Strength Properties of Porous Concrete Pavement Blended with Nano Black Rice Husk Ash

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Abstract. In order to improve the porous concrete pavement strength, one of the elements in the porous concrete structure that needs to be considered is the cement paste binder. This study aimed to evaluate the strength properties of porous concrete pavement blended with nanoparticle from black rice husk ash (BRHA). The performance was evaluated based on compressive strength, density, age of curing and strength activity index. Four nano BRHA replacement levels were considered in the study, i.e. 10%, 20%, 30%, and 40% by weight of cement. Test results showed that porous concrete pavement containing 10% nano BRHA replacement levels exhibits excellent compressive strength and strength activity index. The results also indicate that there is no significant correlation between density of the porous concrete pavement and compressive strength.

1. Introduction

Porous concrete has become increasingly used in a variety of infrastructures such as pavements and overlays subjected to the heavy traffic load [1]. Due to these extended applications, superior strength and durability constitute the main concerns associated with porous concrete pavement [2]. Porous concrete pavement is concrete with limited or no fine aggregates [3]. The concept of porous concrete tends to increase the strength and reduce surrounding noise [4]. Different from conventional concrete pavement, the porous concrete pavement has a high percentage of voids (between 15 % to 25 %) [5]. One of the approaches to strengthen the concrete strength is to minimise the number of voids [6]. Compared with conventional concrete pavement, porous concrete pavement is designed to have a high percentage of voids in its structure. At the same time, the required strength must be achieved to cater vehicle loads [7]. In order to increase the porous concrete pavement strength, one of the elements that need to be considered is the cement paste binder [8]. Besides aggregates, the strength of the porous concrete pavement depends on the cement paste binder [9]. A various study has been conducted in order to explore the advantages of using nano-size in their products. For example, Heikal et al. [10] found that by using nanoparticle size, the strength of the concrete was improved significantly. Several sources can be used to produce nanoparticle size, for instance, black rice husk ash (BRHA), palm oil fuel ash (POFA), fly ash (FA), Kaolin clay and etc. In this investigation, the nanosize produced from black rice husk ash was selected as a main replacement component for the porous concrete pavement mixture.

2. Materials and methods

2.1. OPC

The ordinary Portland cement (OPC) was supplied by the Cement Industries of Malaysia satisfying the requirements of British European Standard specification for ordinary and rapid hardening Portland cement [11]. The chemical compositions of the OPC are listed in Table 1. The chemical analysis was carried out using XRF apparatus in accordance with the procedure given in BS EN 197-1 [11].

Table 1: Chemical compositions of PC

Oxide compounds	Chemical composition (%)
Silicon dioxide (SiO_2)	17.0
Aluminum oxide (Al_2O_3)	3.90
Iron oxide (Fe_2O_3)	3.20
Calcium oxide (CaO)	70.0
Magnesium oxide (MgO)	1.50
Sodium oxide (Na_2O)	0.02
Potassium oxide (K_2O)	0.53
Sulfur trioxide (SO_3)	3.60
Loss on ignition (LOI)	0.25

2.2. Aggregates

In order to obtain the final porous concrete pavement proportioning, the aggregates were washed, dried, and then sieved into their respective size ranges. The size required would depend on the kind of gradation used. The gradation of coarse aggregates used in this study is tabulated in Table 2. Based on the table, a sieve analysis carried out on a representative sample of the coarse aggregates showed that they complied with the requirement of ASTM C33/C33M [12].

Table 2: Coarse aggregate used

Aggregate size (mm)	Upper and lower limits (%)	Mid-gradation (%)
19.00	100	100
12.50	90-100	95
9.50	40-70	55
4.75	0-15	0
2.36	0-5	0

2.3. Water

Water is an important constituent in the manufacture of porous concrete pavement. In this investigation, tap water was used, which is safe for drinking. The general chemical analyses of tap water are shown in Table 3.

Table 3: Chemical analysis of the tap water

Element	Dissolved solid	Calcium	Chloride	Magnesium	Sulphate	Bicarbonate	Potassium
mg/L	80	23	2	2.6	4	81	3.8

pH	6.9

2.4. Nano from BRHA

At the laboratory, the raw BRHA was sieved using a sieve size of 150µm to ensure the homogeneity before the grinding process. Then, the BRHA passing the 150µm was taken and ground by a grinding machine for different grinding times. From the test that has been conducted, it was found that the optimum grinding time of BRHA to achieve nanosize was 63 hours with a mean particle size of 66 nm.

2.5. Mix design and compressive strength test

At the laboratory, a total cement content of 450 kg/m^3, 1115 kg/m^3 of coarse aggregate and 153 kg/m^3 of water were found and used as the control mix proportion for this study. The water to cement ratio (w/c) used was 0.34. Then, the compressive strength test of the porous concrete pavement mixes was performed on 100 × 100 × 100 mm cubes. The specimens were compressed by a compression machine with maximum capacity of 3000 kN with a loading rate of 150 kN/min. The reported compressive strength was the average of the three samples. The test was conducted according to the British standard test method BS EN 12390-3 [13].

3. Results and discussion

3.1. Compressive strength

The compressive strength of the porous concrete pavement containing OPC and nano BRHA at different replacements is illustrated in Figure 1. The test results indicate that the strength of porous concrete pavement incorporating nano BRHA was higher than the controlled mixes even at 90 days. Clearly, strength properties of porous concrete have increased significantly by the aged process. The amorphous silica and the nanoparticle size of BRHA are the principal reasons for the excellent pozzolanic activity and increase in compressive strength. On the other hand, the compressive strength of the porous concrete pavement replacement with 40% nano BRHA is lower than that of the others mixture at all ages as shown in Figure 1. Based on the results, it appears that there is an optimum percentage replacement of nano BRHA in porous concrete pavement approximately 10% beyond which the compressive strength increased significantly.

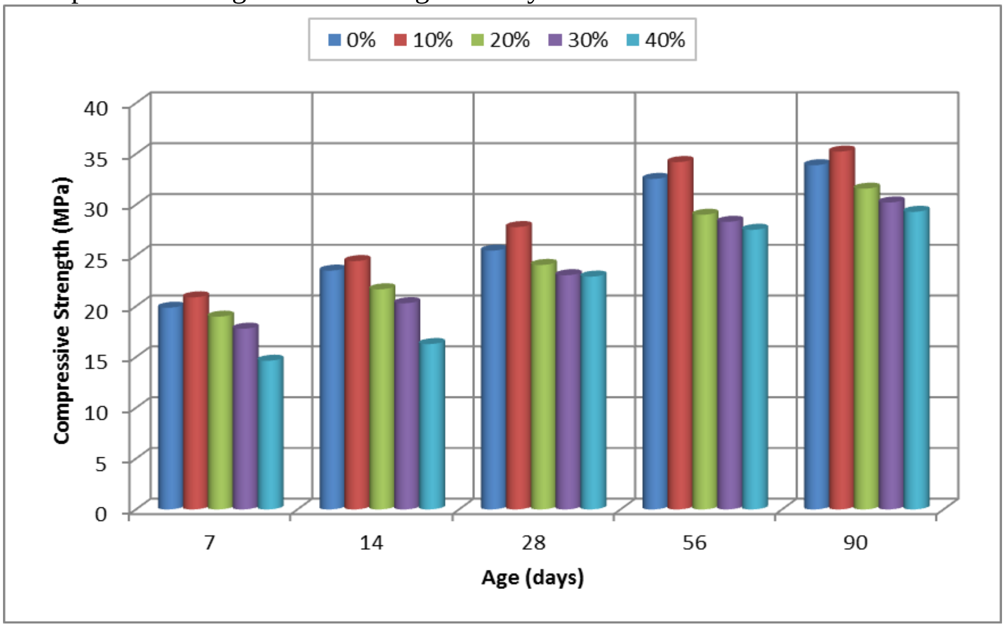

Figure 1: Compressive strength of porous concrete pavement

3.2. Density

The density of the porous concrete pavement specimens was measured right before the specimens were tested. The results are shown in Figure 2. The density of the porous concrete pavement is in the range of 1900 kg/m^3 to 2190 kg/m^3. As for the control specimens, the mean value was calculated as 2106 kg/m^3. While for the specimens with nano BRHA replacement, the mean value was calculated as 2012 kg/m^3. The mean density for specimens with nano BRHA replacement reduced by 4.5% from the control specimens. This is probably due to the effect of the nano BRHA replacement in the porous concrete specimens.

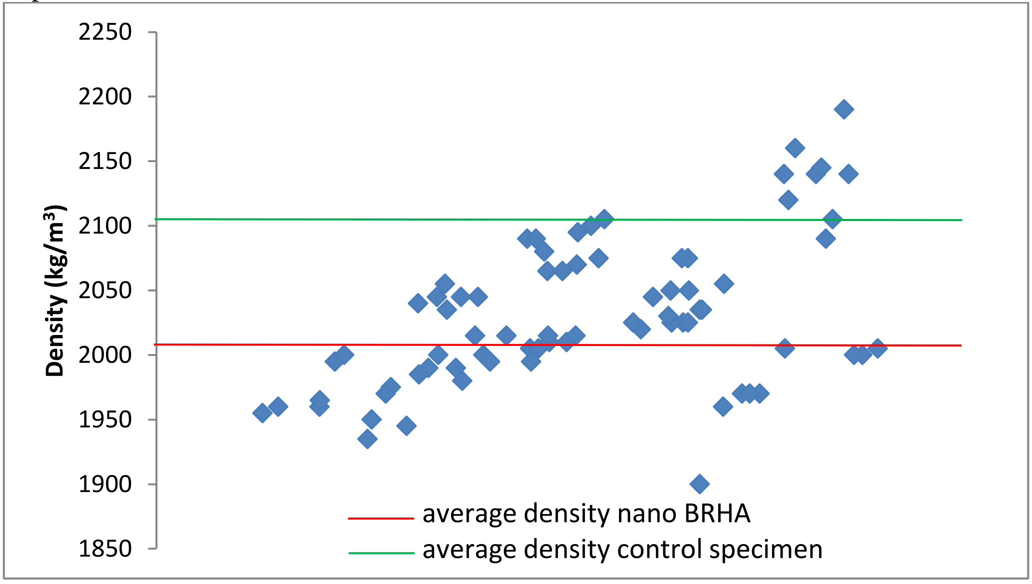

Figure 2: Density of specimens at different nano BRHA replacement

3.3. Compressive strength vs density

The relationship between the density and compressive strength of porous concrete pavement containing different nano BRHA percentage replacements is shown in Figure 3. From the figure, it can be seen that the density of the porous concrete pavement specimens has no significant relationship with the compressive strength. It can be seen that the R^2 of the relationship is 0.2626. Both high and low-density values have high strength. This phenomenon contrasts the typical theory which stipulates that when the density of concrete increases, the compressive strength of the concrete also increases and vice versa. This is probably due to the reaction of the nano BRHA replacement in the porous concrete mixture. A different percentage of replacement gives a different reaction. Although the porous concrete pavement specimens have low density, if the amount of nano BRHA contained in the porous concrete mixture is correct and enough to have a good reaction, it will result in good compressive strength.

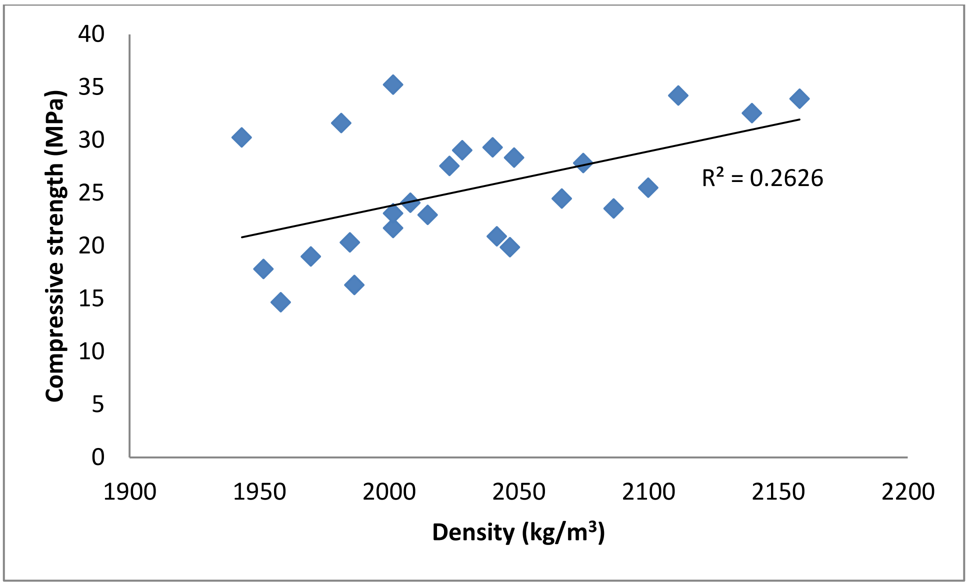

Figure 3: Density vs compressive strength of the porous concrete pavement

3.4. Compressive strength vs age of curing

Figure 4 shows the trend lines between the compressive strength and the age of the specimens for different percentages of nano BRHA replacements. While Table 4 shows the coefficient of determination (R^2) value for the relationship between the compressive strength and the age of the specimens for different percentages of nano BRHA replacements. The R^2 values are 0.90, 0.88, 0.95, 0.93 and 0.87 for 0%, 10%, 20%, 30% and 40%, respectively. All of the specimens show a good relationship between compressive strength and the ages of the specimens. The compressive strength of the specimens for each of the nano BRHA percentage replacements increases with the increase in the specimens' age. The continued hydration develops the strength of cement-based materials [14]. The increase in age gives more time for the hydration process in the specimens. Indirectly, the specimens become more hardened with respect to age. This is because the figure shows that the strength of the specimens increases with the increase in age.

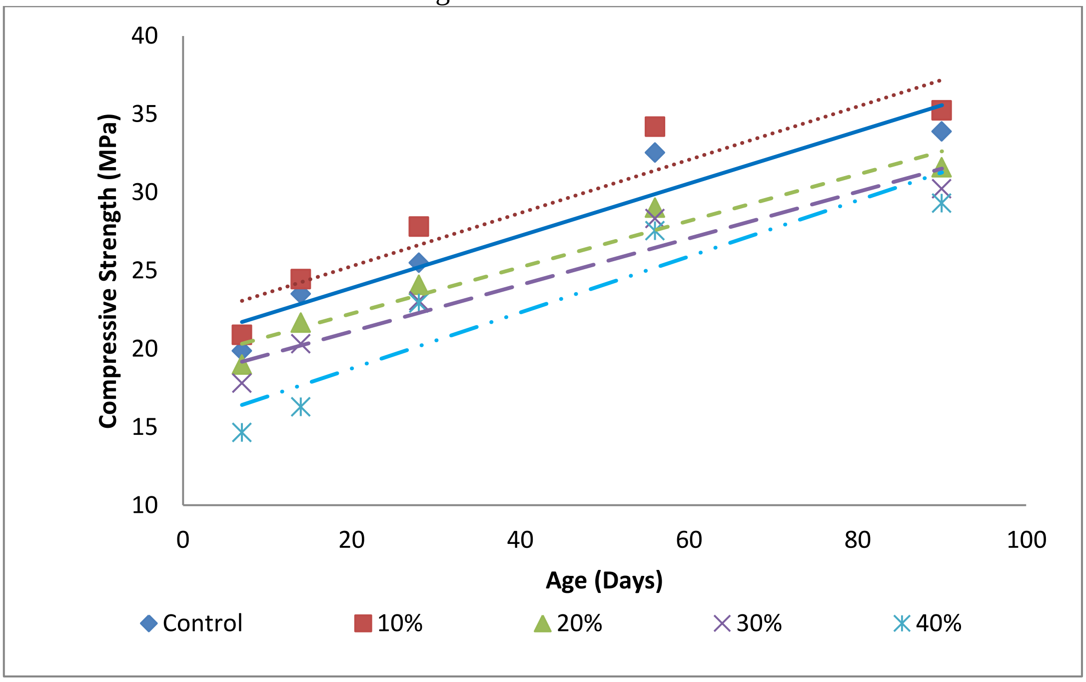

Figure 4: Compressive strength vs age of specimens

Table 4: Correlation value of strength vs curing age

Nano BRHA	0%	10%	20%	30%	40%
R^2 value	0.90	0.88	0.95	0.93	0.87

3.5. Strength activity index

As prescribed by ASTM C311/C311M [15], the strength activity index is used to determine whether natural pozzolan results in an acceptable level of strength development when used with hydraulic cement in concrete. This calculation was adopted here in order to determine the different strength values when a different percentage of replacement is used. The strength activity index was calculated following Equation 1.

$$\text{Strength activity index} = \frac{A}{B} X\ 100 \qquad (1)$$

Where A is compressive strength of the test mixture cube (MPa), and B is compressive strength of the control mix cube (MPa).

The strength activity index of the compressive strength results for all of the nano BRHA replacement percentages is shown in Figure 5. At any specimen age, 10% of nano BRHA replacement shows an increase in strength activity index. The strength activity index increased by 5.14%, 4.01%, 9.08%, 5.10% and 3.94% for 7 days, 14 days, 28 days, 56 days and 90 days, respectively. For 20%, 30% and 40% of nano BRHA replacement, a decrease in the strength activity index is observed at all ages. The lowest strength activity index at all ages belongs to specimens with 40% nano BRHA replacement. The strength activity index decreased to 73.72%, 69.26%, 89.93%, 84.60% and 86.45% for 7 days, 14 days, 28 days, 56 days and 90 days, respectively. This may be due to the quantity of nanoparticle present in the mixes being higher than the amount required to combine with the liberated lime during the hydration process, consequently leading to excess silica leaching out causing a deficiency in strength as it replaces part of the cementitious material [16]. Overall, for the strength activity index, all the specimens have a strength activity index of more than 75% for the 28 days age.

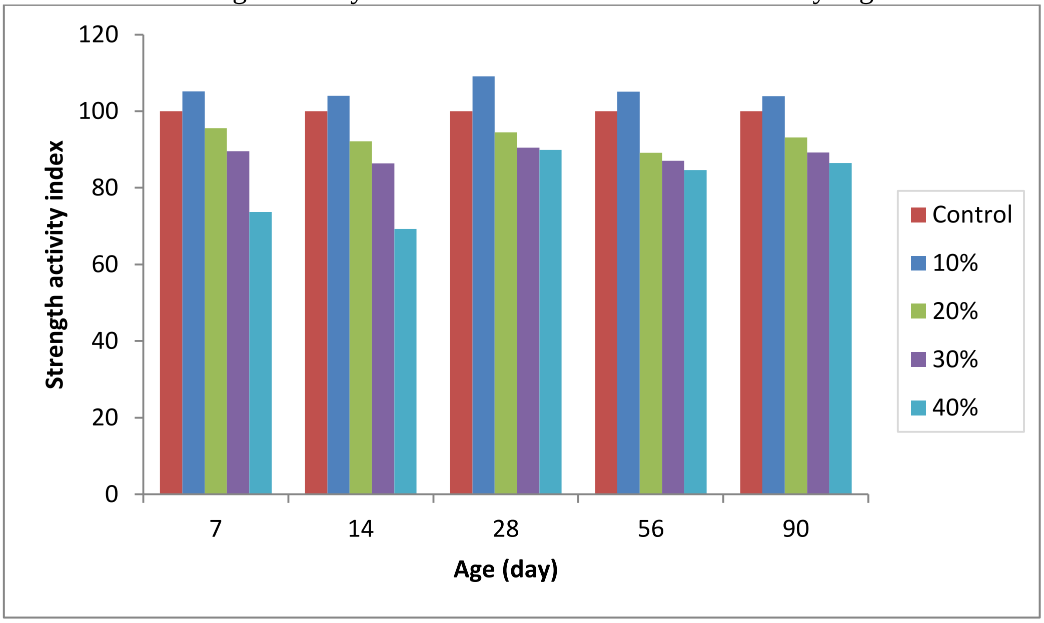

Figure 5: Strength activity index of porous concrete pavement

4. Conclusions

a) From the tests, it was found that the strength of the porous concrete pavement increases with age, the increase in strength partially due to the pozzolanic reaction. Furthermore, the compressive strength increases with increasing nano BRHA content up to a peak level and then decreases with further replacement.

b) The strength activity index of the nano BRHA in porous concrete pavement investigated increased with increased replacement level.

c) The use of nano BRHA at 10% replacement with cement produces the porous concrete pavement with good compressive strength and strength indexed.

5. References

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