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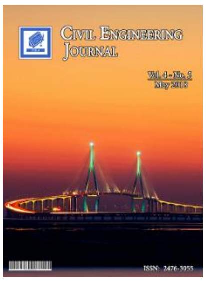

An Analogue Experiment on Pervious Concrete Subject to Dust Fall Blocking

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Abstract

Increased urbanization comes with increased traffic volume which gradually decrease the draining effect of porous asphalt concrete through porosity blocking. This study aims to discuss clogging as a result of dust or sand and the subsequent changes at the permeability function after rainfall. Four groups of pervious concrete mixtures were prepared. Aggregates were coarse and fine bottom ashes from the refuse incinerator. Prior to conducting the experiments, the permeability in the groups ranged from 1399.75 ~ 1412.91 ml/15sec. We adopted the 2011 average monthly dust fall in Pingtung County and magnified it by 10 and 20 times to simulate natural dust fall and clump dust fall on the pavement. Ruling out other factors, our results suggest that natural dust fall has little influence on the water permeability of pervious concrete. Water permeability was reduced sharply when the natural dust fall was increased 15 times. Moreover, it never surpassed the 400 ml/15sec minimum of the Japanese porous pavement technical indicator.

Keywords: Refuse Incinerator Bottom Ash; Pervious Concrete; Dust Fall; Porous Blocking.

1. Introduction

Presently, there has been a growing concern over the rate of urbanization in Taiwan, which have seen a wide adoption of impermeable pavements. The presence of these pavements has caused a series of environmental issues such as, cutting off heat exchange and moisture between the earth surface and air. Impervious pavements have been shown to cause undesirable thermal ambience such as between urban and rural areas [1]. They have further caused a phenomenon known as Urban Heat Islands (UHI) where heat is stored during the day and released in the night. A four year study [2] comparing permeable, porous and impermeable pavements revealed that impermeable pavements contributed to significant soil warming, reaching 5 °C when compared to its porous counterpart. Rehan [3] in mitigating such impacts applied a cool city concept as it is among the most sustainable solutions for urban heat management. On other impacts of impervious systems, a large proportion of pollutants discharged into waterbodies from paved surfaces are associated with non-point sources [4], amongst which there are roads, streets, etc. Urban areas are constantly looking for ways to reduce runoff, and subsequently the pollutants. Proposed solutions, which are generally termed storm water control measures, include bio retention, swales, storm water wetlands and permeable pavements and among these; permeable structures are the most favoured [5]. This is because of their multi-purpose functions such car parking. Recently, Kamali, et al. [6] evaluated permeable pavement responses to urban surface runoff and demonstrated that they can function hydraulically, and be able to filter pollutants provided they are adequately maintained. On soil hydrology, impervious pavements escalate the risks of flash floods from extreme storm events, which are ever increasing due to climate change [7]. Additionally, they weaken the pavement sheer resistance under rain conditions, causing several traffic accidents.

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Against this backdrop, engineers seek alternative strategies to guard and repair the global natural systems. A general pavement system comprises top permeable concrete layer on top of a sub base coarse aggregate layer and subgrade layer, although in some cases configurations may vary [8]. Pervious pavements (either permeable asphalt mixture or concrete), which allow water to infiltrate into the underlying soil are among such alternatives. Pervious concrete has been mainly reserved for high loading construction, while permeable asphalt mixture is widely adopted in light loading such as walkways due to their shorter life span. The more voids in their structure leads to more infiltration, which compromises their strength. Lian and Zhuge [9] through an experimental investigation developed a type of permeable concrete with enhanced strength to mitigate the aforementioned weakness. A more recent evaluation of permeable pavements [10] identified 3 key weaknesses of such innovation; inconvenient maintenance, increased clogging probability and low strength and durability. In redressing the clogging effects, Winston, et al. [11] evaluated 8 small scale and full scale maintenance techniques which included removal of the uppermost 2 cm of fill material, mechanical street sweeping, regenerative air street sweeping, vacuum street sweeping, hand-held vacuuming, high pressure washing, and milling of porous asphalt. Suction techniques were found superior. Brunetti, et al. [12] applied numerical methods to analyse the hydraulic behaviour of permeable pavements with the purpose of designing high quality permeable pavement systems.

Nonetheless, permeable pavements still offer a wider range of benefits; water retention, surface cooling, drainage enhancement etc. In the present study, we discuss clogging as a result of dust or sand (Figure 1 and Figure 2 show porous asphalt blocking due to sand obstruction and closing-up caused by vehicle load) that eventually hinders the drainage function of pervious pavements. In situ infiltration evaluation over a 4 year period [13] revealed that despite a decrease in infiltration rates of the permeable pavements, rates were still four to five times higher than average storm intensity in the studied area. Results demonstrated the suitability of numerical applications in describing the hydraulic behaviour of pavement systems.

Figure 1. Picture of Sand Blocking

Figure 2. Picture of Closing-up

The dust or sand is brought to pavements by wind, vehicles and worn out aggregates, while rainfall and runoff water bring these particles to pores [14]. Subsequently, the evaporation process will leave behind sediment particles blocking the pores. We simulate the blockage and rainfall, and use water permeability test to observe the performance change in permeability. Specific objectives of the study include determining physical properties of the refuse incinerator bottom ash; mix different coarse or fine aggregates of refuse incinerator bottom ash based on different ratios and discuss the relationship between different porosity rates influence on the dust fall blocking; and finally, conduct blocking test of natural dust fall and clump dust fall on the specimens to observe the change in water permeability after rainfall simulation.

2. Methodology

2.1. Experimental Design

The research uses coarse and fine aggregates of the refuse incinerator bottom ash because it possesses advantages such as light-weight, good shape, high porosity, etc. It can effectively reduce costs and may cut down waste residues. However, there has been no relevant standards or research in Taiwan to determine the influence and severity of blocking to the environment. So the research simulates blocking of pervious concrete pavement and the influence of rainfall, and then uses the water permeability test to observe changes in water permeability. Configurations summary of the pervious concrete applied are shown in Table 1 and

Figure 3. Coarse aggregate diameters ranged between 12.5 ~ 19 mm and 4.75 ~ 12.5 mm, while fine aggregates were between 2.36 ~ 4.75 mm and 0.6 ~ 2.36 mm.

Table 1. Proportions of Pervious Concrete

No.	I-type Cement	Coarse Aggregate Diameter (mm)		Fine Aggregate Diameter. (mm)		Water
		12.5 ~ 19	4.75 ~ 12.5	2.36 ~ 4.75	0.6 ~ 2.36	
A	200	400	880	160	160	84.6
B	200	400	1200	-	-	84.6
C	130	800	800	-	-	55
D	130	400	1200	-	-	55

a)

12.5 mm

9.5 mm

6.35 mm

4.75 mm

b)

2.36 mm

1.18 mm

0.6 mm

Figure 3. Picture of a) Coarse and b) Fine Aggregates

2.2. Specimen Blocking Test Procedure

To simulate the natural dust fall landing process, tapping was used and the test device is shown in Figure 4. It entailed bricks, wood panels, nylon ropes and rubber blocks. The height of the platform was 16 bricks and the inner distance between the two bricks wall was 0.75 m. The nylon ropes are tied to 1 m on either sides. After fixing the height and spacing, the percussion force can be stabilized with each tap. The simulated dust agglomerate landing is directly filled with dust on the test piece. Airborne particles are relatively small; hence, clay was used to simulate dust fall. Clay chunk was pulverized into fine powder using a ball grinding machine (Figure 5). This machines employs two circular plates where by one is fixed and the other rotates to perform precise grinding. Hydraulic pressures within the system determine the grinding loads. Generally, fall-out dust particles are greater than 10μm in diameter, and street dust particles have an average diameter of 220 to 515 μm (0.22 ~ 0.515 mm) [15], in which the minimum particle is about 0.15 mm, the opening of #100 sieve. Thus, a #100 sieve was used to simulate natural dust fall seen in Figure 6. To simulate the natural dust, fall off, the sieve was tapped such that 10 times dust fall (17.2 g) was attained. To conduct a rainfall simulation, we applied 4.095 litres of water 5 times on a 15 cm^2 testing area which is equivalent to 0.819 litres of water each time. For this purpose (i.e. rainfall simulation), a pressure sprayer shown in Figure 7 was used through a styrofoam as illustrated by Figure 8. The specimen was then oven dried for 1 hour to ensure that dust sticks on the specimen via the viscosity of the clay. This procedure was repeated twenty times, equalling the quantity of monthly average dust fall laid on a surface of a pervious concrete.

Figure 4. Front View of Dust Fall

Figure 5. Ball-type Grinding Machine

Figure 6. Red Clay Evenly

Figure 7. Pressured Sprayer

Figure 8. Rainfall Simulation by Styrofoam Sealing

3. Results and Discussion

3.1. Basic Physical Properties of Refuse Incinerator Bottom Ash

Aggregates make up the main portion of pervious concrete; therefore, the aggregate's basic physical properties control the pervious concrete performance. Table 2 shows the basic physical properties of the coarse and fine aggregates of the incinerator bottom ash. Since the bottom ash has higher porosity than those of general aggregates, its absorption capacity is certainly higher. Henceforth, to minimize the effects of high absorption capacity on the designed water-cement ration, aggregates were cautiously prepared to near saturation.

Table 2. Basic Physical Properties - General Aggregate vs. Bottom Ash

Aggregate	SSD sp. gr.	Absorption Capacity (%)	Dry Rodded Unit Wt (kg/m^3)	Water Absorption in 30 min (%)

General - Coarse	2.62	0.7	1631	-
General - Fine	2.68	1.8	1616	-
Bottom Ash - Coarse	2.36	5.3	1266	4
Bottom Ash - Fine	2.23	9.2	1125	4.2

3.2. Result of Porosity Rate and In-Situ Water Permeability Test

The average porosity of pervious concrete is shown in Table 3. Generally, groups (B, C and D) without fine aggregates had higher porosity when compared with (A). Although Group B does not contain fine aggregate, its cement ratio is higher than those of Groups C and D. The increase in cement ratio increased the aggregate contact with the cement paste. The increase in binding agent and aggregate contact area can reduce the porosity. Consequently, Group A used more cement and fine aggregate since its porosity rate was the lowest. Prior to the dust fall test, we conducted an in-situ water permeability test (Figure 9). The peripheral area was sealed by oil-based clay and the specimen was in total direct contact with the base plate to make sure the 4 corners were sealed with oil-based clay. The test results are shown in Table 5 and 6. All the groups, A to D, exceeded the minimum 400ml/15sec requirement of Japanese porous pavement technical indicator. The relationship between porosity rate and water permeability is shown in Figure 10. Generally speaking, larger porosity rates result in higher water permeability and vice versa.

Table 3. Average Porosity Rate of Each Group

Group	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Cement (kg/m^3)	Porosity Rate (%)
A	1280	320	200	24.6
B	1600	0	200	27.4
C	1600	0	130	27.7
D	1600	0	130	28.1

Figure 9. In-situ Water Permeability Test Apparatus

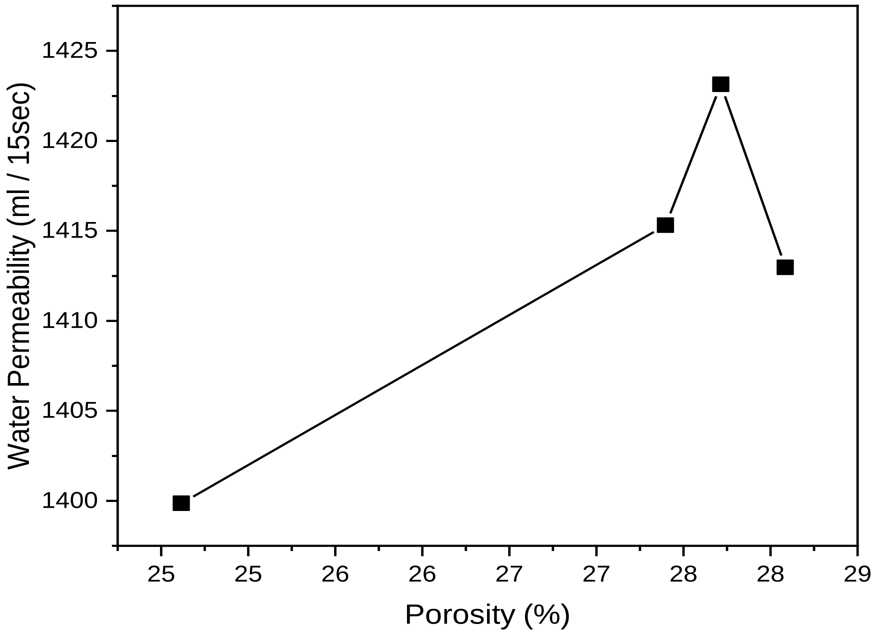

Figure 10. Relationship between Porosity Rate and Water Permeability

3.3. Result of Tapping Dust Fall Test

There is currently no fixed standard to specify the test procedure, so in this study we utilized the foregoing designed test platform to simulate the dust fall. A #100 sieve was used as a dust-fall simulation apparatus and the test dust (i.e. clay) was evenly applied on the screen. A dust-fall simulation had 100 tapings, and weights were taken at every 10th tap. From the 3 simulation tests conducted we obtained an average of 3.61 g dust fall on to the specimen surface (Table 4). After confirming the feasibility of the method applied, which yielded almost similar quantities of average monthly natural dust fall, 10 and 20 times natural dust fall test were conducted.

Table 4. Dust Fall Quantity after Tapping (Unit: g)

Group	Tapping Count (10)										
I	0.47	0.51	0.50	0.41	0.40	0.37	0.29	0.16	0.19	0.16	3.46
II	0.74	0.54	0.55	0.40	0.34	0.32	0.23	0.19	0.26	0.18	3.75
III	0.55	0.45	0.52	0.46	0.36	0.33	0.26	0.23	0.23	0.23	3.62
Average	0.59	0.50	0.52	0.42	0.37	0.34	0.26	0.19	0.23	0.19	3.61

Table 5. Test Result – 10 Times Monthly Dust Fall Simulation

	No.	A	B	C	D	Rainfall Simulation (kg)
Dust Fall (g)	1	3.5	3.5	3.1	3.3	0.819
	2	3.7	3.5	3.4	3.7	0.819
	3	3.2	3.2	3.6	3.1	0.819
	4	3.3	3.8	3.5	3.3	0.819
	5	3.3	3.4	3.7	3.4	0.819
	Total	17.0	17.4	17.3	16.8	4.095
Pre-Test Permeability (ml/15sec)		1399.75	1415.11	1422.94	1412.91	-
Pre-Test Weight (kg)		18.322	18.589	18.774	18.193	-
Post-Test Permeability (ml/15sec)		1403.01	1408.52	1419.59	1426.32	-
Post-Test Weight (kg)		18.137	18.346	18.604	18.067	-

Table 6. Test Result – 20 Times Monthly Dust Fall Simulation.

	No.	A	B	C	D	Rainfall Simulation (kg)
Dust Fall (g)	1	3.8	3.6	3.7	3.3	0.819
	2	3.1	3.3	3.4	3.5	0.819
	3	3.3	3.6	3.5	3.8	0.819
	4	3.5	3.4	3.6	3.6	0.819
	5	3.7	3.2	3.4	3.4	0.819
	Total	17.3	17.1	17.6	17.6	4.095
Pre-Test Permeability (ml/15sec)		1403.01	1408.52	1419.59	1426.32	-
Pre-Test Weight (kg)		18.137	18.346	18.604	18.067	-
Post-Test Permeability (ml/15sec)		1397.59	1414.01	1422.96	1428.62	-
Post-Test Weight (kg)		17.997	18.223	18.521	17.913	-

Monthly dust fall quantity of Pingtung County was 1.72 ton/km^2 in 2011, so its 10 times is 17.2 g. Since from a tapping group we can obtain 3.61 g dust fall, 17.2 g dust fall can be obtained by 5 cycles of tapping. Referring to the rainfall record of Pingtung Station, Central Meteorological Bureau (from October 2010 to March 2011), the simulated rainfall on the tested specimen is 4.095 kg. A pressured sprayer (Figure 7) was used for the simulation, and the quantities of the applied dust and permeability of the specimens before and after rainfall for 10 times monthly dust fall simulation is shown in Table 5. Relationship between porosity and permeability of pervious concrete is shown in Figure 10. All the groups, A to D, exceeded the minimum 400 ml/15sec requirement of Japanese porous pavement technical indicator. This suggests that blocking of 10 times natural dust fall has little influence on pervious concrete. Twenty times monthly dust fall simulation is shown in Table 6. The 20 times dust fall test was conducted by applying 10 times dust fall directly onto the previous tested specimen. The 20 times natural dust fall test appears to be close to the former tests and the relationship between porosity rate and water permeability before and after the test is shown in Figure 11.

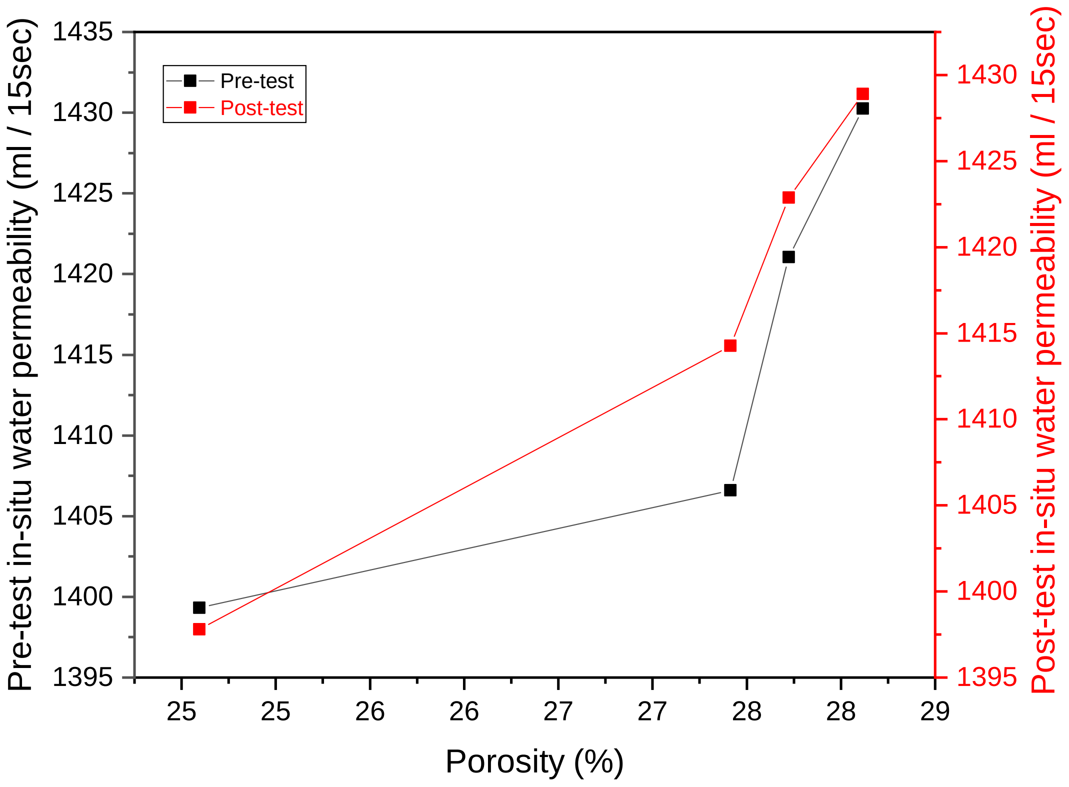

Figure 11. Relationship between Porosity Rate and In-situ Water Permeability Before and After Test

4. Conclusion

1. The in-situ permeability test results ranged between 1399.75 ~ 1412.91 ml/15sec, which meets the minimum 400

ml/15sec required by the Japanese porous pavement technical indicator. This translates to good pervious concrete permeability performance.

2. The tapping test yielded 3.61 g dust, which is close to the average monthly dust fall of Pingtung County during year 2000 to 2011. In consideration of the natural dust fall, permeability of the 4 groups of pervious concrete, containing incinerator bottom ash aggregates, was kept at 1403.01 ~ 1426.32 ml/15sec after 10 times natural dust fall simulation, and 1397.59 ~ 1428.62 ml/15sec for 20 times simulation. Hence, we can conclude that natural dust fall has little impact on the blocking of pervious concrete.

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