recycled fine aggregates. Two dosages and two different gradations of recycled waste tire rubbers were proportioned in the mixes. The experimental analysis showed that small amount of sand can significantly increase the strength of pervious concrete; and the effect was observed independently of both w/c cement included...
in the investigation. At same time, densities of the mixes containing sand, remained in a range of acceptability, assuming a sufficient level of permeability. Most satisfactory results were registered for 10% amount of sand, the highest considered in this research.

The addition of recycled scrap waste tire rubbers as fine aggregate in pervious concrete, showed opposite effects depending on scrap gradation. On one hand, the smaller size rubber, with particle size ranging between 0.08 mm – 1 mm, did not positively affect the mixes increasing density and drastically reducing indirect tensile strength. On the other hand, crumb rubber characterized by particle size from 0.6 mm to 2.5 mm, produced a little growth in strength and satisfactory values of density.

In conclusion, small amounts of fines can improve pervious concrete performances if correctly proportioned: (i) adding natural sand can lead to significant increases in material mechanical properties; (ii) the addition of recycled wasted crumb tire rubber produces both benefits in mechanical properties and, at same time, great economic and environmental advantages.

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