Strength and Porosity of Porous Concrete Pavement Containing Nano Black Rice Husk Ash

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Abstract. Rice husk ash (RHA) as replacement material in the conventional concrete mixture has been widely studying around the world. However, there is a lack of study on nanoparticle produced from black rice husk ash (BRHA) used as a replacement material in porous concrete pavement mixture. Therefore, this study aims to evaluate the performance of porous concrete pavement containing nano black rice husk ash in terms of compressive strength, porosity and its correlation. A nano BRHA dosage of 10, 20, 30 and 40% by weight of binder was used throughout the experiments. Four different grindings of BRHA were examined, and it was found that BRHA ground had a nanoparticle between 64 nm to 85 nm. There appears to be an optimum replacement of approximately 10% nano BRHA, during which time the compressive strength and porosity increase significantly.

1. Introduction

Porous concrete is also referred to as pervious concrete, no-fines concrete and Permeable concrete. 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]. Porous concrete is concrete with continuous voids, which are purposely incorporated into concrete. The porous concrete has a large number of voids; it differs from conventional concrete, which has small or microvoids. The finished surface is not tight, and uniform, but is open and varied, to admit large quantities of stormwater (Specifier's Guide for Pervious Concrete Pavement Design). The ability of the porous concrete pavement to allow water to percolate into the underlying strata depends on its porosity, which is one of its most important pore structure features [2]. This type of concrete is a completely different category from conventional concrete, and therefore its physical characteristics differ greatly from those of normal concrete [3]. In recent years, the use of nanomaterials has received particularly interested in various fields of applications to improve existing technologies and also produce materials with new functionalities [4]. Research and developments have established that the application of nanotechnology can improve the performance of conventional construction materials, such as concrete and steel [5]. Nano-materials are used as a replacement for cement parts. The nanoscale size of the materials can result in significantly enhanced properties from conventional grain-size materials of the same chemical composition. Previous research studies on mixing nanomaterials in cement indicate that the inclusion of nanomaterials modifies the fresh and hardened properties [6]. Nanoparticles have a high surface area to volume ratio and also provide high chemical reactivity [7]. Previous researchers agree that the finer pozzolanic ash has a better reaction compared to coarser pozzolanic ash [8,9]. The fineness of the rice husk ash is important because it influences the rate of reaction and the rate of gain in concrete strength [10,11]. In producing fineness or nano-size of materials, Pacheco-Torgal et al. [7] reported that the production of nanomaterials could be obtained using two methods, namely through high milling energy or by chemical synthesis. The methods consist of ball milling, flame spray pyrolysis, chemical vapour deposition, micro-emulsion, sol-gel and many more [12]. Various grinding methods have been applied by previous researchers to produce fine rice husk ash. Some researchers pulverised the rice husk ash by using a vibrating ball mill [13]. Fernandes et al. [14] grinding the passing rice husk ash using an eccentric ball mill. Salas et al. [15] the RHA was ground by ball milling using ceramic balls and Habeeb and Fayyadh [16] was ground the RHA using a Los Angeles mill. The lack of research conducted on porous concrete containing nanoparticle produced by BRHA is the main reason for this study. Porous concrete has been used for many years, but there are still many outstanding issues related to its structural performance [17]. The fundamental information, i.e. the influence of the water-cement (W/C) ratio, void ratio, cement paste characteristic, the volume ratio of coarse aggregate and etc. has been studied. However, the relationship between strength and porosity of porous concrete pavement is still not yet established [18]. Therefore, this research was conducted.

2. Materials and methods

2.1. OPC and aggregate

The ordinary Portland cement type I with the requirements of BS EN 197-1 [19] was supplied by the Tasek Corporation of Malaysia Berhad and was used as the major binder material in the production of strength concrete pavement grade 20 MPa. On the other hand, crushed granite of size 20 mm was used as the coarse aggregate with a specific gravity of 2.66 and water absorption of 0.86%, respectively.

2.2. Production Nano BRHA through the grinding process

The black rice husk ash (BRHA) samples were collected from the rice mill factory. The rice husk was burned at the factory without controlling the specific temperature. At the laboratory, the raw BRHA was sieved using a sieve size of 150µm to ensure the homogeneity of the BRHA size before the grinding process. Then, the BRHA passing the 150µm sieve was taken and ground for four different grinding times to obtain the nano size (NS). The original BRHA was generally designated as NS_0; further explanation exhibited in Table 1.

Table 1. Grinding designation

Nano BRHA	Time of grinding (hrs)
NS_0	0
NS_1	33
NS_2	48
NS_3	63
NS_4	81

2.3. Mix proportions and curing

The OPC was partially replaced with nano BRHA at dosages of 10%, 20%, 30% and 40% by weight of the cementitious material. A mass water-to-binder ratio of 0.34 was used. A total cement content used in this investigation was 450 kg/m^3, coarse aggregate (1115 kg/m^3) and water (153 kg/m^3). Further, the curing condition is one of the important factors that need to be considered. The standard curing no-fines test cubes were followed according to established British standard BS EN 12390-2 [20]. Immediately after making the cube specimens, the specimens were stored in a place free from vibration and under a condition that prevented moisture loss. Upon demoulding after a period of 16 to 28 hours, the specimens were immersed it in water until air bubbles cease to rise. The specimens were drained and immediately placed in a polyethylene bag. Then, the polyethylene bags were sealed and stored. Tests were performed when the samples were 7, 14, 28, 56 and 90 days old. The results obtained at each age were reported as an average of the three tested samples.

2.4. Compressive strength test

The compressive strength test of the porous concrete pavement mixes was performed on 100 x 100 x 100 mm cubes. The specimens were compressed using a compression machine with a loading rate of 3.5kN/s. The reported compressive strength was the average of the three specimens tested. The test was conducted according to the British standard test method BS EN 12390-3 [21].

2.5. Porosity test

The porosity test was conducted by ASTM D7063/D7063M [22]. At laboratory, the dry specimens were 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 was calculated using Eq. (1), (2) and (3).

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

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

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

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

3. Results and discussion

3.1. Chemical properties

The chemical test of the OPC and nano BRHA was conducted using the X-ray Fluorescence spectrometer (XRF). It was found that the calcium oxide had the highest percentage for OPC (62.27%) followed by silica (22.68%). The other elements had a small percentage for example alumina (4.72%), iron (3.5%), oxide (1.89%), magnesium oxide (0.31%) and potassium oxide (4.29%). It can be seen that the chemical composition of OPC fulfilled the standard requirements, as stated in the American Society for Testing and Materials [23]. Furthermore, SiO_2 (91%) was identified as the main component of the BRHA. The other elements in BRHA are alumina (0.07%), iron oxide (0.07%), magnesium oxide (0.45%), sodium oxide (0.28%), potassium oxide (0.01%) and sulphur trioxide (2.64%). Compared with OPC, the BRHA has a small percentage of calcium oxide and a high percentage of silica. According to ASTM C618 [24], the BRHA used in this study satisfied the Class N requirement for natural pozzolan, which indicates that the total amount of silicon dioxide, aluminium oxide and iron oxide must be equal or greater than 70%.

3.2. Physical properties

The specific gravity of the OPC used in this study was 2.23, where the specific gravity of nano BRHA at the different grinding time are summarized in Table 2. It was found that the specific gravity of nano BRHA was less than that of the OPC. This is due to the porous particles of the materials becoming fine particles after the crushing process. Also, the mean particle size of the OPC is 1353 nm, while the mean particle size of the nano BRHA is presented in Table 2. It clearly shows that an increase in the grinding time, decrease the mean particle size of nano BRHA.

Table 2. Grinding designation

Nano BRHA	Specific gravity	Particle size (m)
NS_1	1.62	85
NS_2	1.64	76
NS_3	1.72	66
NS_4	1.76	64

3.3. Compressive strength

Figure 1 shows the result of compressive strength for the various nano BRHA replacements. Generally, the compressive strength for all specimens increases with the increase in curing age. From the figure, it can be seen that the highest compressive strength for each age is 10% for the replacement specimen, which is 20.88 MPa, 24.45 MPa, 27.80 MPa, 34.20 MPa and 35.23 MPa for 7, 14, 28, 56 and 90 days, respectively. The 40% replacement of nano BRHA is the lowest compressive strength, which is 14.64 MPa, 16.28 MPa, 22.92 MPa, 27.53 MPa and 29.30 MPa for 7, 14, 28, 56 and 90 days, respectively. The compressive strength for each day of testing shows the same trend where the compressive strength starts to increase from 0 % replacement to 10 % replacement of the nano BRHA. Then, the compressive strength starts to decrease from 10 % to 20% replacement of the nano BRHA. The same applies to 20 % to 30 % and 30 % to 40 % replacement. This finding similar to Jaya et al. [11] where the compressive strength starts to increase with 10% replacement, and it starts to decrease when the replacement is beyond 10%. This phenomenon probably occurred due to workability and the lack of required water in the mixture. The use of NS in porous concrete had greater compressive strength than the control specimens [25]. Nevertheless, Wang et al. [26] found in their study that too high or too low a content of NS is not beneficial to upgrading the cement strength. This is probably due to the amount of NS in the mix being higher than the amount required combining with the liberated lime during the process of hydration. From this figure, the 10 % replacement of nano BRHA has the best property for the compressive strength evaluation.

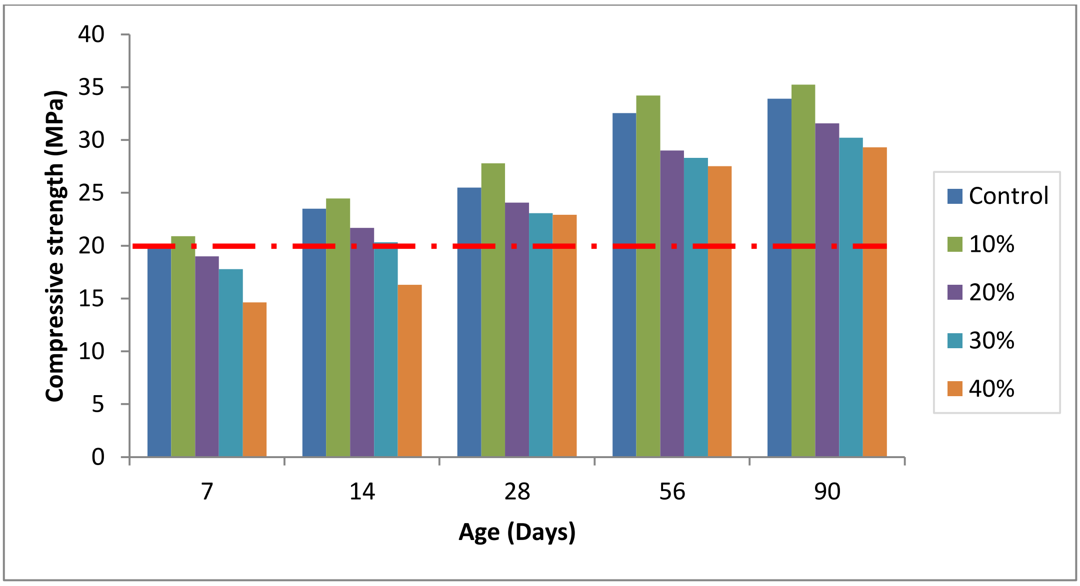

Figure 1. Compressive strength at different nano BRHA replacement

3.4. Porosity

Figure 2 illustrated the porosity of porous concrete pavement at different level of nano BRHA. It can be seen that the porosity of the porous concrete pavement increases with the increase in the nano BRHA replacement. The porosity starts to increase from 0% to 40% when nano BRHA was replaced with cement. The increased in porosity was about 14.75%, 14.85%, 17.40%, 17.99% and 23.94% respectively. There is no significant increment of porosity when nano BRHA was replaced between 0% and 10%. The same applies to 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. 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 nano BRHA in the mixture increases, it will absorb more water. The results also found that there is a strong correlation between the percentage of porosity and the percentage of nano BRHA replacement. This indicating that when the percentage of the nano BRHA replacement increases, the porosity will also increase.

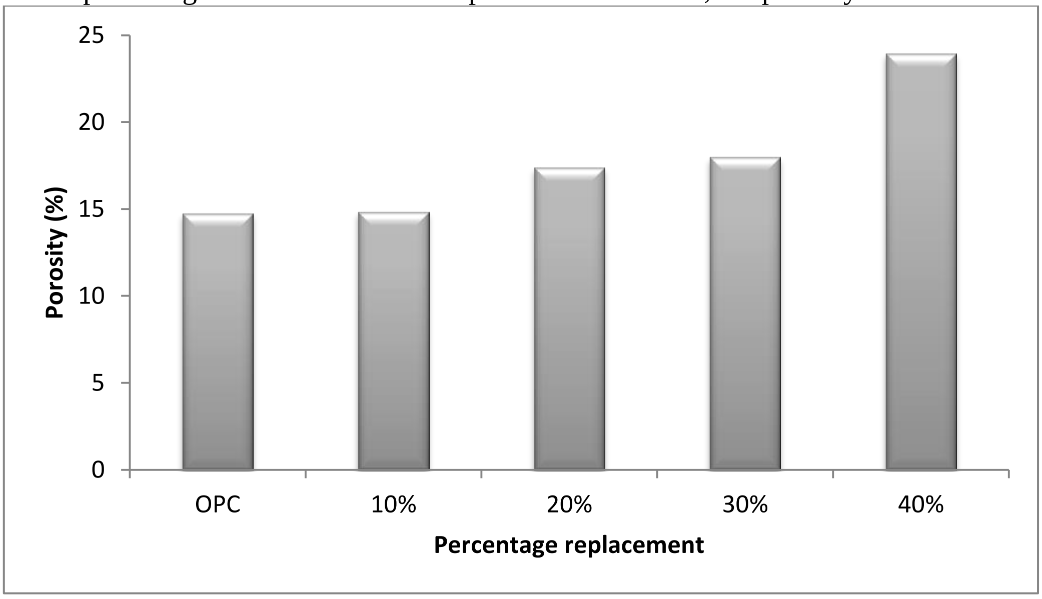

Figure 2. The porosity of porous concrete pavement

3.5. Correlation between strength and porosity

Figure 3 shows the relationship between compressive strength and porosity for the porous concrete pavement. The relationship was determined using a value of 14.75, 14.85, 17.40, 17.99 and 23.94 % for porosity and 25.48, 27.80, 24.07, 23.06 and 22.92 MPa for compressive strength, respectively. The R^2 value for the relationship is 0.8083, and it shows a negative correlation. It was found that increasing porosity will decrease the compressive strength. It is due to the interconnected voids decreasing the strength of the specimens.

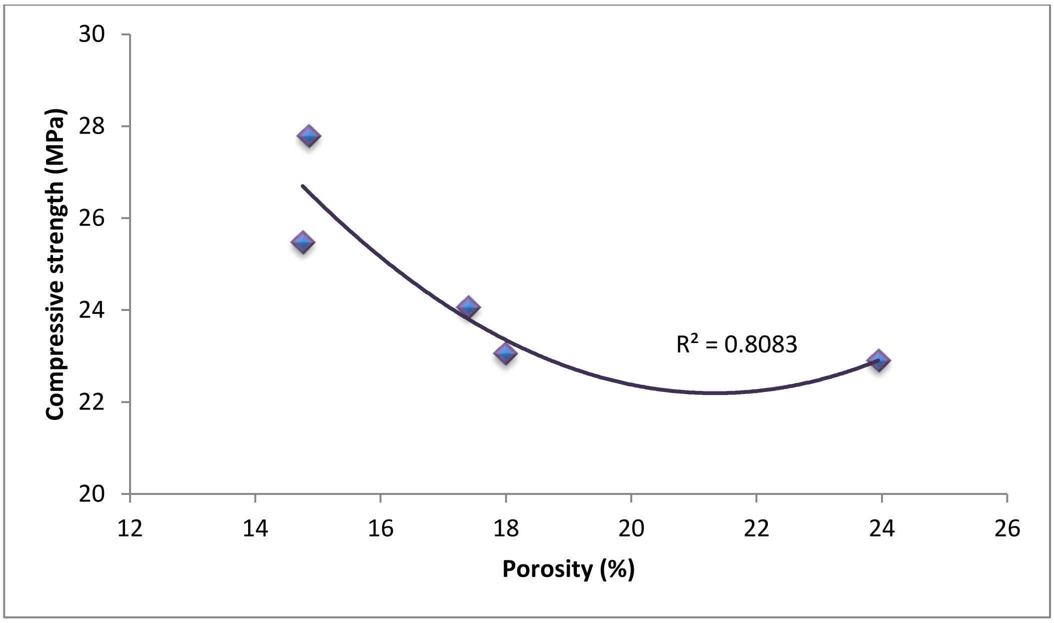

Figure 3. Strength vs porosity of porous concrete pavement

4. Conclusions

a. It was found that the nano BRHA and OPC had the highest percentage of calcium oxide and followed by other elements. The results also show that the nano BRHA used was satisfied with the ASTM requirement for natural pozzolan.

b. The specific gravity of nano BRHA increased with increased grinding time where nanoparticle BRHA decreased as grinding time increased.

c. The compressive strength of the porous concrete pavement incorporating nano BRHA investigated initially increased up to 10% replacement and then began to decrease until 40% level.

d. There appears to be an optimum nano BRHA level of approximately 10%, for which compressive strength and porosity values increased significantly.

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