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Optimizing the Mechanical Properties of Pervious Concrete Containing Calcium Carbide and Rice Husk Ash Using Response Surface Methodology

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ABSTRACT

Pervious Concrete (PC) have continued gaining acceptability significantly over years due to its sustainability and environmentally friendly. There are many benefits of using PC, some of which includes management of storm water runoff, groundwater supplier recharging and reduction of heat island effects etc. Numerous studies have been carried out through employing different approaches in order to improve the overall performance of PC. Due to the advancement in high performance PC using supplementary cementitious materials, extensive application of this material was made possible. In this study, calcium carbide waste (CCW) and rice husk ash (RHA) were used as supplementary cementitious materials and up to 20% replacement was made for both RHA and CCW in the PC mixes. Response surface methodology was used to derive the mathematical relationship between strengths and the variables RHA and CCW. The workability, flexural strength, compressive strength and splitting tensile strength were investigated and at 0%RHA and 10%CCW the strength of concrete increases significantly when compared with the control mix.

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1. Introduction

Concrete which has high porosity due to no or very little amount of fines (fine aggregate), containing gap-graded and sometimes permeable aggregates, controlled amount of cementitious materials and water can be said to be a Pervious Concrete (PC). The paste coats and bind the coarse aggregates particles together to form an arrangement interconnected and of highly permeable voids which improves the rapid drainage of water [1].

The permeable or porous concrete can be classified as one characterized by relatively high volume of interconnected pores ranging between 15% to 30% and sizes between 2 mm to 8 mm, with water permeability between 2 mm/s to 6 mm/s. This is usually achieved by using a gap graded coarse aggregate and minimizing or eliminating fine aggregate in the concrete mix. Moreover, American Concrete Institute (ACI) defines PC as ‘‘concrete containing little or no fine aggregate that results in sufficient voids to allow air and water to pass easily from the surface to underlying layers” [2].

The world is now concentrating on the use of materials that are environmentally friendly which will enhance sustainability. In the construction industry, emphasis is now shifted towards use of materials that will reduce the CO_2 emission to the environment, hence materials that can be used as partial replacement to cement continue to gain acceptability because the cement Industry alone contribute about 10% of the global CO_2 emission. Thus, green concrete now is trying to outweigh the conventional concrete technology through reducing the usage of cement by adopting supplementary cementitious materials such as fly ash, silica fume, ground granulated blast furnace slag, rice husk ash etc. These supplementary cementitious materials can be used to partially or fully replace cement during mixing or blended during production of cement [3].

Yang and Jiang (2003) [4] have evaluated the experimental study on properties of PC when used for pavement applications. In the present study porous material were introduced for roadway application. By introduction of smaller sized aggregate, super plasticizer and silica fume can improve the mechanical strengths of PC. They concluded that the material can achieve maximum compressive and flexural strengths of up to 50 MPa and 6 MPa respectively. To ensure a good wear penetration is achieved, the pressing force was controlled to keep the unit weight between 1900-2100 kg/m^3. Darshan S.Shah et al. (2014) [5] studied the effect of cementitious materials to coarse aggregate ratio, coarse aggregate sizes, and type of cement on the properties of PC. They used a mix ratio of 1:6, 1:8 and 1:10 (cement: aggregate), and gravels of sizes 18.75 mm and 9.375 mm. They found that PC prepared with smaller aggregate size and lower mix ratio (1:6) showed higher mechanical strengths. Maguesvari and Narshima, (2013) [6] studied the characterization of PC for pavement applications. The study gives a preliminary idea about the effect of fine and coarse aggregate on the properties of pervious Concrete. They used aggregates of sizes ranging between 4.75 -9mm, 9-12.5 mm, 12.5-16 mm, 16-19.5 mm. They also used a constant water to cementitious materials ratio of 0.34, cement content of 400 kg/m^3 and aggregate to cementitious materials ratio of 4.75:1. Their findings also reported that smaller sized aggregates give higher strengths compared to larger sized aggregates. They also found that increasing the angularity number of the aggregates leads to increased strength and coefficient of permeability. Mohammed et.al, (2018) [7], studied the effect addition of nano silica by weight of cementitious materials on the properties of PC containing fly ash as supplementary cementitious material, they found nano silica improves the compressive strength of pervious concrete, they also reported that nano silica addition improved the early strength development of PC containing fly ash, through ignition of Pozzolanic reaction of fly ash at earlier age. Yeih et al. (2015) [8] also worked on the effect of aggregate sizes and amount of binder materials on the properties of PC. Their findings showed that increasing the aggregate sizes leads to higher water permeability and interconnected pores. They further reported that increase in binder content resulted to reduction in permeability and interconnected pores. In addition, increase in binder content consequently improved strengths while increase in aggregate sizes decreases the strengths of PC.

Rice husk is the outermost shell which shelters the rice, and is normally obtained through milling of the unprocessed rice from its shell. Rice husk contains about 20% to 30% of the unprocessed rice weight. Rice husk ash (RHA) is obtained by burning dried rice husk through combustion at a temperature of about 750^{o}c to form the ash and remove volatile organic carbon such as lignin and cellulose. Several studies have proved that RHA can be used as a supplementary cementitious material (SCM) due to its high silica (SiO2) content and can therefore be used as a partial replacement to cement in concrete. For RHA to be used as a SCM, it has to be sieved through a 75µm sieve so as to execute the pozzolanic reactivity. Furthermore, RHA have a very high surface area ranging between 50000 to 100000 m^2 per kg [9]. The average size of RHA ranges between from 5 to 10 micron, and its major chemical compound is amorphous silica which ranges between 85% to 90%. In addition, RHA structure is highly micro-porous, this makes it very appropriate for cement replacement through its pozzolanic reactivity. When RHA is used in concrete to partially replace cement, the silica will react with the calcium hydroxide which is a product of cement hydration to form additional calcium silicate hydrate (C-S-H). The C-S-H which is the main element for strength development in the concrete will fill up the pores in concrete thereby densifying the microstructure and improving the interlocking bonding between cement paste and aggregate, thus increasing strengths [10].

The burning of the rice husk has significant effect on the type and properties of the silica in the RHA which consequently have effect on the pozzolanic reactivity of the RHA. Furthermore, the Pozzolanic reactivity of RHA is significantly influenced by its fineness. Generally, RHA seems to be finer than Portland cement but less reactive, but it could dissolve in the mixture and produce an abundant quantity of nucleation sites for the precipitation of CH. This reaction which is Pozzolanic reaction creates a more homogenous and denser [11].

The use of RHA as partial replacement to cement in concrete lowers the water to cementitious materials ratio, reduces permeable voids content and densify the concrete matrix and increase the cement hydration [12]. RHA is have significant effect in the mechanical properties of concrete through its physical and chemical properties. Kartini (2011) [13] studied the effect of RHA as partial replacement to cement in in concrete. They found that when RHA replaced up to 20% cement, there was no significant effect on the strength, at higher replacement levels the compressive strength, flexural strength and tensile strength decreases significantly. Kulkarni et al. (2014)[14] also studied the effect of RHA as SCM in concrete, they found that the strength of the concrete increases by about 16% and 10% for 10% and 20% replacement of cement with RHA respectively. However, when 30% of cement was replaced with RHA, the compressive strength decreases, though it was similar to the strength of the control concrete. Padhi et al (2018)[15], reported that RHA when used as cement replacement decreases the workability of concrete containing natural aggregate and recycled aggregate. They further reported decrease in strengths (compressive, flexural and split tensile) of concrete containing both natural aggregate and recycled aggregates, but the reduction was more pronounced on recycled aggregate concrete.

Calcium Carbide Waste (CCW) which is a by-product of the flammable acetylene gas production. It is called lime hydrate or carbide lime sludge. Calcium carbide (CaC_2) is a chemical composite containing calcium & carbide, mostly produced industrially and colorless when in pure form. The reaction of calcium carbide with water produces this all-important gas that is used in oxygen – acetylene welding, among other uses (Colin, M., 2006) [16]. CCW from the production of acetylene gas are normally disposed of by land filling which may create further problem, like, the leaching of harmful compound and Alkali to ground water. Large quantity of acetylene is mostly used in countries like China as an industrial fuel, mainly due to its lower cost of production and usage domestically in comparison to other imported petroleum of the same purpose. Extraordinarily, acetylene can be used to may use to fasten the ripening of fruit; in a similar way that ethylene is used [17]. Other applications of calcium carbide include the generation, production of chemicals for fertilizers, in steelmaking, in the generation of acetylene in carbide lamps. Calcium carbide generate waste after its chemical reaction is completed and cannot be further used. In order to manage and reduce the accumulation of this kind of waste, this paper suggests their reuse or recycling as construction materials. One of such ways is to replace a percentage of Ordinary Portland Cement (OPC) in concrete. When calcium carbide waste is added to mortar at an increasing percentage, the workability, setting time (initial and final), flexural and compressive strength increase, and the water absorption was also found to be increasing as the percentage of CCW increased [18]. When used as an admixture in concrete, the setting time, soundness of cement and the water required for standard consistency increase as the percentage of calcium carbide waste addition increase. Also, the compressive strength of each mix decrease as the percentage of CCW increases [9].

When cement is partially replaced with RHA and CW the reaction begins with the hydration of cement, according to O'Flahery (1974) [19] hydration begins with a fast reaction between C_3A of cement and water on the first day, a reaction responsible for initial and final setting and strength on the first day. No lime is liberated or released during this reaction. The next reaction is between the C_3S component of cement and water, this reaction contributes more to the development of early strength, from the second day to the fourteenth day. The reaction leads to lime production and subsequently the formation of microcrystalline hydrate $C_3S_2H_3$. Some of the lime separate into crystalline $Ca(OH)_2$. More lime is liberated during this process in comparison to the lime liberated during C2S hydration process. The subsequent hydration process is that of C2S which occurs slowly and it is responsible for strength development at longer period say more than 7 days.

The main setback for using pervious concrete is its poor strength due to large pores in its matrix. This has limited the use of pervious concrete to non-structural application or areas subjected to low traffic volume. For pervious concrete to be used for pavement subjected to medium or high traffic, a method for improving the strength must be devised but without reducing its ability of draining run off water from the surface of the pavement. Therefore, one of the methods of improving the strength of pervious concrete is by using supplementary cementitious materials or pozzolanic materials as additives to cement.

The aim of this studies was to utilize hybrid of rice husk ash (RHA) and calcium carbide waste (CCW) as waste materials to cement replacement, in order to improve the mechanical properties of pervious concrete. Response surface methodology (RSM) was utilized to design the experiment, models development for predicting the strengths of the pervious concrete and carryout optimization. One type of pervious concrete was used using a ratio 1:6 (cement to stone). The percentages of the CCW and RHA are 0%, 5%, 10%, 15% and 20% as replacement by weight of cementitious materials.

2. Materials and methodology

2.1. Materials

Type I Ordinary Portland cement of 42.5R grade conforming to ASTM C150 specifications and with properties as shown in Table 1 was used in this study. The aggregate used was crushed granite which was free from impurities and having a specific gravity of 2.64 and maximum aggregate size of 12 mm. The rice husk was obtained from rice milling factory as a waste material. The rice husk obtained was thoroughly cleaned dry and burnt in an uncontrolled open burning system to produce the ash which was then pulverized and the particles retained on a 75µm BS sieve was used as a partial replacement by weight of cement. The properties of the rice husk ash are shown in Table 1. The calcium carbide waste used for the research work was obtained from road side panel beaters. The calcium carbide waste was air dried and grinded by pounding and then sieved with 75µm BS sieve. Only those that passed through this 75µm sieve were used for the research work.

Table 1
Properties of Cementitious Materials.

Oxide	Compositions (%)		
	Cement	CCW	RHA
SiO_2	20.76	2.1	87.30
Al_2O_3	5.54	0.5	0.15
Fe_2O_3	3.35	0.54	0.16
CaO	61.4	95.69	1.40
MgO	2.46	-	0.57
K_2O	0.76	0.47	3.68
Na_2O	0.19	-	1.12
SO_3	-	0.31	0.24
TiO_2	-	-	-
BaO	-	0.09	-
Loss of Ignition	2.24	-	2.76
Specific Gravity	3.15	2.35	2.04

2.2. Mix proportioning

Proportioning of pervious concrete mixes was carried out according to ACI 211.3R, (2002) [20]. A water to cementitious materials ratio of 0.40 and cementitious materials to aggregate ratio of 1:5 was adopted based on the cement content selected and constituent materials calculated for the control pervious concrete. The Mixes were developed using Response Surface Methodology.

2.2.1. Mix design using response surface methodology

Response surface methodology (RSM) is mostly used to analyze and develop statistical models relating one or more independent variables and their responses. RSM can recognizes both quadratic and linear interactions of the independent variables to concrete properties.

The RSM contains several model types which can be used for analysis and to derive the statistical or mathematical relationships between independent variables and their corresponding responses. Some of the most commonly used model types in RSM includes the Box-Behnken, central composites and historical data. The choice of type of the models depends on the number of variables and the levels of variation for each variable [21,22].

In this study, RSM was used to investigate the effect of hybridization of CCW and RHA on the mechanical properties of pervious concrete, and model development for the relationship between the independent variables and their responses. Different model types exist to derive the mathematical relationships between the individual variables and their corresponding responses in the RSM analysis package. The central composite design model is the most reliable and commonly used. This is due to the choice of selection of the distance from the axial run to the design center (α), which depends on the number in the factorial design portion. The model can be formed as a linear model as shown in Eqn 1 as the mathematical relations between the independent variables and the responses are unknown [21].

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \in \quad (1)$$

where y is the response model, β_0 is the y-intercept for which $X_1 = X_2 = 0$, β_1, and β_2 are the coefficients of the first and second independent variables respectively, X_1 is the first variable coefficient and X_2 the second variables and ϵ is the error.

However, linear model cannot be suitable for the response if the data contains curvature, therefore a polynomial model of higher degrees would be used as given by the second order function as presented in Eqn 2 [23].

$$y = \beta_0 + \sum_{i=1}^{k} k\,\beta_1 X_1 + \sum_{i=1}^{k} \beta_2 X_2^2 + \sum_{i<} \sum_{j} \beta_n X_n + \in \quad (2)$$

where y is the response model, X_i and X_j are the coded values independent variable, i is the linear coefficient, j is the quadratic coefficient, β is the regression constant, β_0 is the y-intercept for which $X_i = X_j = 0$, k is the number of variables used for the model, and ϵ is error.

In this study, a commercially available software package (Design Expert v7.0.0) was used for the RSM analysis. The face centered central composite design (FCCCD) with α ranging from -1.41

to 1.41, was used to develop the mathematical models for 3, 7- and 28-days' compressive strength, split tensile strength and flexural strength using CCW and RHA as independent variables. Each of the variables was varied in five levels, i.e. CCW (0%, 5%, 10%, 15% and 20% replacement by volume of cement), RHA (0%, 5%, 10%, 15% and 20% replacement by volume of cement). Thirteen mixtures were developed by the RSM software, by combining the different variables as presented in Table 2.

Table 2
Mix Proportioning.

	CODED VALUES		ACTUAL VALUES		QUANTITIES BY WEIGHT (Kg/m3)					
RUN	RHA (%)	CCW (%)	RHA (%)	CCW (%)	CEMENT	RHA	CCW	WATER	AGGREGATE	W/C
1			0	0	241.00	0.00	0.00	96.4	1328	0.4
2	0	-1.41	10	0	224.74	16.26	0.00	96.4	1328	0.4
3	0	0	10	10	206.88	16.26	17.86	96.4	1328	0.4
4	1	-1	15	5	207.67	24.40	8.93	96.4	1328	0.4
5	0	0	10	10	206.88	16.26	17.86	96.4	1328	0.4
6	0	1.41	10	20	189.02	16.26	35.72	96.4	1328	0.4
7	-1	1	5	15	206.08	8.13	26.79	96.4	1328	0.4
8	1	1	15	15	189.81	24.40	26.79	96.4	1328	0.4
9	0	0	10	10	206.88	16.26	17.86	96.4	1328	0.4
10	0	0	10	10	206.88	16.26	17.86	96.4	1328	0.4
11	1.41	0	20	10	190.61	32.53	17.86	96.4	1328	0.4
12	-1	-1	5	5	223.94	8.13	8.93	96.4	1328	0.4
13	0	0	10	10	206.88	16.26	17.86	96.4	1328	0.4
14	-1.41	0	0	10	223.14	0.00	17.86	96.4	1328	0.4

2.2.. Samples preparation and testing methods

In this study, manual mixing (Hand mixing) was adopted, by using shovel and tray to mix the materials which have been adequately measured according to the design mix. The cement, RHA and CCW were initially dry mixed for a few minutes, the coarse aggregate was added and thoroughly mixed until they were properly mixed together and after which the required quantity of water was added gradually while the mixing was still in progress. The mixing was continued until a homogenous mix was achieved.

Slump test was used to measure the workability of the fresh pervious concrete in accordance with ASTM C143. The compressive strength of the pervious concrete was measured in accordance with BS EN 12390-4:2000. For each mix, nine cubes of 100 mm x 100 mm x 100 mm were prepared and air dried for 24 hours before removing from the molds and curing in water. The compressive strength was tested after 3, 7, and 28 days of curing, three samples were tested for each period of curing and the average value recorded.

Another important and basic property of pervious concrete which needs to be tested is the tensile strength. Due to the low tensile strength and brittleness nature of the PC, it is not usually expected to resist the direct tension. Nevertheless, it is necessary to determine the tensile strength of the PC as it is essential to know the load at which the concrete members may crack, as it is a form of tension failure. In this study, the splitting tensile strength was determined in accordance to BS EN 12390-6:2000. For each mix nine cylinders of 100 mm diameter by 200 mm height were prepared and tested after 3, 7, and 28 days of curing. Three samples were tested for each curing period and the average value recorded.

The flexural strength is the ability of a beam or slab to resist failure in bending and it is expressed as modulus of rapture. In this study, the flexural strength of pervious concrete was determined in accordance with BS EN 12390-5: 2000, using 100 mm x 100 mm x 500 mm prisms. For each mix, nine prisms were prepared and cured fin water for 3, 7, and 28 days prior to testing.

3. Results and discussions

3.1. Workability

The effect of the hybridization of RHA and CCW on the fresh property of pervious concrete using slump test. Due to the lack of standard mixture proportioning method for PC which account for workability of the concrete, is a major challenge. It was impossible to measure the workability of the concrete using slump cone method because the concrete kept collapsing completely while trying to check for the workability of the pervious concrete. This might be as a result of several factors such as, elimination or reduction of fines, gradation of aggregate, limit on paste content and also inadequate water to cement ratio.

The visual inspection approached which was recommended by NRMCA which is used in assessing the workability of pervious concrete was later used in assessing the workability of the concrete. The approach is known as the hand squeezing or balling method. A sample of PC was grasped in the hand, squeezed and released; if the aggregate particles adhered to the vertical surface of the hand then the paste is considered good enough. However, the mixture can be considered too dry if all the aggregate falls off from the hand and the hand is dried. In addition, the mixture can be considered very wet if aggregates falls off the hand and there is moist paste slurry remaining on the hand, as shown in Fig 1 and Fig 2 [24].

Fig. 1. Visual Inspection Approach for workability [1].

Fig. 2. Hand Squeeze pervious concrete workability evaluation [24].

This method was later adopted to check if the sample was not too wet or dry, meaning it was used to check for the appropriate water to cement ratio to be used.

It was observed that as the quantity of replacement for cement with RHA and CCW increases, the workability of the concrete decrease. This was found through visual observation by comparing the PC mixes with the mixes in Fig 1. The decrease in workability can be attributed to larger surface area of both the RHA and CCW in comparison to cement. Another reason might be attributed to the higher loss of ignition in RHA, which makes it absorbs more water.

3.2. Compressive strength

The results of the effect of the hybridization of RHA and CCW on the compressive strength of pervious concrete is presented in Table 3. From the results obtained it indicate that at 28 days of curing the compressive strength for pervious concrete decreases for mixes containing more than 10%RHA as replacement for cement, also for mixes containing more than 15% RHA and 15% CCW, the compressive strength also decreases. For instance the compressive strength decreases from 7.3MPa which is the control mix to 5.3 MPa, 6.6 MPa, 5.8 MPa and 6.3 MPa for mix (2, 4, 6 and11) respectively .The decrease in the strength gain at early age as compared to the control is due to the slower pozzolanic reactivity of the silicon dioxide (SiO_2) and calcium hydroxide (CH) of RHA in concrete. The delayed reaction might be due to the SiO2 content in the RHA which can only be broken down by the alkalinity of the pore water which required some time to attain the high pH after hydration process [12]. Such decrease can be attributed to the less reactive nature of lime contributed by CCW, when compared with lime liberated during the hydration of cement.

Another factor worthy of mention is imbalances in lime supplied by both CCW and hydration of cement available for reaction with Silica from RHA at other combinations outside the combination.

For the remaining mixes which has CCW as the highest or the same percentage of replacement as that of RHA, the compressive strength significantly increases as compared to the compressive strength of the control mix. For instance, the strength increases from 7.3MPa to 8.3 MPa, 8.7 MPa, 7.5 MPa, 8.6 MPa, 7.8 MPa, 8.1 MPa, 7.9 MPa, 7.9 MPa, and 9.5 MPa for mix (3, 5, 7, 8, 9, 10, 12, 13 and 14) respectively. The increase in the compressive strength may be attributed to the secondary hydration reaction of cement and CCW content. From the result it indicates that mix 14 has the highest compressive strength of 9.5MPa as compared to the control mix with 7.3MPa. This shows that the strength was improved by almost 30%.

Table 3
Compressive Strength Result.

Mix No	% of Replacement	Compressive Strength (MPa)					
		3 Days	S.D	7 Days	S.D	28 Days	S.D
1	0%RHA, 0%CCW	5.6	0.29	6.4	0.38	7.3	0.34
2	10%RHA, 0%CCW	4.7	0.25	5	0.42	5.3	0.31
3	10%RHA, 10%CCW	5.1	0.29	6.4	0.26	8.3	0.31
4	15%RHA, 5%CCW	4.7	0.22	6	0.25	6.6	0.16
5	10%RHA, 10%CCW	6.5	0.36	6.8	0.17	8.7	0.42
6	10%RHA, 20%CCW	4.8	0.27	4.9	0.40	5.8	0.29
7	5%RHA, 15%CCW	6.8	0.12	7.2	0.33	7.5	0.36
8	15%RHA, 15%CCW	5.2	0.22	6.2	0.14	8.6	0.32
9	10%RHA, 10%CCW	5.9	0.29	6.3	0.42	7.8	0.23
10	10%RHA, 10%CCW	5.9	0.39	6.6	0.26	8.1	0.06
11	20%RHA, 10%CCW	4.4	0.10	5.9	0.28	6.3	0.19
12	5%RHA, 5%CCW	5.7	0.09	6.8	0.08	7.9	0.38
13	10%RHA, 10%CCW	5.9	0.29	6.5	0.37	7.9	0.25
14	0%RHA, 10%CCW	6.8	0.33	7.6	0.29	9.5	0.09

3.3. Splitting Tensile Strength

The result of Split tensile strength of pervious concrete containing hybrid of RHA and CCW is presented in Table 4. From the split tensile strength results obtained shows that at 28 days of curing the split tensile strength of pervious concrete decreases for mixes containing more than 10%RHA as replacement for cement, also for mixes containing more than 15% RHA and 15% CCW, the split tensile strength also decreases. For instance, the strength decreases from 1.6MPa which is the control mix to 1.3 MPa, 1.4MPa and 1.5MPa for mix (2, 4, 6 and11) respectively, the strength decreased by 19%, 13%, 6% when compared with the strength of the control mix. This can be attributed to the slower pozzolanic reaction of RHA and CCW thereby decreasing the amount of C-S-H gel formation, which consequently resulted to weaker bonding between the aggregate and cementitious materials paste, thereby causing premature cracking and consequently lower split tensile strength.

For the remaining mixes which has CCW as the highest or the same percentage of replacement with RHA, the split tensile strength significantly increases as compared to that of the control mix. For instance, the strength increases from 1.6MPa to 1.7 MPa, 1.8 MPa, 1.9 MPa, 2.1 MPa and 2.6 MPa for mix (3, 5, 7, 8, 9, 10, 12, 13 and 14) respectively. From the result it indicates that mix 14 has the highest split tensile strength of 2.6MPa as compared to the control mix with 1.6MPa. This shows that the strength was improved by almost 63%. This can be attributed to the high amount of CaO in CCW, which reacts with the SiO_2 in RHA, thereby producing more C-S-

H gel, which resulted to improved compressive strength and stronger bonding between the aggregate and cement paste, hence increasing split tensile strength.

Table 4
Splitting Tensile Result.

Mix No	% of Replacement	Split Tensile Strength (MPa)					
		3 Days	S.D	7 Days	S.D	28 Days	S.D
1	0%RHA, 0%CCW	1.3	0.17	1.4	0.23	1.6	0.11
2	10%RHA, 0%CCW	0.8	0.19	0.9	0.12	1.3	0.17
3	10%RHA, 10%CCW	1	0.16	1.2	0.15	1.7	0.22
4	15%RHA, 5%CCW	0.9	0.19	1	0.15	1.5	0.18
5	10%RHA, 10%CCW	1.3	0.17	1.5	0.19	1.9	0.17
6	10%RHA, 20%CCW	1	0.11	1.1	0.14	1.3	0.17
7	5%RHA, 15%CCW	1.3	0.20	1.4	0.23	1.7	0.12
8	15%RHA, 15%CCW	0.9	0.15	1.5	0.10	2.1	0.18
9	10%RHA, 10%CCW	1.3	0.17	1.5	0.08	1.8	0.10
10	10%RHA, 10%CCW	1.3	0.22	1.4	0.16	1.8	0.16
11	20%RHA, 10%CCW	0.8	0.20	0.9	0.18	1.4	0.07
12	5%RHA, 5%CCW	0.9	0.09	1.1	0.21	1.9	0.09
13	10%RHA, 10%CCW	1.1	0.10	1.3	0.16	1.9	0.14
14	0%RHA, 10%CCW	1.4	0.14	1.7	0.09	2.6	0.19

3.4. Flexural strength

The results of flexural strength test are presented in Table 5. From the results obtained for flexural strength it shows that at 28 days of curing the flexural strength for pervious concrete decreases for mixes containing more than 10%RHA as replacement for cement, also for mixes containing more than 15% RHA and 15% CCW, the flexural strength also decreases. For instance, the strength decreases from 4.1MPa which is the control mix to 3.9MPa, 3.7MPaand 3.6MPa for mix (2, 4, 6 and11) respectively, the strength decreased by 5%, 10% and 12% as compared with the flexural strength of the control mix.

For mix (3, 5, 7, 8, 9, 10, 12, 13 and 14) the flexural strength was found to increase significantly when compared with that of the control mix. The strength increases from 4.1MPa to 4.9 MPa, 4.7 MPa, 4.5 MPa, 4.6 MPa, 4.4 MPa and 5.2 MPa for mix (3, 5, 7, 8, 9, 10, 12, 13 and 14) respectively. This improvement in the flexural strength were observed in mixes which have CCW as the highest percentage of cement or the same percentage of replacement with RHA. From the result it indicates that mix 14 has the flexural strength improved by about 27%. This can be attributed to the higher amount of CaO in CCW which reacts with the SiO^2 from RHA and produces more C-S-H gel, which improves bonding between aggregate and cement paste and hence increases bending resistance of pervious concrete.

Table 5
Flexural Strength Result.

Mix No	% of Replacement	Flexural Strength (MPa)					
		3 Days	S.D	7 Days	S.D	28 Days	S.D
1	0%RHA, 0%CCW	2.5	0.29	3.8	0.16	4.1	0.32
2	10%RHA, 0%CCW	3.3	0.33	3.7	0.22	3.9	0.26
3	10%RHA, 10%CCW	2.8	0.24	3.8	0.28	4.9	0.19
4	15%RHA, 5%CCW	3	0.37	3.4	0.21	3.9	0.10
5	10%RHA, 10%CCW	2.5	0.18	3.4	0.19	4.9	0.26
6	10%RHA, 20%CCW	2.8	0.24	3.5	0.17	3.7	0.17
7	5%RHA, 15%CCW	3	0.16	3.7	0.27	4.7	0.19
8	15%RHA, 15%CCW	2.9	0.17	4	0.30	4.5	0.17
9	10%RHA, 10%CCW	2.5	0.30	4	0.21	4.6	0.28
10	10%RHA, 10%CCW	2.7	0.35	3.9	0.12	4.4	0.11
11	20%RHA, 10%CCW	3.1	0.21	3.3	0.27	3.6	0.14
12	5%RHA, 5%CCW	3.9	0.16	4.7	0.15	5.2	0.28
13	10%RHA, 10%CCW	2.6	0.25	3.5	0.22	4.6	0.09
14	0%RHA, 10%CCW	4.3	0.17	4.7	0.16	5.9	0.17

3.5. Model development using response surface methodology

The Response surface methodology (RSM) was used to evaluate the effect of hybridization of both RHA and CCW on the harden properties of pervious concrete, and to develop relationship between the variables and measured responses. The variables and responses which were obtained after experimental testing in the laboratory used for the RSM analysis are presented in Table 6.

Table 6
Developed Experimental Design and Responses.

RUNS	FACTORS				RESPONSES		
	CODED VALUES		ACTUAL VALUES		28 Days Compressive Strength (MPa)	28 Days Splitting Tensile Strength (MPa)	28 Days Flexural Strength (MPa)
	A: RHA (%)	B: CCW (%)	A: RHA (%)	B: CCW (%)			
1	0.00	-1.41	10	0	5.3	1.3	3.9
2	0.00	0.00	10	10	8.3	1.7	4.9
3	1.00	-1.00	15	5	6.6	1.5	3.9
4	0.00	0.00	10	10	8.7	1.9	4.9
5	0.00	1.41	10	20	5.8	1.3	3.7
6	-1.00	1.00	5	15	7.5	1.7	4.7
7	1.00	1.00	15	15	8.6	2.1	4.5
8	0.00	0.00	10	10	7.8	1.8	4.6
9	0.00	0.00	10	10	8.1	1.8	4.4
10	1.41	0.00	20	10	6.3	1.4	3.6
11	-1.00	-1.00	5	5	7.9	1.9	5.2
12	0.00	0.00	10	10	7.9	1.9	4.6
13	-1.41	0.00	0	10	9.5	2.6	5.9

3.5.1. Analysis of Variance

Table 7 presents the statistical relationship between modelled responses and their independent variables which was obtained via ANOVA. The F-values of the models are 8.15, 5.12 and 16.54 for compressive, splitting tensile strengths and flexural respectively. Meaning the models were all significant having only 0.79%, 0.29%, and 0.07% respectively, that a model F-value of the respective extent could occur due to noise. The 95% confidence interval ($P < 0.05$) was used to check the significance of all models and all their terms. The compressive strength model and the terms A and B^2 were the only significant model terms as their Prob > F values were less than 0.05, while model terms B, AB and A^2 were all insignificant due to the fact that their P values are more than 0.05, meaning that the variables interaction effects are insignificant in the model. The model for split tensile strength and its terms B^2 only was significant as the P-values were <0.05 whereas model terms A, B, AB and A^2 were all insignificant as their P values were greater than 0.05. Considering flexural strength, the model and its terms A and B^2 were the only significant model terms as their Probability > F values were less than 0.05, whereas model terms B, AB and A^2 were all insignificant as their P values were greater than 0.05.

All the insignificant model and terms were removed using the backward elimination regression. The positive and negative symbols before a model term shows synergistic and antagonistic effects of the independent variables.

The models with all insignificant terms removed are expressed in Eqns 3 to 5 for compressive, splitting tensile strength and flexural strength models, respectively for 28days curing.

$$F_C = 8.23 - 0.59 \times A - 1.09 \times B^2 \quad (3)$$

$$F_S = 1.9 - 0.21 \times A - 0.24 \times B^2 \quad (4)$$

$$F_f = 4.76 - 0.59 \times A - 0.38 \times B^2 \quad (5)$$

Where F_c, F_s, and F_f are the compressive, splitting tensile and flexural strengths, respectively, in MPa, A is % of Rice Hush Ash (RHA) and B is % of Calcium Carbide Waste (CCW).

Table 7
ANOVA for Developed Response Models.

Variable	Factors	Sum of Squares	df	Mean Square	F-Values	p-value
Compressive Strength (MPa)	Model	11.15	2	5.58	8.15	0.0079
	A-RH	2.79	1	2.79	4.08	0.0709
	B^2	8.36	1	8.36	12.23	0.0058
	Lack of Fit	6.33	6	1.05	8.24	0.0304
Splitting Tensile Strength (MPa)	Model	0.76	2	0.38	5.12	0.0294
	A-RH	0.36	1	0.36	4.83	0.0527
	B^2	0.40	1	0.40	5.42	0.0421
	Lack of Fit	0.72	6	0.12	17.10	0.0080
Flexural Strength (MPa)	Model	3.84	2	1.92	16.54	0.0007
	A-RH	2.82	1	2.82	24.32	0.0006
	B^2	1.02	1	1.02	8.77	0.0143
	Lack of Fit	0.97	6	0.16	3.45	0.1254

Where A: rice husk ash, B: calcium carbide waste, A^2 and B^2: second order effect, A * B: interaction effects, D.F: degree of freedom, F-values: Fisher-statistical test values, P- values: Probability values.

For model validation, checking adequacy and fitness, degree of predictability of the models, the degree of correlation was used as shown in Table 8. All the models have average significant R^2 values. Therefore, only approximately 38.01%, 49.38% and 23.21% of the experimental data of compressive, splitting tensile and flexural strength models, respectively, cannot be explained or correlated using the models. Thus, all of the models were acceptable statistically. Furthermore, the adjusted R^2 and the predicted R^2 were in good agreement for the flexural strength, as the difference between the two is lower than 0.2. Though, for the split tensile and compressive strength, the variation between the adjusted and predicted R^2 is higher than 0.2 which might indicate a possible problem with the model and/or data or large block effect. In addition, the adjusted R^2 which is an amended version of R^2 which was adjusted for the number of predictors in the models, while the predicted R^2 is the measure of the variation of the data for the predicted model. For a good model the adjusted R^2 should be reasonably in agreement with the predicted R^2, and this happens when the difference between the two is less than 0.2 [25].

The standard deviation (SD) was used to check the variation of the experimental data with reference to the models. The SD values were lower in comparison to the mean, a higher degree of correlation existed between the models and experimental data. Moreover, the adequate precision (AP) values were greater than 4 for all the models. This shows that the AP were desirable with the adequate signal, hence the design space can be navigated using the developed models.

Table 8
Models Validation.

Responses	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
Mean	7.56	1.76	4.52
SD	0.83	0.27	0.34
CoV (%)	10.94	15.51	7.53
R^2	0.6199	0.5062	0.7679
Predicted R^2	0.2827	0.0580	0.5801
Adjusted R^2	0.5439	0.4074	0.7215
Adequate Precision	7.575	5.931	11.079

The relationships between the responses and the two independent variables were plotted using a 3-dimensional (3D) response surface. Figs. 3, 4, and 5 shows the 3D response surface plots for compressive, splitting tensile, and flexural strengths for PC respectively with supplementary cementitious materials. From the 3D plots it can be seen that CCW increases the compressive strength, split tensile strength and flexural strength of pervious concrete while RHA decreases the strengths of pervious concrete. In addition, it can be seen that the best result for compressive strength is shown by the reddish portion of the 3D in Fig 3.

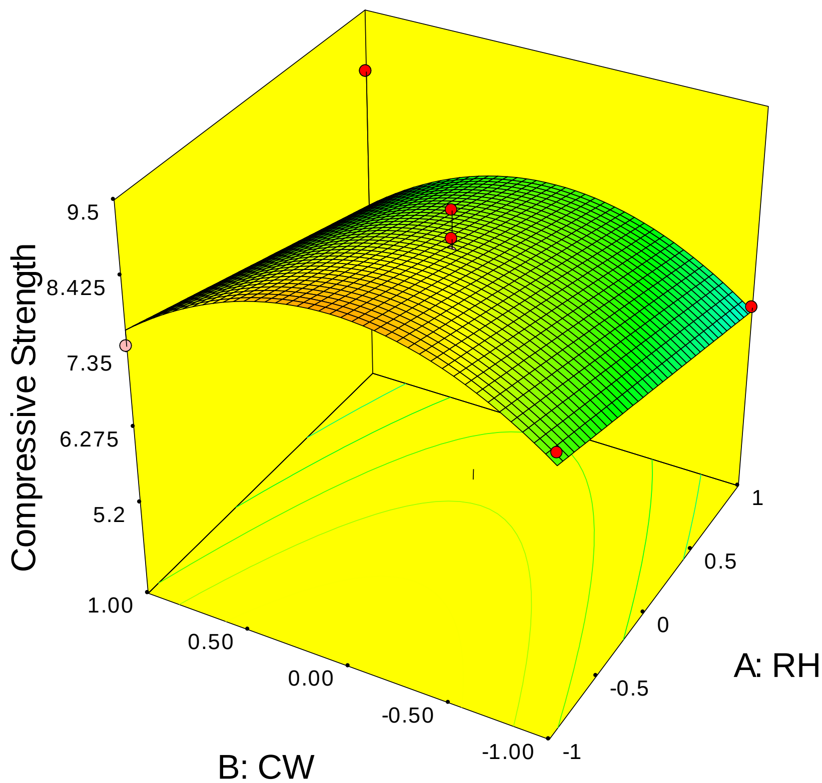

Fig. 3. 3D plot for compressive strength of pervious concrete.

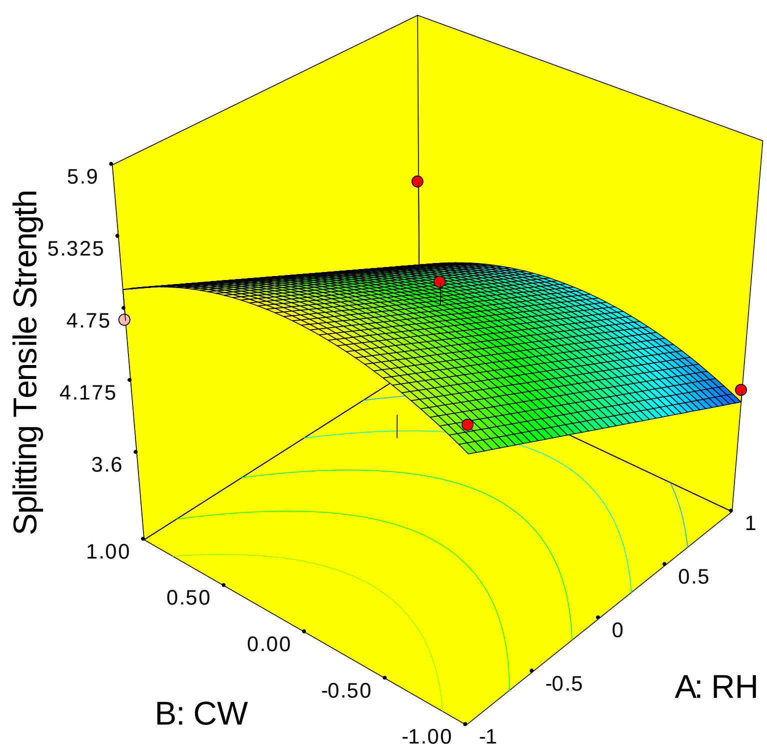

Fig. 4. 3D plot for splitting tensile strength of pervious concrete.

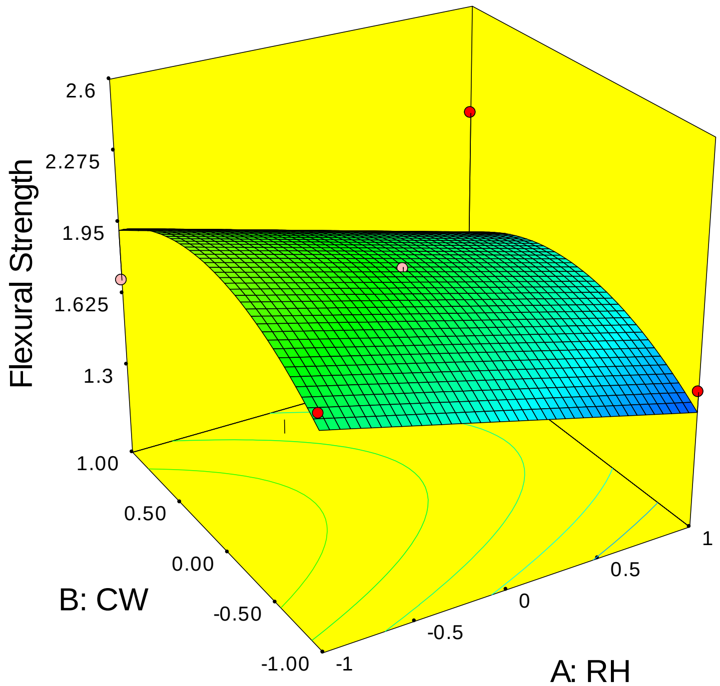

Fig. 5. 3D plot for flexural strength of pervious concrete.

4. Conclusions

The following conclusions were drawn based on the experimental works, statistical and results analysis:

- The workability of the PC decreases with increase in percentage of RHA and CCW as replacement for cement.
- The use of RHA as SCM to cement decreases the compressive strength, splitting tensile strength and flexural strength of PC. The decrease is more effected at early age.
- The use of CCW as SCM to cement in PC containing RHA increases the compressive strength, splitting tensile strength and flexural strength of PC. Therefore, CCW is said to lessen the negative effect of RHA in PC.
- The strength for pervious concrete decreases for mixes containing more than 10%RHA as replacement for cement, also for mixes containing more than 15% RHA and 15% CCW, the strength also decreases. Therefore, for the optimize mix the compressive, splitting tensile and flexural strengths were 9.5MPa, 2.6MPa and 5.9MPa respectively.

Credit authorship contribution statement

Musa Adamu wrote the manuscript and carried out analysis, Sani Sikiru Olalekan designed and carried out the experiment, Mohammed Magana Aliyu read, revised the manuscript and supervised the work.

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