The Influence of Various Materials to the Void Ratio of Pervious Concrete

Eva Arifi¹, Evi Nur Cahya², Desy Setyowulan¹

¹Department of Civil Engineering, Universitas Brawijaya, Malang, 65145, Indonesia
²Water Resources Engineering Department, Universitas Brawijaya, Malang, 65145, Indonesia

E-mail: evaarifi@ub.ac.id

Abstract. Pervious concrete is an alternative to reduce surface runoff in urban areas. To examine effect of different materials on the void ratio of pervious concrete is studied in order to evaluate the efficiency of pervious concrete solving surface runoff problems. Various materials have been used in mix proportion of pervious concrete. Different size of aggregate, the use of supplementary material for cement, recycled aggregate as an alternative to replacing natural coarse aggregate, and fiber usage were utilized in a series of experiment to evaluate the value of void ratio that greatly affects the effectiveness of pervious concrete to cope surface runoff in urban areas. The result shows that the size of aggregate strongly affected the void ratio of pervious concrete, while the effect of the use of supplementary material for cement in pervious concrete to its void ratio was not significant. However, pervious concrete made of recycled aggregate proved to have a higher void ratio compared to pervious concrete using natural coarse aggregate. When utilizing fiber in mix proportion of pervious concrete, the higher rate of fiber reduced its void ratio.

Keywords: Recycled aggregate, fly ash, pervious concrete, void ratio.

1. Introduction

Population growth, urbanization, and unwise natural resource consumption are the main causes of global warming. The common pavement characteristic that impermeable raises an increase in surface runoff problems and pollution from stormwater. Further, this results in a reduction in the use of groundwater as a natural thermostat to regulate heat and moisture in cities, resulting in greenhouse and hot land effects [1].

Pervious concrete is one of the environmentally friendly alternatives to conventional pavements with small quantities of fine aggregate and high void ratio, allowing water to penetrate the soil and minimize surface runoff [2].

The void ratio, as permeable pavement, is an important factor to maintain when making pervious concrete. Controlling the quantity of water and cementitious material and using limited fine aggregate to create enough void to allow stormwater to drain through the pavement. A recognized best management practice by the U.S. Environmental Protection Agency (EPA) is an appropriate pervious concrete that provides first-flush pollution control and storm management [3]. The most common use for pervious concrete is for parking lots, residential roads, driveways, and sidewalks to solve the reduction of water table problems, making pervious concrete is a low impact, environmentally friendly and sustainable pavement alternative [4,5].
Due to its high void content, pervious concrete gains lower strength than common impermeable concrete pavement, thereby only been used for light traffic loads. Many studies have been conducted to enhance the strength performance of pervious concrete. Nevertheless, the void ratio of pervious concrete is greatly affected by its constituent material. The particle size of aggregate, binder characteristics, aggregate volume affects the void ratio and strength performance of pervious concrete [1,6-8]. Therefore, the experiment to investigate the influence of various materials on the void ratio of pervious concrete is important to be conducted.

2. Material and Methods
The performance of pervious concrete allowing water to infiltrate into the soil is strongly influenced by its void ratio. Several materials were used in making pervious concrete to evaluate the effect of its use on the void ratio of pervious concrete. Different size of aggregate, the use of supplementary material for cement, recycled aggregate as an alternative to replacing natural coarse aggregate, and fiber usage were utilized in a series of experiment to evaluate the value of void ratio that greatly affects the effectiveness of pervious concrete to cope surface runoff in urban areas.

2.1. Material Used
Cement to aggregate ratio in the mix proportion was set to 1:4 in this experiment. No sand was added in the mix design of pervious concrete, while the water to cement ratio was arranged to 0.3. Polypropylene fiber and glass fiber were also utilized to investigate the effect of fiber used to the void ratio of pervious concrete.

2.1.1. Cement and fly ash. Portland pozzolan cement, which met the type IP of ASTM C 595M-1995, was used in making pervious concrete. Fly ash Type C was also used as a partial replacement of cement in the experiment.

2.1.2. Aggregate. Three sizes of aggregate were used in the experiment to determine its effect on the void ratio of pervious concrete. Also, to promote sustainable construction, recycled coarse aggregate reclaimed from concrete waste was utilized in pervious concrete. Table 1 and Table 2 describe the physical properties of aggregate. As seen in Table 1, similar characteristics were indicated by the physical properties of natural coarse aggregate with different sizes. The physical properties of recycled coarse aggregate, however, indicated lower quality which had lower unit weight and specific gravity and higher absorption rate compared to natural coarse aggregate due to mortar attached in recycled aggregate.

| Properties         | Aggregate Type | Aggregate Size |
|--------------------|----------------|----------------|
|                    | NCA            | 0.5 – 1 cm     | 1 – 2 cm | 0.5 – 2 cm |
| Unit weight (gr/cm³) | 1.263          | 1.367          | 1.329 |
| Specific gravity   | 2.619          | 2.611          | 2.612 |
| Absorption (%)     | 1.575          | 1.581          | 1.563 |

Table 1. Physical properties of aggregate size using natural coarse aggregate

| Properties         | Natural Coarse Aggregate | Recycled Coarse Aggregate |
|--------------------|--------------------------|---------------------------|
| Unit weight (gr/cm³) | 1.367                    | 1.254                     |
| Specific gravity   | 2.611                    | 2.375                     |
| Absorption (%)     | 1.581                    | 3.150                     |

Table 2. Physical properties of coarse aggregate with 1-2 cm aggregate size
### 2.2. Mix Properties

To investigate the size aggregate, the use of supplementary material for cement, recycled aggregate as an alternative to replace natural coarse aggregate, and fiber usage effect to the void ratio of pervious concrete, following mix designs were conducted to produce pervious concrete.

#### 2.2.1. Size of aggregate effect

The following mix designs were set as defined in Table 3 to investigate the size of aggregate effect to the void ratio of pervious concrete.

| Aggregate Type | Aggregate Size (cm) | W/C | Cement-to-aggregate ratio (C/A) |
|----------------|---------------------|-----|---------------------------------|
| NCA            | 0.5 – 1             | 0.3 | 1 : 4                           |
| NCA            | 1 – 2               | 0.3 | 1 : 4                           |
| NCA            | 0.5 - 2             | 0.3 | 1 : 4                           |
| RCA            | 0.5 – 1             | 0.3 | 1 : 4                           |
| RCA            | 1 – 2               | 0.3 | 1 : 4                           |
| RCA            | 0.5 - 2             | 0.3 | 1 : 4                           |

NCA = Natural Coarse Aggregate; RCA = Recycled Coarse Aggregate

#### 2.2.2. The use of supplementary material

Fly ash and silica fume were used as supplementary material for cement in pervious concrete.

| Aggregate Type | W/C | Binder-to-Aggregate Ratio (B/A) | Fly Ash | Silica Fume |
|----------------|-----|---------------------------------|---------|-------------|
| NCA            | 0.3 | 1 : 4                           | 0 %     | 0 %         |
| NCA            | 0.3 | 1 : 4                           | 10 %    | 0 %         |
| NCA            | 0.3 | 1 : 4                           | 25 %    | 0 %         |
| NCA            | 0.3 | 1 : 4                           | 0 %     | 7 %         |
| NCA            | 0.3 | 1 : 4                           | 10 %    | 7 %         |
| NCA            | 0.3 | 1 : 4                           | 25 %    | 7 %         |

NCA = Natural Coarse Aggregate

#### 2.2.3. Recycled aggregate and fiber usage

To promote sustainable construction, recycled coarse aggregate reclaimed from concrete waste was also used in the experiment. As previous studies have shown that recycled coarse aggregate decreases the compressive strength of pervious concrete, hence glass fiber and polypropylene fiber were added to improve the strength of pervious concrete. Therefore the effect of fiber addition in pervious concrete to the void ratio is needed to be analyzed.

### 2.3. Methods

#### 2.3.1. Density of pervious concrete

Density is one parameter that can illustrate the characteristics of concrete, including pervious concrete. Iffat [9] stated that concrete with higher density generally yields higher strength. Previous research by Aoki [10] and Berry [11] have found that, with increasing density, the compressive strength of pervious concrete generally increases. Nonetheless, due to different aggregate densities and angularities, it is difficult to determine the accurate relation between the density of pervious concrete using recycled coarse aggregate to its compressive strength. [11]. Furthermore, varying degrees of compaction also affected the density variations in pervious [12].
Table 5. Mix properties for recycled aggregate and fiber usage

| Aggregate Type | W/C | Cement-to-Aggregate Ratio (C/A) | Glass Fiber | Polypropylene Fiber |
|----------------|-----|---------------------------------|-------------|---------------------|
| NCA 0.27       | 1 : 4 | 0 %                             | 0 %         |
| NCA 0.27       | 1 : 4 | 0.75 %                          | 0 %         |
| NCA 0.27       | 1 : 4 | 1.5 %                           | 0 %         |
| NCA 0.27       | 1 : 4 | -                               | 0 %         |
| NCA 0.27       | 1 : 4 | -                               | 0.75 %      |
| RCA 0.27       | 1 : 4 | -                               | 1.5 %       |
| RCA 0.27       | 1 : 4 | 0 %                             | 0 %         |
| RCA 0.27       | 1 : 4 | 0.75 %                          | 0 %         |
| RCA 0.27       | 1 : 4 | 1.5 %                           | 0 %         |
| RCA 0.27       | 1 : 4 | -                               | 0 %         |
| RCA 0.27       | 1 : 4 | -                               | 0.75 %      |

NCA = Natural Coarse Aggregate; RCA = Recycled Coarse Aggregate

2.3.2. Void ratio. The void ratio was calculated according to the ASTM C1688 [11]. The void ratio is defined as the total percentage of voids present by volume in a specimen. The void ratio of pervious concrete is determined using equation 1.

\[
\text{Void ratio (\%)} = \frac{T-D}{T} \times 100
\]

\[
\text{Where, } \quad D = (M_c-M_m)/V_m \quad (\text{Density})
\]

\[
\text{M_c} = \text{mass of measure filled with concrete}
\]

\[
\text{M_m} = \text{net mass of concrete by subtracting mass of measure}
\]

\[
\text{V_m} = \text{volume of measure}
\]

\[
\text{T} = \frac{M_s}{V_s} \quad (\text{Theoretical Density})
\]

\[
\text{M_s} = \text{total mass of materials batched}
\]

\[
\text{V_s} = \text{total absolute volume of materials}
\]

3. Result and Discussion

3.1. Density of Pervious Concrete

The density of fresh pervious concrete made from different size of aggregate is drawn in Figure 1. It is shown that the smaller size of aggregate used in pervious concrete increased the density of fresh concrete. However, the density of fresh concrete was reduced by replacing natural coarse aggregate with recycled coarse aggregate.

Polypropylene fiber and glass fiber were used to increase the strength of pervious concrete in the experiment. Figure 2 demonstrates the density of fresh pervious concrete with the addition of fiber. The result showed that its density was less influenced by the use of fiber in pervious concrete.

In the pervious concrete mix design, fly ash and silica fume were used as cement substitute. Figure 3 described the density of fresh pervious concrete using supplementary cementitious material for cement. From the figure, it can be seen that supplementary cementitious material used in the experiment indicated to increase density of fresh pervious concrete with the increase of fly ash for the same amount of silica fume. Furthermore, a similar trend as Figure 1, the density of fresh concrete was decreased by replacing natural coarse aggregate with recycled coarse aggregate.
3.2. Void Ratio

The main purpose of this experiment was to evaluate the influence of various materials on the void ratio of pervious concrete. Different size of aggregate, the utilization of supplementary material for cement, substituting natural coarse aggregate with recycled aggregate, and fiber usage were used in the experiment.

The void ratio of pervious concrete using different size of aggregate is displayed in Figure 4. It is shown that larger aggregate size improved the void ratio of previous concrete, while mix size of aggregate gave average void ratio between the 5-10mm and 10-20mm size of aggregate. Furthermore, Figure 5 illustrates the void ratio of previous concrete using two types of fiber. It is clear that a higher
rate of fiber reduced the void ratio of pervious concrete, and glass fiber provided a higher void ratio compared to polypropylene when used in pervious concrete. Figure 5 explained the effect of the utilization of recycled aggregate in pervious concrete. The Higher percentage of recycled coarse aggregate used in pervious concrete raised the void ratio of pervious concrete.

**Figure 4.** Void Ratio of pervious concrete using different size of aggregate.

**Figure 5.** Void Ratio of pervious concrete using two types of fiber.

Figure 6 describes the void ratio of pervious concrete using supplementary material for cement. Although showing a slight reduction in void ratio due to fly ash ratio addition, however, the effect of supplementary material in pervious concrete was shown to be less significant.

**Figure 6.** Void Ratio of pervious concrete using supplementary materials for cement.
4. Conclusions
The void ratios of pervious concrete were analyzed to examine the influence of various materials on the void ratio of pervious concrete. The following conclusions are derived from the results:

1. Different sizes of aggregate significantly affected the void ratio of pervious concrete in producing pervious concrete. The smaller size of aggregate reduced the void ratio of pervious concrete.
2. When using supplementary material for cement in pervious concrete, its void ratio was not significantly affected.
3. Pervious concrete made of recycled aggregate reclaiming from concrete waste has been shown to have a higher void ratio compared to pervious concrete using natural coarse aggregate, due to the characteristic of recycled aggregate that still has mortar attached from its original concrete, making it more porous and absorptive.
4. The higher percentage of fiber used in pervious concrete reduced its void ratio.

References
[1] Cheng A, Hsu HM, Chao SJ, Lin KL 2011 *Int. J. Cryst. Growth* 222 701
[2] Rizvi R, Tighe SL, Norris J, Henderson V 2009 *Session of the Annual Conference of the Transportation Association Of Canada*, Vancouver, British Columbia
[3] Joshi T, Dave U 2016 *Int. J. of Civil Eng and Tech* p 276-284
[4] Patil P, Mural SM 2014 *Int. J. of Eng. Res. & Tech.* p 819 - 822
[5] Shinde GU, Valunjkar SS 2015 *Int. J. of Eng. Res. & Tech.* p 16-19
[6] Kunieda M, Otono T, Yoshida T, Kamada T, Rokugo K, Dept. of Civil Engineering, Gifu University Gifu Japan
[7] Ravindrarajah RS, Kassis SJ 2014 *Australian Conference on the Mechanics of Structures and Materials* p 53-58
[8] Ravindrarajah RS, Yukari A 2010 *Our World In Concrete & Structures*
[9] Iffat S 2015 *Concr. Res. Letters* 6(4) p 182-189
[10] Aoki Y, Sri Ravindrarajah R, Khabbaz H 2012 *Road Mater. Pavement* 13(1) 020055-7
[11] Berry BM, Suozzo MJ, Anderson IA, Dewoolkar MM 2012 *Transportation Research Board 91st Annual Meeting* (The National Academies of Sciences, Engineering, and Medicine, Washington DC)
[12] Sri Ravindrarajah R, Aoki Y 2010 Proceeding of *The 35th CORAL Conference on Our World In Concrete & Structures* Singapore Concrete Institute, Singapore