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Porosity and permeability properties of Nano black rice hush ash in porous concrete pavement

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Abstract. Porous concrete is a concrete with continuous voids, which are purposely incorporated into concrete. The ability of the porous concrete pavement to allow water to percolate into the underlying strata depends on its porosity and permeability, which is one of its most important pore structure features. In this study, porous concrete pavement containing Nano from black rice hush ash (BRHA) was examined through the porosity and permeability test. A 66 nanometres size was used. Results showed that the porosity value of the specimens increases with increasing Nano BRHA content. In addition, the coefficient permeability of specimens was found to increase with Nano BRHA content increased. The results also indicated that the permeability coefficient has a strong correlation with porosity value.

1. Introduction

Porous concrete is a special type of cementitious material composed of gap graded aggregates, coated with a thin layer of cement paste and bonded by the cement paste layers partially being in contact [1]. This type of concrete is a completely different category from conventional concrete [2] and therefore its physical characteristics differ greatly from those of normal concrete [3]. The research on porous pavement materials has been conducted by developed countries, such as the US and Japan since the 1980s [4]. Because of the multiple environmental benefits associated with controlling storm-water runoff, restoring groundwater supplies and reducing water and soil pollution have been widely used in Japan, the USA and Europe. Porous concrete has been utilised in road pavements due to water-permeating, water-draining and water retaining capacity [5]. In addition, it is currently used in various applications that require noise absorption or thermal insulation [6]. Schaefer et al. [7] mentioned four points why a porous concrete overlay is suitable as a road pavement. Firstly, the porous concrete pavement can absorb noise on the road. Secondly, it will increased skid resistance between tyres and the pavement. Thirdly is it will decrease water splash and spray on the road and lastly it will improve friction as surface wearing coarse. Various studies have been conducted by other researcher and usually, the voids percentage ranges are between 15% and 30% [8,9]. There are several reasons why the hardened concrete strength tends to decrease. One such reason is the voids content in the hardened concrete itself. It is also found that, when the void percentage increases, the strength of the hardened concrete tends to decrease [10]. As reported by Chen et al. [11] there are four major factors that will influence porous concrete strength, namely concrete porosity, water to cement ratio (W/C), cement paste characteristics and size and volume content of the coarse aggregate. In order to enhance the strength and durability of the concrete, silica fume and superplasticizers can be used in the mixture's design [12]. The mixture of porous concrete needs to be modified by adding additional material or by replacing some percentage of cement with other materials for example nano-material, silica fume, rice husk ash, palm oil fuel ash and etc. Previous researchers agree that the finer pozzolanic ash has a better reaction compared to coarser pozzolanic ash [13,14]. Nano is one of materials can improve existing technologies and also produce materials with new functionalities [15]. Hence, this study was investigated the characteristics of porosity and permeability coefficient of porous concrete pavement incorporating Nano from black rice hush ash.

2. Materials and method

2.1. OPC and BRHA

The cement used in this investigation is an ordinary Portland cement supplied from Tasek Cement, Malaysia. Before used, the cement was kept in air tight to ensure the consistency of the quality and properties. On the other hand, the black rice husk ash (BRHA) was collected from the rice mill factory, Malaysia. The rice husk was burned at the factory without controlling the specific temperature. The chemical compositions of OPC and BRHA were determined by x-ray fluorescence. Table 1 shows the chemical composition of OPC and BRHA used through the study. It was found that the chemical composition for OPC fulfilled the standard composition requirements as stated in the Standard Specification for Portland cement [16] where BRHA fulfilled with ASTM C618 [17] for Class N, which indicates that the total amount of silicon dioxide, aluminium oxide and iron oxide equal or greater than 70%.

Table 1 Chemical composition of OPC and BRHA

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
OPC	22.68	4.72	3.5	62.27	1.89	-	0.31	4.29
BRHA	91.33	0.07	0.07	0.45	0.28	0.01	2.64	0.05

2.2. Aggregate

Crushed granites aggregates were used for the porous concrete pavement preparation in this investigation. The aggregates were supplied by Hanson Quarry located in Malaysia. The aggregate has been supplied in one batch for entire experimental works in order to optimize the consistency of the aggregates properties. The gradation of the aggregate used in this study is shown in Figure 1. It can be seen that the aggregate gradation was complied with the requirement of ASTM C33/C33M [18].

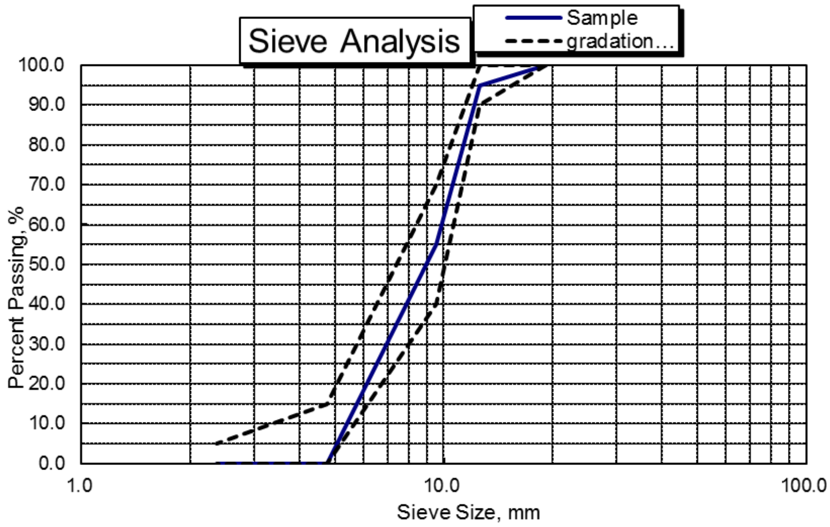

Figure 1. Aggregate gradation used in this study [18]

2.3. Nano BRHA production

Initially, the burned rice husk ash was sieved using a sieve size of 150μm to ensure the homogeneity of size before the grinding process. Then, the BRHA passing the 150μm sieve was taken and ground at different grinding times to obtain the Nano size of the BRHA. It was found that the optimum grinding time is 63 hours with a particle size of 66 nanometers in resulted compressive strength and strength activity index increased significantly [19].

2.4. Mixture design

In order to mix the porous concrete mixture, all the materials were placed into the drum mixer in the following order: coarse aggregate and OPC. These materials were first mixed for approximately 1 minute under dry conditions to achieve a homogeneous dry mixture. Water was then added into the drum mixer, and the mixing operation was performed continuously for another 3 minutes. Then, the mixture was cast into a steel cube mould (100 x 100 x 100 mm) in 2 layers, followed by the compaction process. After casting, all the moulded specimens were covered by wet hessian for 24 hours in order to avoid any evaporation of moisture from the specimens. Finally, the moulded cubes were demoulded and tested.

2.5. Porosity test

The porosity test of the porous concrete pavement was conducted in accordance with ASTM D7063/D7063M [20]. This method was primarily used for bituminous pavement mixes, but its scope does cover other materials including concrete cylinders. At laboratory, the dry specimens was weighed and designated as mass A. The specimens were then vacuum sealed using the Corelok® vacuum sealer, inside a bag having a mass, B, and then submerged underwater and weighed both sealed, E, and unsealed, C. The value of the porosity of specimens was calculated using Equations (1), (2) and (3).

$$\text{Porosity} = \frac{SG2-SG1}{SG2}\, x\, 100 \qquad \text{Eq. (1)}$$

$$\text{Bulk specific gravity} = SG1 = \frac{A}{B-E-\frac{B-A}{F_T}} \qquad \text{Eq. (2)}$$

$$\text{Apparent specific gravity} = SG2 = \frac{A}{B-C-\frac{B-A}{F_{T1}}} \qquad \text{Eq. (3)}$$

Where F_T and F_{T1} are the apparent specific gravity of the plastic sealing material when sealed and unsealed, respectively.

2.6. Permeability test

The permeability test was conducted with the purpose of measuring the water flow through the specimens. This test is conducted according to the ASTM PS 129 [21] specification. To perform this test, the discharge time of the specimens was recorded once the water started to flow at a specific marked interval on the standpipe. The measurement of the discharge time was recorded four times for each of the specimens. This test also records the temperature of water each time the measurements are performed. The permeability coefficient, *k* (cm/s) was calculated using Eq. (4).

$$k = \frac{al}{At}\ln(\frac{h_1}{h_2}) \qquad \text{Eq. (4)}$$

Where *A* (cross section area of specimen, cm^2), *a* (cross section area of standpipe, cm^2), *l* (height of specimen, cm), h_1 (initial height of water above the specimen, cm), h_2 (height of the water after time, cm), and *t* (time taken for the water to fall from h_1 to h_2, second).

3. Results and discussion

3.1. Porosity

Figure 2 shows the porosity of porous concrete pavement with different percentage of Nano BRHA replacement. As shown in the figure, the porosity of the porous concrete specimens increases with the increase in the Nano BRHA percentage replacement. The porosity starts to increase from 0% Nano BRHA replacement to 40% Nano BRHA replacement. The porosity starts from 14.75%, 14.85%, 17.40%, 17.99% and 23.94% respectively. As we can see, there is no significant increment of porosity between the 0% and 10% replacement of Nano BRHA. The same applies to the 20% to 30% Nano BRHA replacement; there is no significant increment in porosity. The difference between 0% to 10% and 20% to 30% is only 0.1% and 0.59%, respectively. From the result, the increase in porosity with the increasing percentage of the Nano BRHA replacement is due to the Nano BRHA in the mixtures absorbing the water. When the amount of the Nano BRHA in the mixture increases, it will absorb more water. In consequence, the workability of the mixtures will be decreased [19]. In addition, because of the decrease in workability, the hardened specimens became more porous. Besides, the figure also shows a strong relationship between the percentage of porosity and the percentage of Nano BRHA replacement indicating that when the percentage of the Nano BRHA replacement increases, the porosity will also increase. The R^2 value of the graph is 0.828.

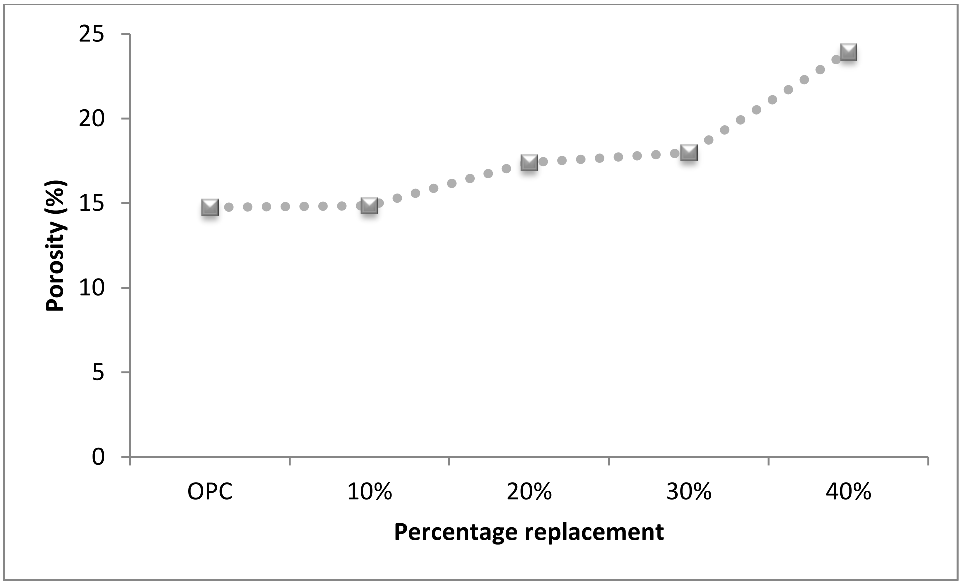

Figure 2. Porosity of porous concrete pavement at different Nano BRHA

3.2. Permeability

The permeability coefficient results of the porous concrete specimens for various Nano BRHA percentage replacements are shown in Figure 3. As we can see from the figure, the lowest permeability coefficient is for specimens with 0% Nano BRHA replacement and the highest permeability coefficient is for specimens with 40% Nano BRHA replacement. The permeability coefficient for specimens with 0%, 10%, 20%, 30% and 40% Nano BRHA replacement is 0.10, 0.11, 0.19, 0.20 and 0.35 cm/s, respectively. The permeability coefficient of porous concrete specimens was found to increase with the increase in the percentage of the Nano BRHA replacement. The permeability coefficient for all specimens increases by 10%, 90%, 100% and 250% respectively from 0% to 40% Nano BRHA replacement. There is a big different between 30% and 40% Nano BRHA replacement of the permeability coefficient. This is probably due to the big different porosity of specimens with 30% and 40% Nano BRHA replacement. The increase in permeability is due to increase in the interconnected voids in the specimens when the percentage of the Nano BRHA replacement increases. The increase in the water absorbed due to the increasing percentage of the Nano BRHA replacement results in reduced workability of the mixtures. It is contributing to the increase of the interconnected voids and directly increases the permeability of the hardened specimens. Kia et al. [22] mentioned that the permeability is not only dependent on the total pore volume, but also on other characteristics, such as size distribution, shape, degree of connectivity and tortuosity of the pores.

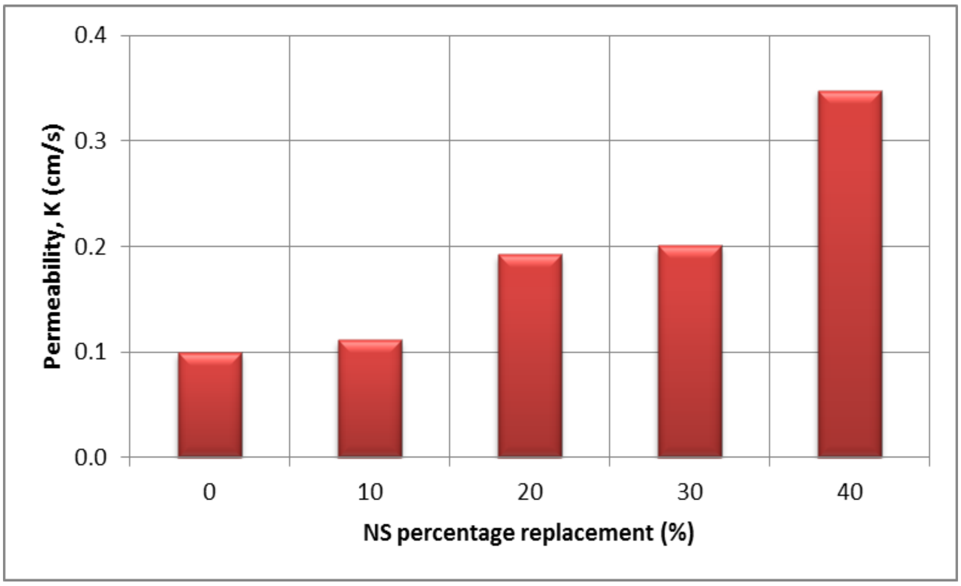

Figure 3. Permeability coefficient of porous concrete pavement at different Nano BRHA

3.3. Relationship between porosity and Permeability

The permeability of the porous concrete specimens has a strong correlation with porosity. The trend line is linear and positive as shown in Figure 4. The correlation was determined using values of porosity in the range of from 14.75% to 23.94% and permeability in the range of from 0.10 to 0.35 cm/s, respectively. It was found that when the porosity increases, the permeability will increase. Porosity is characteristic of the interconnected voids that exist in the hardened specimens while the permeability is defined as the ability of the hardened specimens to allow water to pass through their structure. Thus, this result will be explained by the fact that the increase in porosity is caused by the increases in the interconnected voids in the hardened specimens. As a result of the increasing in interconnected voids, the specimens will allow more water to pass through their structure and directly lead to an increase in the permeability of the hardened specimens. The coefficient of determination (R^2) value of 0.9914 showed a strong relationship between porosity and permeability.

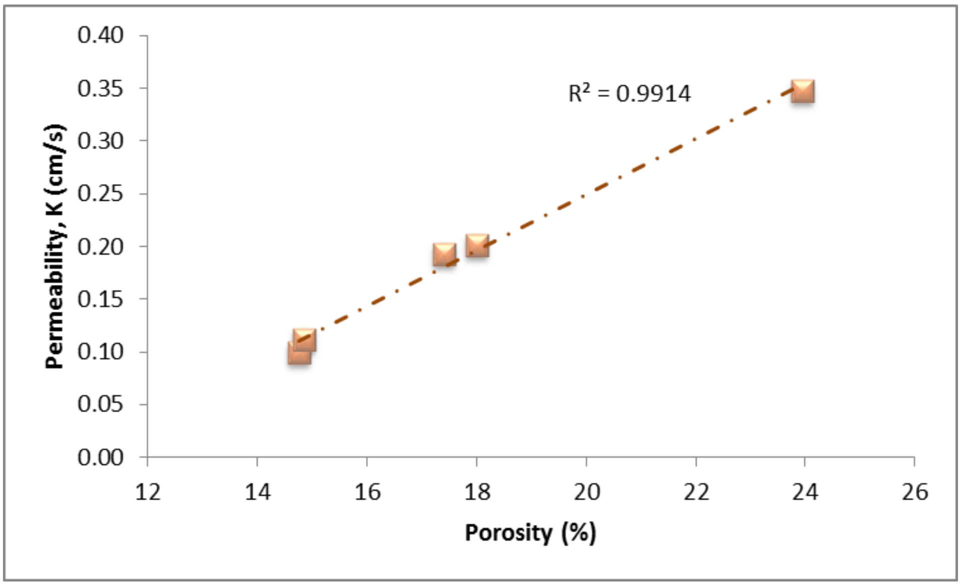

Figure 4. Relationship between porosity vs. permeability

4. Conclusions

The following conclusions are drawn from the data obtained from this study.

- The use of Nano particle from BRHA resulted in good durability development in comparison with the ordinary Portland cement.
- Nano BRHA has high potential to increase in permeability coefficient. This is due to increase in the interconnected voids when the percentage of the nano BRHA increases.
- It is found that the relationship between porosity and permeability has a strong correlation with r-square value more than 90%.

5. References

[1] Agar Ozbek A S, Weerheijm J, Schlangen E and Van Breugel K 2013 *Cem. Concr. Compos*. **39** pp. 1-11.
[2] Deo O and Neithalath N 2011 *Constr. Build. Mater*. **25** pp. 4181-4189.
[3] Chindaprasirt P, Hatanaka S, Chareerat T, Mishima N and Yuasa Y 2008 *Constr. Build. Mater*. **22**(5) pp. 894-901.
[4] Jing Y and Guoliang J 2003 *Cem. Concr. Res*. **33** pp. 381-386.
[5] Bhutta M, Tsuruta K and Mirza J 2012 *Constr. Build. Mater*. **31** pp. 67-73.
[6] Kim H K and Lee H K 2010 *Appl. Acoust*. **71**(7) pp. 607-615.
[7] Schaefer V R, Kevern J T and Wang K 2010 *Int. Conf. Sustain. Constr. Mater. and Tech*. Vol. 2 pp. 28-30.
[8] Jo B.-W, Kim C.-H, Tae G.-H and Park J.-B 2007 *Constr. Build. Mater*. **21** pp. 1351-1355.
[9] Aamer Rafique Bhutta M, Hasanah N, Farhayu N, Hussin M W, Tahir M B M and Mirza J 2013 *Constr. Build. Mater*. **47** pp. 1243-1248.
[10] Pindado M Á, Aguado A and Josa A 1999 *Cem. Concr. Res*. **29**(7) pp. 1077-1083.
[11] Chen Y, Wang K, Wang X and Zhou W 2013 *Constr. Build. Mater*. **42** pp. 97-104.
[12] Yang J and Jiang G 2003 *Cem. Concr. Res*. **33**(3) pp. 381-386.
[13] Mahmud H B, Chia B S and Hamid N B A A 1997 *Proc. Int. Conf. Eng. Mater*. (Ottawa, Canada) pp. 275-284.
[14] Zhang M H and Malhotra V M 1996 *ACI Mater. J*. **93** pp. 629-636.
[15] Senff L, Labrincha J A, Ferreira V M, Hotza D and Repette W L 2009 *Constr. Build. Mater*. **23**(7) pp. 2487-2491.
[16] ASTM C150 / C150M 2018 *Standard Specification for Portland Cement*. ASTM International, West Conshohocken, PA.

[17] ASTM C618 2017 *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. ASTM International, West Conshohocken, PA.
[18] ASTM C33/C33M 2018 *Standard Specification for Concrete Aggregates*. ASTM International, West Conshohocken, PA.
[19] Mohd Ibrahim M Y, Ramadhansyah P J, Mohd Rosli H, Wan Ibrahim M H 2018 *IOP Conf. Ser. Mater. Sci. Eng*. **290**(1), pp. 1-6.
[20] ASTM D7063/D7063M 2011 *Standard Test Method for Effective Porosity and Effective Air Voids of Compacted Bituminous Paving Mixture Samples*. ASTM International, West Conshohocken, PA.
[21] ASTM PS 129 2001 *Standard provisional test method for measurement of permeability of bituminous paving mixtures using a flexible wall permeameter*. ASTM International, West Conshohocken, PA.
[22] Kia A, Wong H S and Cheeseman C R 2017 *J. Environ. Manage*. **193** pp. 221-233.

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