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Experimental study on the effects of fine sand addition on differentially compacted pervious concrete

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HIGHLIGHTS

- Sand addition to mixes produces a significant increase in mechanical properties.
- Porosity and drainability were reduced while increasing the sand content.
- The effect of sand addition was influenced by the water content of the mixes.
- Proper energy of compaction produced satisfactory drainability and strength.
- An analytical model for material properties was implemented based on lab results.

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ABSTRACT

Pervious concrete provides a sound solution for managing storm waters in built environments where the water runoff as well as the natural recharge of the groundwater are important issues. The use of pervious concrete is also commonly related to other environmental benefits such as the Urban Heat Island reduction, traffic noise absorption, and pollutant filtering. Despite the broad capabilities, comprehensive standards are still limited and many issues have not yet been completely fixed. For example, compaction is often underestimated and one of the common compaction effort is provided by hand-rolling; however, different compaction energies, techniques, or timing can significantly affect mechanical and functional properties of the material. Performance can be furthermore improved by adding a small amount of fine sand, as suggested by many; sand can lead towards better raveling and skid resistance, also improving the maximum flexural strength. On the other hand, too much sand and improper compaction energy may lead to an excessively low void content and reduced drainability features. Compaction and sand addition should be therefore analyzed more in details.

The present research aimed at (1) evaluating the effect of differential levels of compaction energy and (2) analyzing the influence of fine sand addition into several pervious concrete mixtures.

Results suggested that adding small amounts of fine sand (around 5% of the total aggregate weight) to pervious concrete mixtures provided better mechanical and surface properties, and a consequent reduction of drainability. However, the correct balance of mechanical and hydrological properties can be achieved due to both accurate mix-design and proper compaction plan.

1. Introduction and background

The Environmental Protection Agency (EPA) listed Pervious Concrete Pavement (PCP) as one of the Best Management Practices for storm water management. The small amount of cement paste and the gap-graded aggregate distribution provide high porosity and the interconnected void system allows the water to percolate through the material. The void content typically ranges from 15% up to 35% of the concrete total volume [1–3] and a viscous cement paste (water/cement ratio – w/c – between 0.2 and 0.4 and cement/aggregate ratio – c/a – between 0.18 and 0.23) is adopted to achieve greater strength [4]. Several studies demonstrated PCP to provide the following benefits: reduce water run-off [5], allow the natural recharge of the groundwater and the

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evaporation of water from the soil beneath [6,7], limit the costs for roadway drainage systems [6], acoustic absorption [8], reduction of the urban heat island effect [9], and filter for contaminants in water [10].

The research on PCP progressed in recent years studying mix proportioning, construction logistics, material testing, and maintenance activities: some methodologies are available for mix proportioning [3,11] and the National Ready Mixed Concrete Association tried to standardize the construction practices [12]. The ASTM Committee C09.49 recently completed four standards about fresh and hardened unit weight determination, measurement of in-situ infiltration rate, and resistance to degradation *(*ASTM C1688/C1688M-2013, ASTM C1754/C1754M-2012, ASTM C1701/C1701M-2009, and ASTM C1747/C1747M-2013*)*. However, several other fundamental issues occurring during placement and testing procedures are still far to be definitive and broadly accepted.

The fine aggregate size (i.e., below 3 mm) is typically not included in the mix [4] to guarantee the proper drainability feature (void content) of pervious concrete mixes. Even though, including a small portion of fine sand (up to 7% of sand introduced as replacement of the coarse aggregates) has been proposed for enhancing freeze–thawing durability [13], surface friction, and resistance to raveling when exposed to high traffic volumes [5]. The role of the added-sand content on strength and drainability needs to be further observed [14]. Previous applications in Europe and Japan adopted small-size aggregates (i.e., passing at 2.36 mm or No. 8 ASTM sieve) as addition to standard PCP mixes providing a durable surface layer for roadway applications [15,16]. Other studies incorporated up to 15% of fine sand (mass ratio of fine aggregate to coarse aggregate); however, 5–10% was found to be an optimal amount for balancing strength [5,14,17,18] and drainability. Previous research showed that a *w*/*c* ratio lower than 0.27 is not suitable for mixes containing sand because the paste would be not sufficiently hydrated and will develop poor strength and durability. A *w*/*c* above 0.33 and addition of sand can otherwise produce drainability limitations due to excessive paste volume [14]. Greater percentage of fine aggregate in the mix generally produce an increase in the mortar thickness surrounding the aggregate and at the same time, porosity decreased and compressive strength significantly increased [14]. Fly ashes, latex emulsion, and other polymers have been also included to improve the PCP strength and durability, as well as a small amount of fibers [5,19–23].

For pervious concrete to achieve specific characteristics mix design is as responsible as a clear definition of construction best practices. Methodology of compaction (hand-roller, drum roller, vibratory plate roller, etc.), number of passes, and timing of compaction are only few of the numerous variables to take into account when dealing with pervious concrete applications. The same material could behave very differently and exhibits very different performance according to the compaction energy provided on the construction site. In situ and laboratory compaction methods and timing of proper compaction are, in fact, still not standardized. The compaction energy applied to the material has been proven to be fundamental for the mechanical and drainability properties of the mix [24–26]. To date, several compaction methods are reported to be used on site depending on countries' best practices and technical specifications [19,27–29]. The use of spud vibrators is not generally recommended for PCP construction operations because of the possibility to provide low-voids areas and cavities [27]. A common practice is to compact the fresh pervious concrete placed within fixed forms by using hand-steel rollers [3]; however, adjusting the mix-design and the timing of compaction can allow the adoption of steel drum light rollers. The proper compaction energy and timing should be calibrated so not to break the chemical links during the hardening process of the pervious concrete. The following methods can be acknowledged as the most adopted laboratory compaction methods: vibration, dropping, rodding, standard Proctor/Marshall hammer blowing, and gyratory compactor. Previous studies proved the suitability of impulsive compaction to reproduce in-situ pervious concrete characteristics with a low standard deviation [27,30].

2. Research objectives

The main goal of the present study was to look for a balance between the strength of the material, which would be adequate to support medium-to-high traffic loadings, and its ability to allow the water to percolate through the pavement structure and easily reach the soil beneath. Two main aspects were thus evaluated: the effect on mixture properties caused by the addition of small percentage of sand depending on the *w*/*c* ratios, and the consequence of different compaction energies. A statistical analysis of results was finally conducted to find relationships and correlations among the several variables.

3. Laboratory investigation

Three base mixes were identified according to three *w*/*c* ratios and two different percentages of sand were added into each one of them; a total of 9 mixes and 360 cylindrical specimens were tested and 9 slabs were built. Compaction energy was also evaluated according to four steps provided by means of the Marshall compactor: 5, 10, 15 and 20 compaction blows, respectively. The base mixes (the reference mixes: MIX A, MIXB and MIXC) and the mixes with fine sand added (sand mixes) were tested to measure the mechanical characteristics (strength, stiffness, and particle loss resistance, respectively), the volumetric properties (bulk density and void content), and the functional properties (drainability and skid resistance). The repeatability in each test was equal to five.

4. Materials, mix design, and specimen preparation

4.1. Materials

The materials used for the mix design of the mixes and the selected mix proportions derived from previous works that took into consideration several different compaction energies and mix proportions [26,31]. Based on previous results, the base mixes that better achieved a balance between mechanical and drainability properties were selected for this study. A CEM II 42.5R A-LL Portland limestone cement was selected for this study according to EN 197-1, the European standard for composition, specifications and conformity criteria for common cements. The aggregate size distribution is shown in Fig. 1. The three reference mixes had the same aggregate distribution curve but different *w*/*c* ratios; namely, 0.27, 0.30,

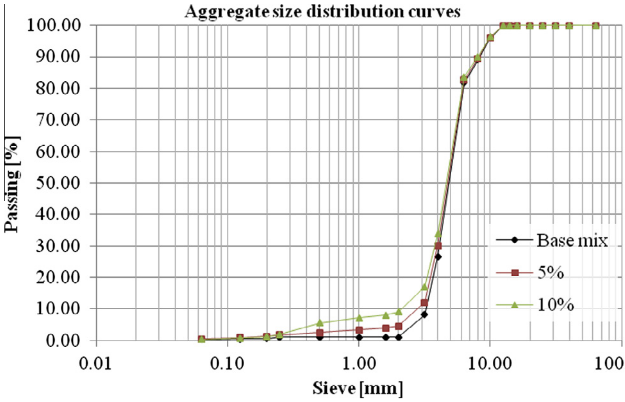

Fig. 1. Aggregate size distribution curves of base mixes without sand and mixes containing 5% and 10% of sand.