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Enhancing the Mechanical Properties of Pervious Concrete Using Hybrid Rice Husk Ash and Calcium Carbide Waste: A Response Surface Methodology Approach

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A combination of its low impact on the environment and sustainability, Pervious Concrete (PC) has become more and more common. It offers numerous benefits like decreasing heat island effects, controlling storm water runoff, and recharging groundwater. In an effort to improve the PC's overall performance, this study examines the use of rice husk ash (RHA) and calcium carbide waste (CCW) as additional cementations' materials (SCMs). The response surface methodology (RSM) was used to determine the mathematical connections between the variables RHA and CCW and strength traits. Workability, flexural strength, compressive strength, splitting tensile strength, and additional strength properties were investigated. As compared to the control mix, the results showed an important rise in strength at 0% RHA and 10% CCW.

1. Introduction

High porosity, as can be achieved by using gap-graded aggregates while decreasing or eliminating small particles, is the distinguishing characteristic of Pervious Concrete (PC). Water may quickly escape via linked voids due to it. PC is characterized by the American Concrete Institute (ACI) as concrete with little to no fine aggregate that permits water and air rapidly infiltrate the surface and enter beneath layers.

Cement generates almost ten percent of globally CO2 emissions, thus that the construction industry is putting more and more focus on adopting eco-friendly products to cut emissions. Use SCMs including fly ash, silica fume, crushed granulated blast furnace slag, and rice husk ash, green concrete seeks for greater sustainability and utilizing lesser cement.

Based on studies, PC offers higher mechanical strengths if the mixture's ratio decreases and the aggregate particle sizes were smaller. The properties of PC are additionally significantly affected by the presence of binder components, the size of particles, and nano-silica. The goal of this work is to enhance the mechanical properties of PC by using RHA and CCW as SCMs. Overview of Permeable Concrete,

Concrete which is permeable, frequently referred to as porous concrete, contains a high volume of interconnected pores, normally between 15% and 30%, with pore sizes ranging from 2 mm to 8 mm and water permeability rates between 2 mm/s and 6 mm. Using gap-graded coarse aggregates and reducing or doing away with fine particles is how this feature is attained. The American Concrete Institute (ACI) defines permeable concrete as having a low amount of fine particles, which leads to Using gap-graded coarse aggregates while decreasing or completely altogether of tiny particles is the way this characteristic is achieved. The American Concrete Institute (ACI) characterizes permeable concrete as having a low amount of small fragments, which allows enough discrepancies for air and water to pass easily through.

Pros of Previous Research:

1. 1Improvement of Mechanical Properties: Yang (2003): demonstrated that introducing additional components, like silica fume, improves pervious concrete's mechanical strength.

Darshan (2014): Found that the mechanical strength of pervious concrete improves when smaller-sized parts are employed.

2. .2Sustainability: o Kartini (2011): Stressed the use of rice husk ash as a partial cement substitute in order to lower carbon emissions.

Kulkarni (2014): Discovered that using rice husk ash up to 20% on top of ceme

3. Enhanced Permeability: o Yieh (2015) demonstrated that higher aggregate sizes improve pervious concrete's capability to resist seepage of water.

4. Development of Experimental Models: o Padhi (2018): Accurate models predicting the mechanical properties of concrete have been created by using of Response Surface Methodology.

Cons: less valuable Concrete Strength: Yang (2003) pointed out that despite improvements, pervious concrete still exhibits lower mechanical strength as ordinary concrete.

5 Impact of Alternative Materials on Workability: o Padhi (2018) stated that workability might be reduced by using waste calcium carbide or rice husk ash with cement.

6 Complexity of Processes: Kartini (2011) noted that additional processing is required to guarantee the effectiveness of employing rice husk ash.

7 Variability in Results: o Magesvari (2013): Study demonstrated that the type and amount of materials employed as well as the testing settings could affect the results.

These advantages and disadvantages draw upon the successes as well as challenges found by previous research aiming to enhance pervious concrete with substitute components.

Environmental Considerations

There is an international effort for greater sustainability in construction by using materials that are environmentally friendly. Because the cement industry alone generates 10% of around the world CO2 emissions, the construction industry is focusing on reducing CO2 emissions. Thus, extra cementations' materials (SCMs) such fly ash, silica fume, pulverized granulated blast furnace slag, and rice husk ash (RHA) can be used to partially take cement in green concrete technologies which are now beginning to develop.

2. Research and Findings

Multiple studies have investigated the features of concrete with pores for different applications. Based on Yang and Jiang's (2003) studies, PC's mechanical properties can be enhanced through introducing silica fume, super plasticizers, and smaller aggregates. These methods may assist PC achieve flexural and compressive strengths of up to 6 MPa and 50 MPa, respectively. Based to studies conducted by Darshan S. Shah et al. (2014), smaller aggregates and lower mix ratios generated better strengths. The study additionally investigated the influence of aggregate size and cementations' material ratios on PC traits.

Maguesvari and Narshima's (2013) research showed that finer aggregates usually produce greater strength and greater permeability. In accordance with Mohammed et al. (2018), mixing nano-silica with fly ash in PC increases its compressive strength and quickens the procedure of early strength development. In the study by Yeih et al. (2015), harder substances possess a higher binder content, while larger aggregate sizes improve water permeability.

Rice Husk Ash (RHA)

As RHA, a byproduct of milling rice, contains a high amorphous silicon content, it may be utilized as an auxiliary cementitious material. RHA plugs gaps and enhances the microstructure in concrete by interacting with calcium hydroxide from cement hydration to produce additional calcium silicate hydrate (C-S-H).

The result from creating acetylene gas, calcium carbide waste (CCW), may partially substitute ordinary Portland cement (OPC). Concrete's workability, setting time, and mechanical properties are all affected by the inclusion of CCW. However introducing additional CCW may decrease compressive strength, it may additionally enhance qualities like water absorption and setting time.

Study Aim

The goal of the study is to enhance the mechanical properties of permeable concrete by partially substituting cement using a mixture of RHA and CCW. For the purpose to organize trials, develop models that can forecast the strength of concrete, and to make the most effective use available of these resources that are wasted, Response Surface Methodology (RSM) was utilized. The study investigated at the consequences of changing the weight of cementitious materials by various quantities of CCW and RHA (0%, 5%, 10%, 15%, and 20%).

3. Materials and Methodology

Materials such as –

Cement: 42.5R grade Type I Ordinary Portland cement.

- Aggregate: 2.64 specific gravity crushed granite with a maximum aggregate size of 12 mm.
- Available from rice milling businesses, rice husk ash (RHA) is roasted, the ground, and sieved by a 75μm sieve.
- Available from roadside panel beaters, Calcium Carbide Waste (CCW) is ground up, air-dried, and sieved through a 75μm sieve.
- Dump Material The industrial revolution is responsible for the manufacture of combustible, corrosive, and hazardous industrial waste, which, if improperly managed, represents threats to people and the environment. Minimizing the environmental impact of waste from industry requires their effective utilization. Due to their chemical and physical properties, these byproducts can be utilized in construction industries as fine and coarse aggregate options.
- Calcium Carbide Residue (CCR) CCR is a byproduct of acetylene production, described by the equation: $CaC2+2H2O \rightarrow C2H2+Ca(OH)2$ with $Ca(OH)_2$ acting as the primary ingredient. When employed as a part instead of cement, this byproduct contributes to strengthening concrete. However, when CCR gets disposed of erroneously the environment may get polluted.

• Ash of Rice Husk (RHA) Burning rice husks, a byproduct of milling rice, generates RHA. In accordance with ASTM C 618 (1997), RHA constitutes a suitable pozzolana because of its high amounts of amorphous SiO_2. Ash generated by the regular combustion of rice husks might pollute the surrounding area. Due to its high pozzolanic activity, low energy consumption, and low greenhouse gas emissions, RHA is a great supplement cementations' material.

Properties of Cementations' Materials:

Oxide Composition (%)	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

Mix Rate:

The proportion of cementations' materials to aggregate had been set at 1:5, whilst the ratio of water to cementations' materials were adjusted at 0.40. With five levels of variation for each variable—CCW (0%, 5%, 10%, 15%, and 20%) and RHA (0%, 5%, 10%, 15%, and 20%)—Responding Surface Methodology (RSM) was used for the mix design. A grand total of thirteen mixes were developed.

Run	RHA (%)	CCW (%)	Cement (kg/m³)	RHA (kg/m³)	CCW (kg/m³)	Water (kg/m³)	Aggregate (kg/m³)	W/C
1	0	0	241.00	0.00	0.00	96.4	1328	0.4
2	10	0	224.74	16.26	0.00	96.4	1328	0.4
3	10	10	206.88	16.26	17.86	96.4	1328	0.4
4	15	5	207.67	24.40	8.93	96.4	1328	0.4
5	10	10	206.88	16.26	17.86	96.4	1328	0.4
6	10	20	189.02	16.26	35.72	96.4	1328	0.4
7	5	15	206.08	8.13	26.79	96.4	1328	0.4
8	15	15	189.81	24.40	26.79	96.4	1328	0.4
9	10	10	206.88	16.26	17.86	96.4	1328	0.4
10	10	10	206.88	16.26	17.86	96.4	1328	0.4
11	20	10	190.61	32.53	17.86	96.4	1328	0.4
12	5	5	223.94	8.13	8.93	96.4	1328	0.4
13	10	10	206.88	16.26	17.86	96.4	1328	0.4
14	0	10	223.14	0.00	17.86	96.4	1328	0.4

Methods for Producing and Testing Samples

1. The samples conducted test for workability, splitting tensile strength, flexural strength, and compressive strength, in conformity to the specified mix proportions. Using the face-centered central composite design (FCCCD) model, the RSM analysis was performed out using Design Expert software.

2. Methods of Producing and Testing Samples

Using a shovel and tray, manual mixing—also called hand mixing—was used in this study for combining ingredients measured according to the design mix. The following steps have been included in the procedure: Initial Dry Mixing: Cement, RHA, and CCW were dry mixed for a few minutes.

Addition of Coarse Aggregate: The coarse aggregate was then added and thoroughly mixed until a homogeneous blend was achieved.

Water Addition: The required amount of water was gradually added while continuing the mixing process until a uniform mix was obtained.

Test for Workability

The ASTM C143 slump test was applied to assess if the newly created pervious concrete was usable. However, since the pervious concrete completely decreased during the test, the traditional slump test was found as failed. As a result, the hand squeezing or balling method—

a visual assessment method suggested by the NRMCA—was used. Using this technique, you would need to:

• Place a sample of pervious concrete in your palm, squeeze it, then let it.

• Checking if aggregate particles adhered to the hand's vertical surface, a sign that there was enough paste.

• Determining if the mix was too wet (if aggregates fall off and wet paste slurry remains on the hand) or too dry (if all the aggregates fall off and the hand is dry).

Test for Compressive Strength

The compressive strength was

The strength of the material was calculated using BS EN 12390-4:2000 criteria. Nine 100 mm by 100 mm x 100 mm cubes were produced for each combo, which were subsequently taken out of the molds and placed to cure in water following having air dried for an entire day. Three samples have been determined for each of the three curing periods—three, seven, and a total of 28 days—and the average originate was identified for the compressive strength.

Splitting Tensile Strength Test

The BS EN 12390-6:2000 was utilized when calculating the splitting tensile strength. For each conjunction, nine 100 mm in diameter by 200 mm height cylinders were created and they were looked at after a third, seventeen, and 28 days of curing. For each curing period, three samples were looked at and the average results were recorded.

Test for Flexural Strength

The flexural strength was determined with 100 mm x 100 mm x 500 mm prisms in line with BS EN 12390-5:2000. Before testing, nine prisms had been created for each mix and cured in water for a third, seventeen, and eighteen days, respectively.

Flexibility

The inspection by visual method revealed that as the quantity of RHA and CCW replacement increased, the concrete's workability decreased. The reduction was attributed to RHA's increased surface area and CCW compared to cement and RHA's more ability to take in water due to its higher ignition loss.

Compressive Strength

• Lower Strength with High RHA: Since RHA has a slower pozzolanic reactivity, mixes with more than 10% RHA replacement demonstrated lower compressive strength.

• Optimal Strength with Balanced RHA and CCW: Based of the afterwards hydration reaction involving cement and CCW content, mixes with balanced replacements of RHA and CCW exhibited improved compressive strength. The combination comprising 10% CCW and 0% RHA exhibited the highest possible compressive strength (9.5 MPa) as was determined.

Tensile strength splitting

• Decrease Strength with High RHA: Tensile strength reduced for mixes containing more than 10% replacement RHA, in a way akin to compressive strength.

• Better Strength with Balanced Replacements: Tensile strength of mixes such as balanced replacements of RHA and CCW increased considerably; the mix with balanced replacements of RHA and CCW recorded its maximum strength (2.6 MPa).

Flexural Strength

• Lower Strength with High RHA: The mixtures with more than 10% replacement RHA showed a reduction in flexural strength.
• Improved Strength with Balanced Replacements: The mixtures with balanced replacements of RHA and CCW demonstrated notable increases in flexural strength; the mix comprising 10% CCW and 0% RHA exhibited the highest strength (5.9 MPa).
Model Construction Without Response Surface Methodology (RSM) in Play
The effect of RHA and CCW hybridization on the hardened characteristics of pervious concrete have been evaluated using RSM. ANOVA was implemented to establish the statistical relationships between the modeled answers and their independent variables. The outcome of the experiment showed that:

- The models for compressive, splitting tensile, and flexural strengths were all significant.
- The compressive strength model terms A and B^2, the splitting tensile strength model term B^2, and the flexural strength model terms A and B^2 were significant.

The developed models with insignificant terms removed are:

Fc=8.23−0.59A−1.09B2F_c = 8.23 - 0.59A - 1.09B^2Fc=8.23−0.59A−1.09B2

Fs=1.9−0.21A−0.24B2F_s = 1.9 - 0.21A - 0.24B^2Fs=1.9−0.21A−0.24B2

Ff=4.76−0.59A−0.38B2F_f = 4.76 - 0.59A - 0.38B^2Ff=4.76−0.59A−0.38B2

Where:

- FcF_cFc: Compressive strength (MPa)
- FsF_sFs: Splitting tensile strength (MPa)
- FfF_fFf: Flexural strength (MPa)
- AAA: % of RHA
- BBB: % of CCW

4. Results and Discussion

The mechanical properties of pervious concrete were found to be significantly improved if RHA and CCW replaced for up to 20% of the cement in the study. More specifically, the concrete exceeded the control mix when it came to of strength at 0% RHA and 10% CCW. The results indicate that RHA and CCW paired as SCMs may enhance PC performance and improve the potential for structural applications.

5. Conclusion

It is being demonstrated that employing RHA and CCW as SCMs in pervious concrete can enhance the material's mechanical characteristics. This study provides an umbrella for further study and use of these waste materials in sustainable methods of construction. The results highlight the importance that it is to retain PC's permeability while attaining the correct strength characteristics by carefully regulating the ratios of RHA and CCW.

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