Sustainable pervious concrete incorporating sorghum husk ash as cement replacement

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Abstract. The sustainability of Pervious Concrete (PC) can be enhanced by the utilization of waste materials for its construction. Employment of Sorghum Husk Ash (SHA) in partially replacing binder to produce a more sustainable PC was carried out in this research. Preparation of various mixtures of PC was done adopting the same size of aggregate (4.75 – 9.50), the same water/cement ratio (0.4) as well as the same aggregate/cement ration (4:1) and was investigated at 0, 5, 10, 15, 20 and 25 % substitution levels of binder with SHA. Produced PC samples were tested for density, porosity, permeability and compressive strength. The results revealed that density decreased while permeability and porosity raised with rising percentage of SHA. Fresh density was obtained to range from 2000 to 1965 kgm\(^{-3}\) whereas hardened density ranged between 1981 and 1940 kgm\(^{-3}\), 21.5 to 24.5 % values were obtained for porosity while permeability had values of 4.8 to 10.1 mms\(^{-1}\) for 0 - 25 % SHA correspondingly. The compressive strengths of 8.2 Nmm\(^{-2}\) was achieved for 25% SHA and 11.4 Nmm\(^{-2}\) for 0 % at 28 days curing time. The 5% SHA was found to be 13.2 Nmm\(^{-2}\) which is 16 % greater than 0 % SHA PC while that of 10 – 25 % correspondingly reduced by 4.4 - 28.1 %. The research revealed that SHA can practically be utilised to substitute cement with comparable and even make a better mixture than using 100 percent cement in PC fabrication.

1. Introduction
Rapid development of nations has put burden on researchers and engineers to discover diverse traditions to moderate the impermeable surfaces and to handle controlling of storm-water in a workable and atmosphere pleasant approach [1]. The main benefit of PC is the fitness of carrying huge water quantity through its aperture arrangement that is widely linked underground, therefore eradicating storm-water overspill hitches, removing pollutants and getting the water quality better [2-6]. PC is a sustainable concrete recommended by the government of America as a proper gauge to control the influence of development on the environments. PC is a concrete blend that comprise of cement, evenly classified stone aggregate and water [6]. The porousness of PC varies from 1.4 to 12.2 mms\(^{-1}\). PC has porosity in the collection of 15 - 35%. Its compressive strength is usually between 2 and 28 N/mm\(^2\). It is often used in car parks, footpaths, sidewalks and other slight volume roads [3, 7].

There are several agro-wastes readily available in Nigeria which have potentials to be used for construction purposes but have not been exploited by construction industry. Among them is SHA which is usually obtained by burning of sorghum husk, a protective shell of sorghum seed. This study adopted...
SHA because of its plentiful availability and environmental hazard associated with its disposal. This is because the second biggest manufacturer of sorghum worldwide is Nigeria with approximately 6.6 million metric tons being produced in the country every year [8]. About 4 to 11 % content of SHA is produced from burning of sorghum husk [9]. SHA has a good pozzolanic property when properly burnt [9, 10].

A number of researchers have carried out experiment on the use of admixtures on properties of PC. The fatigue life, fracture and strength properties of PC were studied by [11] using superplasticizer and silica fume as cementitious material. It was revealed that PC with high strength may be obtained by utilizing cementitious resources. Study on the behaviour of PC with bottom coal ash (BCA) as admixtures was carried out by [12]. It was revealed that strength of PC improved with raise in proportion of BCA. Another study by [12] revealed that lower replacement of silica fume resulted in elevated early strength but the strength drastically reduced at higher replacement levels. Similar results was obtained using fly ash and silica fume as admixture as reported by [13]. Moreover, the strength property of PC was studied by [12] using superplasticizer and flyash as cementitious material. It was revealed that strength of PC increased with raise in proportion of fly ash. Fly ash was therefore recommended for strength requirements.

Zhuge [14] inspected the consequence of various admixtures on the performance of PC. PC material with improved mechanical properties and satisfactory hydrological properties was developed. The effect of adding silica fume, fly ash, and polymers was investigated. It was discovered that small amount of additives had less influence on both mechanical and hydrological properties of PC. Similarly, the effect of marble sludge powder on properties of PC was studied by [15]. The strength properties of PC mixtures at 0, 5, and 1 % marble powder addition were investigated. It was concluded from the results that strength of PC improved as the proportion of marble powder rises.

This main effort of the current study is to produce an environmentally sustainable PC that incorporates SHA as partial cement replacement up to 25% using cheap locally available gravel aggregate in Nigeria.

2. Materials and methods

2.1 Materials

Dangote 42.5R brand of Ordinary Portland Cement (OPC) was adopted for this research investigation.

Its specific gravity of was obtained to be 3.15. Aggregate utilized for this study was gotten from a quarry located at Awo in Osun State, Nigeria. The aggregates sieve analysis was carried out on gravel to obtain aggregate required size of 4.75-9.50 mm for the experiment. Figures 1 offered the sieve analysis for gravel sample utilized for the experiment and liken them with the higher and lesser boundaries of British Standard code [16]. The coarse gravel was established to be in the yardstick for single-sized aggregate material. Bulk density, water absorption, specific gravity, AIV and ACV were obtained to be 1467 kg/m^3, 0.45 %, 2.66, 20.08% and 21.81 % correspondingly. Sample of husks of sorghum were obtained Aoyaya Village in Ogbomoso Local Government Area, Oyo State. Sorghum husk samples were subjected to a temperature of 700°C for a period of at least 3 hours to produce SHA. The SHA acquired was subjected to X-ray Fluorescence (XRF) to obtain its chemical composition. The proportion of silica, alumina and ferric oxide added together is 77.29% (Table 1), this fulfil ASTM standard [17] condition for pozzolana.Tap water obtained from concrete laboratory was consumed for the experiment.

2.2 Methods

A total of six PC mixtures to include a control and five PC mixes with SHA were prepared for the experiment. The codes 5S, 10S, 15S, 20S and 25S indicated the fraction of SHA by mass of binder as shown in Table 2. Newly fabricated PC were poured into 100 x 200 mm plastic cylindrical moulds adopting three layers filling and tamping using steel rod 25 times together with standard proctor hammer dropped 10 times each in order to determine PC properties. Specimens were cured for 7, 28 and 56 days
with the mean of three specimens recorded as the result for each hydrologic and strength properties tested. Porosity was determined based on ASTM C1754 [18] while permeability was obtained with the falling head device shown in figure 2 in accordance with [19]. The compressive strength test was carried out as shown in figure 3 in accordance with ASTM C39 [20].

| Table 1. Results of SHA Chemical analysis |
|-----------------------------------------|
| Chemical components | % |
| SiO$_2$          | 55.3 |
| Al$_2$O$_3$     | 10.1 |
| Fe$_2$O$_3$     | 11.9 |
| SO$_3$          | 0.5  |
| MgO             | 1.2  |
| K$_2$O          | 4.5  |
| Na$_2$O         | 0.7  |
| CaO             | 10.4 |
| SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ | 77.3 |
| Specific gravity | 2.1  |
Table 2. PC Mix Quantities

| Mix   | Rate SHA | Cement (kg/m³) | SHA (kg/m³) | Water (kg/m³) | Gravel (kg/m³) |
|-------|----------|----------------|-------------|---------------|----------------|
| 0S PC | 0        | 368.40         | 0           | 147.36        | 1473.61        |
| 5S PC | 5        | 349.98         | 18.42       | 147.36        | 1473.61        |
| 10S PC| 10       | 331.56         | 36.84       | 147.36        | 1473.61        |
| 15S PC| 15       | 313.14         | 55.26       | 147.36        | 1473.61        |
| 20S PC| 20       | 294.72         | 73.68       | 147.36        | 1473.61        |
| 25S PC| 25       | 276.30         | 92.10       | 147.36        | 1473.61        |

Figure 2. Falling-head permeameter

Figure 3. Test arrangement for cylinder strength
3. Results and Discussion

3.1 SHA Effects on Fresh and Hardened Densities of PC

Figure 4 reveals the result of fresh density and hardened density of PC at various substitution of SHA. It is clearly shown in the figure that increase in the amount of SHA marginally decrease fresh as well as hardened densities. Though, the outcome of hardened density gotten for 5SPC stayed faintly elevated compared to 0SPC. The early filling effect of fine division parts of SHA might be accountable for this. Furthermore, fresh density varies from 2000 to 1965 kgm$^{-3}$ whereas hardened density varies between 1981 and 1940 kgm$^{-3}$. Fresh densities reduced by 0.01, 0.19, 0.66, 0.93 and 1.72 % for 5 – 25% substitution of SHA correspondingly. Hardened density increased by 0.21% when SHA substitution was 5% before it reduced by 0.72, 1.41, 1.81 and 2.09% for 10 – 25% SHA substitution correspondingly. However, the results gotten were contained by the range 1600 - 2000 kg/m$^3$ specified by [21]. Nevertheless, the lesser specific gravity (2.1) of SHA as likened to OPC (3.15) could be the cause of the reduction in density with increasing SHA.

3.2 SHA Effects on PC Porosity and Permeability

Figure 5 displays the porosity and permeability of PC as affected by the addition of SHA. It may well be detected that rise in SHA proportions resulted in better porosity and permeability. The result of porosity gotten for 5SPC was nearly the indistinguishable from result of 0SPC. Conversely, PC porosity containing 10 - 25 % SHA improved by 3.35, 6.09, 10.92 and 13.99 % correspondingly when likened to the 0SPC. Rise in porosity could be attributed to elevated porosity of particles of SHA. In addition, the permeability of 5% SHA substitution was comparable to 0SPC. The results were between 4.8 and 10.1 mms$^{-1}$ for 0 to 25 % SHA substitution correspondingly. Tennis et al. [21] obtained similar outcomes with permeability in the range of 2 – 12 mm/s. PC is required to have adequate permeability in the array of 1.4 to 12.2 mm/s [6]. Similar results were obtained by [19, 22].

![Figure 4. Densities of PC Mixes](image-url)
3.3 SHA Effects on PC Compressive Strengths

Figure 6 shows the results of compressive strength of all PC mixes at 7, 28 and 56 days. It was seen that compressive strength rises from 0SPC to 5SPC before it began to fall at 10, 15, 20 and 25SPC in that order. This put forward 5SPC as the top blend at all days of testing. The grow in compressive strength at 5SPC might be ascribed to the filling impact of the fine ash and additionally to its pozzolanic effect. 5SPC compressive strength was obtained as 13.19 N/mm². This was higher than the value of 0SPC (11.44 N/mm²). However, 10.89, 8.97, 8.51 and 8.24 N/mm² was gotten for 10 – 25% SHA substitution correspondingly. On the other hand, both 5SPC and 10SPC substitution were greater than 0SPC at 56 days telling that extra strength might be added owing to pozzolanic response at later time. Conversely, compressive strength of the 6 inspected blends satisfied the specification of 2.8 to 28 N/mm² described for PC [6].
3.4 PC Properties Correlation

Models that describe the correlation amid PC permeability and porosity, compressive strength and density using Excel 2013 software are presented in Figures 7 to 9. Figure 7 displays the relationship among perviousness and sponginess of the investigated mixtures of PC. Five models of Excel were verified to forecast permeability at definite porosity but power model was selected owing to maximum $R^2$ of 0.99. Equation (1) offered the systematic model gotten.

$$y = 0.02e^{0.25x} \quad (1)$$

$x$ and $y$ are the porosity (%) and permeability (mm/s) respectively.

The correlation sandwiched between hardened density and porosity is shown in Figure 8. After testing about five models, the one with the maximum correlation $R^2 = 0.98$ was selected to forecast the hardened density. The systematic polynomial model gotten is presented in equation (2).

$$y = 4.44x^2 - 218.80x + 4635 \quad (2)$$

$x$ and $y$ are the porosity (%) and hardened density (kg/m$^3$) respectively.

The relationship amid compressive strength and porosity is shown in Figure 9. After testing about five models, the one with the maximum correlation $R^2 = 0.88$ was selected to forecast the 28 day compressive strength. Equation (3) offered the polynomial critical model found.

$$y = 0.54x^2 - 26.18x + 326.22 \quad (3)$$

$x$ and $y$ are the porosity (%) compressive strength (N/mm$^2$) respectively.

The relationship amongst all the properties are similar the those obtained by [23]

![Figure 7. Relationship between Porosity and Permeability](image-url)
4. Conclusion
This study presents the hydrological and strength properties of SHA blend PC. Sustainable PC was produced by incorporating SHA as partial cement replacement up to 25%. As the quantity of SHA bigger, the porosity and permeability of PC increased respectively. Compressive strength increased at 5% SHA before it started to drop off at 10, 15, 20 and 25% correspondingly suggesting 5% as the top mix at all days of testing. The compressive strength value of PC at 5% substitution level was 15.3% greater than control while those of 10, 15, 20 and 25% reduced by 4.8, 21.6, 25.6 and 28% in that order. Conversely, the 5% substitution of SHA as well as 10% were elevated above the control mixture at 56 days signifying that further strength may perhaps be obtained owing to pozzolanic effect at future time. Models that make clear the correlation between porosity and permeability, density and compressive strength of PC mixtures were developed. The $R^2$ value indicates that the models established were capable
of forecasting above 88% of the properties built on porosity. It is concluded that SHA incorporation as cement replacement had substantial effect on both strength and hydraulic properties of PC. Hence it is an alternative concreting material suitable for the production of sustainable PC. Further study is recommended to find the durability of PC incorporating SHA PC.

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