Influence of AAC grains on some properties of permeable pavement utilizing of CDW and industrial by-product

Kim Tuan Ngo¹, Tien Dung Nguyen¹, Quang Minh Phan¹, Van Tuan Nguyen¹ and Ken Kawamoto²

¹National University of Civil Engineering, Vietnam
²Graduate School of Science and Engineering, Saitama University, Japan

E-mail: dungnt1@nuce.edu.vn

Abstract. Construction and Demolition Waste (CDW) has been being accounted for a large amount of waste in urban areas around the world, especially for developing countries like Vietnam due to rapid urbanization and economic growth. The recycling and reuse of CDW are not only significant in reducing the consumption of natural materials but also can be a solution to improve the urban environment. In recent years, several studies have shown that the use of recycled materials from CDW in permeable pavement systems has a good effect on hydrological aspects and soil absorption capacity, thereby minimizing the risk of flooding and ground water depletion, increasing heat island effect. In this study, two main types of aggregates used are recycled aggregate (RA) and autoclaved aerated concrete (AAC) grains recycled from industrial by-products. The workability and forming ability are greatly affected by the moisture of the material before mixing. The results show that increasing AAC grain size leads to a slight decrease in the porosity of pervious concrete with the same AAC content. On the other hand, increasing AAC content from 5 to 10% results in significant fall in void content from 18% to 14.5%, thereby decreasing drainage speed. The compressive strength values show that without AAC, pervious concrete has the highest mechanical strength while increasing content and size of AAC leads to the compressive strength decreases. The surface temperature of pervious concrete samples is 4–5°C lower than that of normal concrete surface due to the increased effective surface area. The use of AAC grains helps to reduce the sample surface temperature by another 4°C.

1. Introduction

Permeable pavement systems are designed to collect stormwater on the pavement surface and then allow it to infiltrate into the subgrade and deeper layer (Figure 1). Therefore, it can be considered as a modern approach for urban stormwater management system, according to sustainable drainage systems’ manual (SuDS Manual). This pavement system has a great ability in collecting the rainfall water, allowing it to pass through the base and subbase layers where is temporarily stored. In deep layer, water can leave the pavement through an underdrain system. As a result, permeable pavement has been regarded as an effective tool in helping with stormwater control [1]. The evaporation rates, water retention properties of permeable pavement are largely dependent on the particle size distribution of the bedding material [2].
Permeable pavement is usually classified into four major categories: namely porous asphalt, porous concrete, permeable interlocking concrete pavement, and grid pavement systems that can be plastic or concrete [3] [4]. This is hydraulic cement concrete proportioned with sufficient interconnected voids leading to a permeable material, allowing water to easily pass through. The concept “pervious concrete” or “porous concrete” typically describes a type of concrete with non-workability, open-graded material including of Portland cement, coarse aggregate, little or no sand, water and admixtures [5].

According to ACI 522R-10, the combination of these ingredients will produce a hardened material with connected pores ranging in size from 0.08 to 0.32 in. (2 to 8 mm). The void content can range from 15 to 35%, with typical compressive strengths of 400 to 4000 psi (2.8 to 28 MPa). The drainage rate of pervious concrete pavement will vary with aggregate size and density of the mixture, but will generally fall into the range of 2 to 18 gal./min/ft² (81 to 730 L/min/m²) or 192 to 1724 in./h (0.14 to 1.22 cm/s) (ACI 522R-10). Recently, there were much research about using mineral additives for improving strength of binders paste and reducing the amount of cement, which directly affects the strength of pervious concrete [6].

Besides, heat island refers to high temperature of urban areas has an important impact on the energy consumption of buildings by increasing the energy consumption for cooling purposes. Several techniques have been proposed, developed and applied with success. The affect of surface layer on the evolution of urban heat island is very important. Reducing heat island effect is mainly based on the use of highly reflective surfaces for solar radiation in combination with high thermal emission (reflective pavement) or the use of latent heat of water evaporation to decrease their surface and ambient temperature (water retention pavements) [7].

Permeable and water retentive pavements generally include additional voids in comparison with conventional pavements in order to allow water to flow through into the sub-layers and the ground. The evaporation of water helps to reduce the surface temperature of the pavements and contribute to the mitigation of the urban heat island. Using construction waste and industrial by-products as raw material for water-retentive pavements is considered as one of the most effective water-retentive ones [8].

The use of construction and demolition waste (CDW) and industrial by-product as a source of aggregate for the production of new concrete has become more common in recent years. The increase of landfill cost and the scarcity of natural resources for aggregate encourage the use of waste from construction sites as a alternative source of aggregates. Recycled aggregate from CDW could be an alternative to natural aggregates in construction, particularly recycled aggregate from waste crushed concrete from demolished concrete buildings can make up 75% of concrete. Recycling of CDW is a relatively simple process. It involves destroying, transporting, crushing and sieving into a raw material with a specified size and quality. Recycled CDW has specialty technical and hydraulic properties compared to typical natural materials, as well as their physical and mechanical properties [9]. Therefore, the use of recycled materials for permeable pavement systems can be a sustainable solution for the construction industry.

However, there has not been much research and application of pervious concrete in Vietnam. Generally, Vietnam is a country with a tropical climate, the average rainfall is from 1500 to 2000 mm a year [10]. Therefore, it is necessary to introduce and disseminate porous concrete technology in
Vietnam, in order to minimize the adverse effects of heavy rainfall as floods and mudslides, especially in Hanoi and Hochiminh city.

The purpose of this research study is to entirely replace normal aggregate with recycled aggregate into pervious concrete to create a sustainable concrete product for pavement and for precast pervious concrete applications. Another aim of this research study is to explore the characteristics of pervious concrete using industrial by-products as a new approach for manufacturing a “cooling pavement” system to solve drainage problems and reduce heat island effect.

2. Experimental work

2.1. Materials

Pervious concrete is composed of cement, coarse aggregate, and water. Recycled aggregate (Crushed brick, concrete, and masonry) were used and completely replaced natural aggregate (Figure 2). The specification of cement and coarse aggregate (natural and recycled one) are shown in the Table 1 and Table 2.

| Description          | Obtained result | Description          | Obtained result |
|----------------------|-----------------|----------------------|-----------------|
| Specific gravity (g/cm³) | 3.1             | Bulk density (kg/m³)  | 1,420           |
| Finess: Sieving (%)  | 1.2             | Specific Surface area (cm²/g) | 3,100       |
| Initial setting time (minute) | 55              | Final setting time (minute)  | 275            |
| Compressive strength (MPa): | 3 days 24     | 28 days 46            |                 |

Table 1. Test results of Cement PC40

| Specifications       | Unit       | Natural aggregate 5-10 mm | Recycled aggregate 5-10 mm |
|----------------------|------------|---------------------------|-----------------------------|
| Specific gravity     | g/cm³      | 2.72                      | 2.65                        |
| Bulk density         | kg/m³      | 1,360                     | 1,310                       |
| Compacted bulk density | kg/m³   | 1,660                     | 1,430                       |
| Dry density          | g/cm³      | 2.62                      | 2.32                        |
| Saturated surface dry | %         | 0.14                      | 6.85                        |
| The flat and elongated particle | % | 1.4                       | 3.9                         |

Table 2. Test results for coarse aggregate

AAC (autoclaved aerated concrete) is a lightweight, precast, foam concrete building material invented in the mid-1920s that simultaneously provides structure the insulation, and fire- and mold-resistance. AAC products include blocks, wall panels, floor and roof panels, cladding (façade) panels and lintels. The AAC used in this study was manufactured by Viglacera Yen Phong Company. The particle size was adjusted to be from 0.63 mm to 10 mm based on sieve analysis, in accordance with Vietnamese standards (TCVN 7570-2006).
2.2. Mix proportions
The pervious concrete mixtures comprised of Portland cement, water and coarse recycled aggregates like normal concrete. One major difference is the requirement of high void content. The sum of void space is straightforwardly related to the drainage rate of the pavement. Although pervious concrete contains the same basic ingredients as the conventional concrete, the proportions and properties of the ingredients can vary, especially recycled aggregate and AAC grains used in this study have high-water absorption property (Fig. 3). Hence, it is vital to preserve the mix design water content in pervious concrete for appropriate mixing. High water absorption of recycled aggregate and AAC grains may result in lower water content and dry dramatically in the mixture. This could affect the mixing adversely and the produced concrete will have a large void ratio, low strength and may not fulfill the specific mix design requirements. Therefore, recycled aggregate and AAC grains were first pre-mix with water to avoid the absorption of mix water by the aggregates (not change water/cement ratio) in the fresh mixture. In order to produce pervious concrete with a good water permeability, single size recycled aggregates were employed. To improve the water-retentive properties of pervious concrete, the AAC grains were used with the proportion adjusted from 5% to 10%. The water-to-cement ratio (w/c) was fixed by 0.33.

2.3. Specimens preparation
As in the conventional concrete, a mechanical mixer used in mixing the pervious concrete samples. The constituent weights were prepared and batched. The recycled aggregates were added to the mixer
and pre-mix with water (the water content does not exceed water absorption value). After that, cement materials were slowly added into the mixer. Then, the water was added gradually, while mixing continued for two minutes from the start time. The mixer was stopped for two minutes, and finally very short mix with additional AAC grains. Note that, AAC grains also have pre-mix with water before adding to a mixer in final step.

Pervious concrete samples of 100 mm x 200 mm were prepared (Fig. 4). The cylinder and beam samples were made and cured in accordance with ASTM C192 Standard Practice for Making and Curing Concrete Test Specimen in the Laboratory. The samples were cast using the methods: self-consolidating (SC), also referred to as self-compacting. The cylinder was completely filled and struck and capped under pressure. They were cured at room temperature for 1-day. And then, the specimens were cured in the water until the day of experiment. A minimum of 6 samples was prepared for each mix, of which there were used for compressive strength tests while the remaining were used for permeability and percent void analysis.

With an outdoor temperature measurement experiment, the mixture after mixing is constructed directly outdoors. It was cured and covered with a damp cloth, watered daily until the day of testing.

Figure 4. Pervious concrete samples

3. Testing method
The experiments performed in the study were: porosity, compressive strength, and co-efficient of water permeability, water absorption and evaporation test, surface temperature test.

3.1. Porosity
Porosity is the ratio of voids volume to the total volume of specimens. The total porosity was measured using the water displacement method based on the Archimedes’ principle of buoyancy, which states that the buoyancy force is equal to the weight of fluid displaced. The total void ratio includes both inter pores and intra pores and can be measured using the buoyancy float apparatus. The weight of dry sample, submerged mass, and total volume must be measured to calculate the porosity value:

$$P = [(1 - \frac{W_1 - W_2}{\rho_w \cdot V})] \times 100$$  \hspace{1cm} (1)

Where:

- $P$ - total porosity of pervious concrete [%]
- $W_1$ - weight of a pervious concrete sample air-dried for 24 hours [kg]
- $W_2$ - weight of a pervious concrete sample submerged in water [kg]
- $V$ - volume of a pervious concrete sample [mm$^3$]
- $\rho_w$ - density of water [kg/mm$^3$].

3.2. Permeability test
Water permeability test is one of the important properties for pervious concrete as it is critical for stormwater management in applications. The test method complying with the falling head principle was used to measure the permeability coefficient. Figure 5 shows the setup for testing the permeability.
coefficient. The average permeable coefficients of three cylinders were reported. Cylindrical specimens were sealed by plastic cover and rubber to avoid the water spilling from the lateral surfaces of the specimens. Before measurement, the specimens were immersed into water for 24 h to ensure that the samples were fully saturated. The permeability of each sample, K, was computed using the following formula:

\[ K = \left( \frac{2.3 \cdot a \cdot L}{F \cdot t} \right) \cdot \log \left( \frac{H_1}{H_2} \right) \] (cm/s) \hspace{1cm} (2)

Where:
\( a \) - Cross section area of pipe [mm²]
\( L \) - specimen length[mm]
\( F \) - cross sectional area of specimens [mm²]
\( H_1 \) – The original height of the water column [mm]
\( H_2 \) – The height of the water column after flow “t” seconds [mm]
\( t \) – time to water flow from \( H_1 \) to \( H_2 \) [s]

Figure 5. Permeability coefficient test

3.3. Compressive Strength
28-day compressive strength tests were performed in accordance with ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. The pervious concrete samples were capped with cement paste after 3-days before being placed in the loading frame for testing. Three samples were used for the strength test for each different mixing design (changing in AAC proportion). The height and diameter were measured and recorded.

3.4. Water absorption and evaporation test
The purpose of the experiment is to determine the moisture change when temperature conditions are accelerated at 110°C. The test compares the loss of sample weight between 2 type samples. Sample of 10% AAC content and the other sample is without AAC. Before the experiments, both samples were saturated in water at least 24 hours. The mass-loss process of the samples was recorded every 5 minutes until the mass is constant.

3.5. Surface temperature test
The surface temperature test evaluates the ability of these pavements to reduce the surface temperature through monitoring specimens. The temperature of pavement surface is expected to be reduced since the water retained in the pavements consumes the heat around it when it evaporates. Permeable pavement is technology expected to reduce the surface temperature as it reflects infrared rays from the sun, which are the source of heat and the water draws necessary heat from the surround when it evaporates, which results in the temperature reduction.

Three types of material were used, pervious concrete with 10% AAC content, pervious concrete without AAC and the last one is conventional concrete. All specimens were constructed in the outdoor testing site to monitor the surface temperatures during an outdoor exposure test in summer. The
temperatures were monitored by handheld temperature measuring devices and were recorded at 10 minutes intervals.

![Surface temperature test](image)

**Figure 6.** Surface temperature test

### 4. Results and discussion

#### 4.1. Effect of recycled aggregate and AAC grains on total void ratio

Figure 7 shows the total void ratio of porous concretes using recycled aggregates and AAC grains and the effect of AAC grains content on total void ratio. The total void ratio of porous concrete using recycled aggregate was slightly higher than that of porous concrete with adding AAC grains. The first series, AAC grains were added with small grain size (0.63 – 1.25 mm). The porosity is 18% and 14.5% when the adding AAC content is 5% and 10%, respectively. In the second series, bigger grain size AAC was added, porosity achieves 17.5% and 13.5% when the AAC content is 5% and 10%, respectively. The results showed that, at the same AAC content, when the AAC grain size increases, the porosity of pervious concrete slightly decreases. On the other hand, increasing AAC content leads to a significant fall in void content. It due to AAC grains were coated by cement paste and its surface becomes a solid part in total volume. It results in decreasing the macropore structure of porous concrete which is formed due to the gap between the coarse aggregate particles.

![Total void ratio](image)

**Figure 7.** Effect of recycled aggregate and AAC grains on total void ratio

#### 4.2. Effect of recycled aggregate and AAC grains on the relationship between total void ratio and coefficient of water permeability

Figure 8 demonstrates the effect of AAC grains content on the relationship between total void ratio and coefficient of water permeability of porous concretes. Regardless of AAC content, the coefficient of water permeability for all porous concretes increases as the total void ratio increases, respectively. The relationship between the coefficient of water permeability and porosity of all porous concretes is
linear. However, the effect of connectivity on pore structure has not been analyzed in this paper. This is also a major factor affecting the permeability of the samples.

**Figure 8.** Effect of recycled aggregate and AAC grains on relationship between total void ratio and coefficient of water permeability

4.3. *Effect of recycled aggregate and AAC grains on relationship between total void ratio and compressive strength*

Generally, the compressive strength of porous concrete is related to the strength of the aggregate and total void ratio. One of the drawbacks of recycled aggregate is low quality, leading to a reduction of bonding between aggregate and cement paste and partly by the increased void ratio. Moreover, the bearing frame of concrete is partially affected when using AAC particles because the intensity of AAC particles is very weak. Especially when these particles lie between the link of coarse aggregates. The more AAC content increases and the bigger the particle size, the greater the effect of this phenomenon. The compressive strength showed that without AAC, pervious concrete had the highest mechanical strength. Increasing the content and size of AAC, the compressive strength of the sample decreases. However, mechanical strength still met the requirement for sidewalk or parking area application.

Regardless of recycled aggregate and AAC content, the compressive strengths of all pervious concretes were slightly decreased with an increase in the total void ratio (Fig. 9). All pervious concretes showed an almost linear relationship between compressive strength and total void ratio.

**Figure 9.** Effect of recycled aggregate and AAC grains on relationship between total void ratio and compressive strength

4.4. *Effect of recycled aggregate and AAC grains on Water absorption and evaporation*

According to Figure 10, without AAC the sample weight decreases rapidly and quickly reaches a stable level. Another result has been noted that the AAC sample weight decreases slowly over time. This is evidence of good water-retaining capacity of the AAC grains.
Due to the presence of water-absorbing AAC particles, the initial moisture content of the 10% AAC sample was almost 3 times higher than that of the non-AAC sample. Moreover, due to water holding capacity, the AAC sample will gradually lose water. The release of steam is much higher than that of the sample without AAC. This is an important basis for predicting the effective reduction of the urban heat island effect. The surface temperature is expected to be reduced since the water retained in the pavements consumes the heat around it when it evaporates.

**Figure 10.** Effect of recycled aggregate and AAC grains on water absorption and evaporation

4.5. *Effect of recycled aggregate and AAC grains on reduce surface temperature*

The surface temperature characteristics of three material types are shown in Figure 11.

**Figure 11.** Effect of recycled aggregate and AAC grains on reduce surface temperature

The chart shows the top line is the temperature of the conventional concrete surface. The middle line is temperature of pervious concrete without AAC. The last one is temperature of water retention pavement (pervious concrete with AAC). The top line shows that the normal concrete surfaces absorb and retain heat, unable to escape the heat, lead to the highest temperature. By increasing the effective surface area, the surface temperature of the permeable concrete is lower than 3 - 5°C compared to normal concrete. This can be explained by the convection heat exchange between the road surface and the air.

The temperature difference of a sample containing AAC particles compared to a concrete sample can often reach nearly 10°C. This can be explained by a combination of two factors: a more effective surface area and water retention capacity of AAC grain.
5. Conclusions
This paper was conducted to investigate the properties of pervious concretes prepared from recycled aggregates and industrial by-products. The effects of raw material on total void ratio, permeability, compressive strength, water absorption, and evaporation test, reduce surface temperature test was evaluated. Based on this experimental study, the following conclusions can be drawn:

- The total void ratio of porous concrete slightly decreases regardless of AAC content in comparison with normal concrete. The total void ratios were achieved within the acceptable range of 13.5%–18% for permeable pavement concretes.
- The compressive strength of pervious concrete using recycled aggregate and AAC grains was lower than the pervious concrete without AAC grains. Increasing AAC content decreases the mechanical strength of permeable concrete.
- Regardless of aggregate and AAC content, results showed an almost linear relationship between the compressive strength and total void ratio, and between the coefficient of permeability and total void ratio for all pervious concretes.
- The content of AAC particles gradually improves the water-retaining properties of the permeable pavement, followed by a reduction in the surface temperature of the pavement surface under sunlight.

Reference

[1] S. Watanabe, “Study on storm water control by permeable pavement and infiltration pipes,” Water Science & Technology, vol. 32, no. 1, pp. 25-32, 1995.

[2] C. T. Andersen, I. D. L. Foster and C. J. Pratt., “Role of urban surfaces (permeable pavements) in regulating drainage and evaporation: development of laboratory experiment,” Hydrological processes, vol. 13, no. 4, pp. 597-609, 1999.

[3] T. Wang, J. Harvey and D. Jones, “A Framework for Life-Cycle Cost Analyses and Environmental Life-Cycle Assessments for Fully Permeable Pavements,” Institute of Transportation Studies, University of California, California, USA, 2010.

[4] G. Nader and D. Shivaji, “Development of no-fines concrete pavement applications,” Journal of Transportation Engineering, vol. 121, no. 3, pp. 283-288, 1995.

[5] Stephen A. Arhin, Errol C. Noel and J. Thomas, “Evaluation of Mix Designs and Test Procedures for Pervious Concrete,” Howard University, Washington, D.C, 2014.

[6] Van Dong N., Hanh P.H., Van Tuan N., Minh P.Q., Phuong N.V., “The effect of mineral admixture on the properties of the binder towards using in making pervious concrete,” Ha-Minh C., Dao D., Benboudjema F., Derrible S., Huynh D., Tang A. (eds) CIGOS 2019, Innovation for Sustainable Infrastructure. Lecture Notes in Civil Engineering, Vols. vol 54. Springer, Singapore, 2020.

[7] M. Santamouris, “Using cool pavements as a mitigation strategy to fight urban heat island – A review of the actual developments,” Renewable and Sustainable Energy Reviews, Elsevier, vol. 26, no. C, pp. 224-240, 2013.

[8] A. Mohajerani, J. Bakaric and T. Jeffrey-Bailey, “The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete,” Journal of Environmental Management, Elsevier, United Kingdom, vol. 197, pp. 522-538, 2017.

[9] B. Shishir and S. K. Singh, “A Sustainable Approach towards the Construction and Demolition Waste,” International Journal of Innovative Research in Science, Engineering and Technology, vol. 3, no. 2, 2014.

[10] (ISPONRE), “Vietnam assessment report on climate change,” Hanoi, 2018.