Effect of Recycled Aggregates on Previous Concrete Properties

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Abstract. Portland cement Pervious Concrete (PCPC) is a special type of concrete characterized by a highly connected pore system that allows water from different sources to infiltrate through to recharge the ground water. This paper present selected results on the key mechanical and hydrological performances of pervious concrete designed with different recycled aggregates from various sources and materials types. Seven pervious concrete mixes containing different recycled materials in addition to a control mix, were optimized and tested in terms their mechanical and hydrological properties. The results obtained indicate acceptable mechanical properties of the designed PCPC with an appropriate water penetrability depending on the granular system and compaction effort employed. Among these optimized mixes, selected mixes meeting strength and permeability requirement for a PCPC could be used in some common flat applications as an efficient drainage system. Potential use of these pervious concrete optimized mixes based on recycled materials includes but not limited to sidewalk, pavement in low traffic area, parking lots in regions known by heavy rainfall, floor for car washing stations, etc.

1. Introduction & literature survey
Portland cement pervious concrete (PCPC) is receiving renewed worldwide interest because of the many advantages is offering and the strict environmental regulations in some countries. First used in 1852 in the UK, pervious concrete, called also enhanced porosity concrete or porous Portland cement pavement is now widely used in many countries around the world for paving applications.

Pervious concrete is recognized as a structural infiltration best management practices (BMPs) by the Environmental Protection Agency (EPA) for providing first flush pollution control, reducing pollutants in post-construction runoff and storm water management [1]. Pervious concrete pavement is qualified for classification as green building managed by the US green building Council (USGB) through its Leadership in Energy and Environmental Design (LEED) [2]. Therefore, it is considered as a green and sustainable alternative material to conventional pavements and one of the most important environmentally friendly materials.

The use of pervious concrete in countries where heavy rain is frequent, especially in Europe and North America, is becoming widely spread over the last decades due to its multiple advantages and possible applications. It is a special type of concrete with a high interconnected pore structure. The void content of PCPC typically ranges between 15-30% and compressive strength could ranges from 2
to 30 MPa, resulting in high permeability and drainage capacities in the range of 1.4-12 mm/s [3-5]. Common and regular applications of pervious concrete are: parking lots, light traffic pavement, driveways and entrances, access roads, sidewalks and pathways, pedestrian walkways, streets/roads shoulders, surface course for tennis courts, patios, plazas, slope stabilization, swimming pool decks, groins and seawall, zoo areas, drains, insulation (noise barriers/walls), reduction of heat island in large cities, friction course for highway pavements, permeable base under a normal concrete pavement, greenhouse floors and aesthetics as well as many other possible applications [4-7]. Furthermore, pervious concrete paving reduces the runoff from paved areas, which reduces the need for separate storm water retention ponds and allows the use of smaller capacity storm water sewers [1,8]. Thus, significantly reduces hydroplaning and flooding. Pervious concrete also naturally filters storm water and can reduce pollutant loads entering into streams, ponds and rivers. It captures the first flush of rainfall (with most pollutants) and allows that to percolate into the ground, so that soil chemistry and biology can treat the polluted water [9]. In addition, pervious concrete pavement can also reduce the impact of development on trees and landscaping by allowing the transfer of both water and air to root system which allows trees to flourish even in highly developed areas.

The use of various types of recycled aggregates in construction industry, especially in conventional concrete is now well known and established [10], however, its use in special types of concrete such as pervious concrete is still limited, less documented and yet to be profoundly investigated [11]. Recycled aggregate (RAs) derived from different sources and industrial activities were collected, screened, cleaned to remove any major contaminants and eventually crushed to reduce it into aggregate size.

The main objective of this paper is to investigate the effect of using various types and contents of recycled aggregate as a partial replacement of natural aggregate to design Portland cement pervious concrete.

2. Materials and methodology

2.1. Materials used

Two types of materials were used: Natural and recycled Aggregates collected from different sources. Natural aggregate consists of two different fraction sizes 20 mm and 10 mm while the recycled aggregate were all consisting of one single fraction with a size ranging from 20 mm to 5 mm. Recycled aggregates (RA) from different sources including rubber, seashell, mixed colored crushed glass, shredded plastic, recycled concrete aggregate and ferrochrome aggregate. Normal Portland cement locally produced by Oman Cement Factory having a density of 3.14 and a Blaine Fineness of 3150 cm²/g was used in all mixes. Laboratory tap water was used as a mixing water for pervious concrete. A water reducing agent (WRA) named “Plastiment 100 plus” manufactured by Sika Company Inc. and having a density of 1.16 kg/lt. was employed to improve workability of pervious concrete. The content added varies depending on the mix proportions used.

2.2. Mix Design

One single water-cement ratio of 0.30 was selected for this study. The PCPC mixes were designed with various granular fractions combinations using both natural and different recycled aggregate.

All concrete specimens tested on fresh and hardened properties were prepared from the same concrete batch made in a pan type laboratory mixer having a capacity of 0.120 m³. The mixing was done according to the following steps. The coarse aggregates were introduced in the mixer and dry mixed for 30s and then half water was added and mixed for an additional 30s. The mix was left for 3-5 min to allow water absorption by the aggregate and the cement was then introduced with the remaining water and a proper amount of water reducing agent and mixed for 2-3 min time.
Table 1. Specific gravity and water absorption of natural 10 mm and recycled aggregates.

| Aggregates                        | Specific gravity | Water absorption (%) |
|-----------------------------------|------------------|----------------------|
| Natural aggregate 10 mm          | 2.78             | 1.02                 |
| Natural aggregate 20 mm          | 2.76             | 0.5                  |
| Recycled concrete aggregate      | 2.43             | 5.5                  |
| Ferrochrome                      | 2.88             | 0.74                 |
| Shredded plastic                 | 1.01             | 0.05                 |
| Rubber                           | 1.05             | 0.4                  |
| Glass                            | 2.51             | 0.13                 |
| Seashell                         | 2.65             | 0.5                  |

Immediately after concrete mixing, slump, density and voids content tests were conducted as per ASTM C143-12 and ASTM C1688/C1688M-13, respectively before casting concrete in their molds. As per the recommendations regarding workability of pervious concrete, the target slump for all mixes was fixed to a value ranging between 0 and 20 mm. All pervious concrete specimens including cylinders, prisms, and cubes were then cast and compacted by rodding 25 times in three equal layers. The mix design details are given in Table 2.

Table 2. Mix proportions for 0.085 m³ of pervious concrete mixes.

| Pervious concrete mixes code | Aggregate combinations | w/c | a/c | Coarse aggregate (kg) | Cement (kg) | Water (kg) | WRA (ml) |
|-----------------------------|------------------------|-----|-----|-----------------------|-------------|------------|----------|
| PC1                         | 65% 20mm +35% 10mm     | 0.30| 5   | 131                   | 26.1        | 7.83       | 240      |
| PC2                         | 55% 20mm +35% 10mm +10% Rubber | 0.30| 5   | 131                   | 26.1        | 7.83       | 150      |
| PC3                         | 65% 20mm (>5mm) +35% 10mm (>5mm) | 0.30| 5   | 131                   | 26.1        | 7.83       | 90       |
| PC4                         | 45% 20mm +35% 10mm +20% 20mm Seashell | 0.30| 5   | 131                   | 26.1        | 7.83       | 25       |
| PC5                         | 45% 20mm +35% 10mm +20% 20mm Glass | 0.30| 5   | 131                   | 26.1        | 7.83       | 25       |
| PC6                         | 64% 20mm +35% 10mm +1% 20mm Plastic | 0.30| 5   | 131                   | 26.1        | 7.83       | 25       |
| PC7                         | 45% 20mm +35% 10mm +20% 20mm Ferrochrome | 0.30| 5   | 131                   | 26.1        | 7.83       | 25       |

2.3. Tests on concrete mixes
All pervious mixes were subjected to series of testing at fresh and hardened states. At fresh state, workability using Slump test ASTM C143-12 [12] (figure. 1), and Density and air void using standard proctor test ASTM C1688/C1688M-13[13] were conducted immediately after the end of mixing sequence.
At hardened state, density, strengths, porosity and permeability were the main testing conducted after 28-day of water curing.
All specimens were cast in metallic or rigid plastic moulds, covered with plastic sheet immediately after casting and kept in their moulds in laboratory environment for the first 24 hours. The specimens were then demoulded, labeled and cured in water tank at 22±3˚C and 100 % RH till the time of testing. The compressive strength test of pervious concrete specimens was conducted according to ASTM C39/C39M-14a [14] standard test method. Cylinders of size 100 x 200 mm were used.

The test method consists of applying a compressive axial load to cylinders at a constant rate of 2 kN/s until failure occurs. Before the compression test was performed, cylinders were subjected to capping process to ensure a uniform distribution of the applied load on the cross-section. Flexural strength measured using ASTM C C78/C78M-10, (2010) [15].

Permeability was tested on specimen of size 100 mm diameter and 200 mm length after 28 days of water curing.

An in-house built apparatus of water permeability was set based on the design recommended by ACI 552R-08 [4]. The device was used to measure water permeability of all pervious concrete mixes specimens tested. The device should ensure a vertical water flow through the cylindrical specimen without lateral water leakage.

Cubic concrete specimen measuring 100 mm x 100 mm x 100 mm were used to perform porosity test for hardened concrete state. In addition to that the total porosity was measured by finding the difference of sample cubic weight submerged in the water and the weight after air drying for 24 hour in laboratory conditions, the difference in the measured weights divided by the sample volume as the following equation 1 [16]:

$$P = 1 - \left( \frac{(W_1 - W_2) / \rho_w}{V} \right) \times 100\%$$

where
P is the total porosity of pervious concrete (%)
$W_1$ is the pervious concrete sample weight air dried for 24 hours (kg)$W_2$ is the pervious concrete sample submerged underwater weight (kg)$V$ is the pervious concrete sample volume (mm$^3$) and$
\rho_w$ is density of water (kg/mm$^3$).

Figure. 1 Slump test of a pervious concrete mix
Permeability of pervious mixes is determined by using falling head permeability method with reference to ASTM D4511-11 [17]: Standard Test Method for Hydraulic Conductivity of Essentially Saturated Peat, the equation for coefficient of permeability is given as.

\[ k = \frac{L(Q/t)}{(A\Delta H)} \]  

where
- \( k \) = hydraulic conductivity m/s;
- \( Q/t \) = rate of water outflow, m\(^3\)/s;
- \( A \) = cross sectional area of specimen, m\(^2\);
- \( L \) = length of specimen, m and
- \( \Delta H \) = value of constant hydraulic head, m required to maintain a sustained flow rate.

![Figure 2. Typical hardened pervious concrete specimen](image)

### 3. Results and discussions

A total of 7 mixes were designed with a variety of natural and recycled granular fractions, cast and tested for various properties both at fresh and hardened states.

#### 3.1. Fresh properties

As pointed out earlier, all pervious concrete mixes designed and tested have fulfilled the workability requirement with a slump value equal to 0 while keeping their cohesiveness and ability to be transported, placed and finished. Table 3 provides fresh theoretical and experimental densities and porosity of the seven PCPC mixes investigated. The results indicate a very small drop in the fresh densities of PCPC mixes made with recycled aggregate as compared to the PCPC mixes made with natural aggregate. Furthermore, no significant change in the porosity as a result of replacing part of the natural aggregate fraction by different recycled aggregates. The main parameters affecting the density of PCPC are the density of the pervious ingredients, especially the aggregate itself, and the shape and size of aggregate as it affects the PCPC porosity. Rubberized PCPC showed the lowest density and also the lowest porosity due to its low specific gravity and ability to fill the voids in the PCPC while PCPC made with natural aggregate retained on 5 mm sieve has exhibited the highest porosity with a medium density.
Table 3. Fresh theoretical and experimental densities of pervious concrete mixes.

| Previous concrete mix | Fresh density (kg/m³) | Theoretical density (kg/m³) | Theoretical porosity (%) | Experimental porosity (%) |
|-----------------------|-----------------------|----------------------------|--------------------------|--------------------------|
| PC1: 65% 20 mm + 35% 10 mm | 1786.8 | 2573.5 | 26.6 | 30.6 |
| PC2: 55% 20 mm + 35% 10 mm + 10% 20 Rubber | 1700.0 | 2347.4 | 19.5 | 27.6 |
| PC3: 65% 20mm (>5mm) + 35% 10mm (>5mm) | 1735.3 | 2574.1 | 26.6 | 32.6 |
| PC4: 45% 20 mm +35% 10 mm +20% crushed Seashell | 1661.8 | 2355.6 | 19.8 | 29.5 |
| PC5: 45% 20 mm +35% 10 mm +20% crushed Glass | 1757.4 | 2543.5 | 25.7 | 30.9 |
| PC6: 64% 20 mm +35% 10 mm +1% shredded Plastic | 1727.9 | 2473.4 | 23.6 | 30.1 |
| PC7: 45% 20 mm +35% 10 mm +20% Ferrochrome | 1757.4 | 2588.9 | 27.0 | 32.1 |

3.2. Hardened properties

Pervious concrete mixes were tested at hardened state in terms of their density, compressive and flexural strengths, porosity and permeability. The average 28-day hardened density results shown in figure 3 indicates no significant drop in the density with the lowest value recorded for the rubber PCPC due to the intrinsic properties of rubber and the relative high content used. Compressive and flexural strengths results at 28 days are presented in Fig. 4. It is evident that the partial replacement of natural aggregate by different recycled materials has decreased both the compressive and flexural strengths of the PCPC.

Figure. 3 Densities of pervious concrete mixes at 28 days
The reduction is proportional to the type and amount of recycled aggregate used in the PCPC mix. Compressive strength was more affected by the organic (plastic) nature of aggregate.

Rubber PCPC exhibited the lowest compressive strength while glass aggregate led to the highest one as compared to the other recycled materials. Meanwhile, flexural strength was also affected by the recycled aggregate type and content. A significant reduction was recorded for all PCPC made with recycled aggregates compared to the natural aggregate PCPC.

![Figure 4. Compressive and flexural strengths of PCPC mixes](image1)

![Figure 5. Porosity and permeability of the investigated PCPC](image2)
On the other hand, most of the PCPC designed with recycled aggregates showed a higher porosity compared to their corresponding mix with natural aggregate as shown in Fig. 5. Furthermore, the recycled aggregates PCPC mixes offered generally a better water permeability than the PCPC with natural aggregate. Also, the results illustrated in Fig. 5 indicate a good correlation between porosity and water permeability. The higher the porosity, the higher the water permeability.

4. Conclusions
Based on the results obtained, the following conclusions can be made.

The type, size and granular combinations of recycled aggregates seem to highly affect the resultant fresh and hardened properties of the pervious concrete including density, strength and porosity.

It has been found that aggregates (natural or recycled) grading, size and content is the major parameter governing both the mechanical and hydrological properties of the pervious concrete.

The water permeability and drainage capacity are governed by the mix design and the pore system characteristics of the pervious concrete.

Using various recycled and waste aggregates to produce PCPC has indicated a great potential to turn on the PCPC into a super green material with ability to save virgin aggregate and use of the PCPC as a drainage system.

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