Covenant Journal of Engineering Technology (CJET) Vol.5 No.1, June, 2021
ISSN: p. 2682-5317 e. 2682-5325 DOI: xxxxxxxxxx

An Open Access Journal Available Online

Effects of the Partial Replacement of Cement with Cassava Peel Ash and Rice Husk Ash on Concrete

John Oloche Obute*, Oluwatobi Olufemi Akin, Yusuf Dada Amartey, Stephen Pinder Ejeh

Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria
***Corresponding Email: jobute2@gmail.com**

Received: 18.06.2020 Accepted: 03.02.2021 Published: 30.06.2021

Abstract: Being the third-largest emitter of greenhouse gases (GHG) globally, the cement industry has come under scrutiny by the international community lately. In a bid to remedy the situation, researchers worldwide are keen on finding alternative materials to partially or fully replace Portland cement in concrete production. Materials such as industrial waste, biological waste, agricultural and domestic waste have been used. In this study, a ternary blend of Ordinary Portland Cement, Cassava Peel Ash (CPA), and Rice Husk Ash (RHA) were introduced as the binder System in concrete production to reduce the use of Portland cement. The concrete mix was prepared to put CPA at 5% for all combinations while the RHA was varied from 0 to 25% of the total binder content. With a 0.65 water/binder ratio, an optimum strength was reached at 20% replacement of CPA (5%) and RHA (15%). The partial replacement of cement with CPA – RHA in concrete has also positively affected concrete's water absorption properties. From the use of these materials, GHG emissions are reduced, and the waste generated from the pile of cassava peel and rice husk is eliminated.
Keywords: Concrete, Portland cement, Cassava Peel Ash, Rice Husk Ash, Ternary blend

1. Introduction

Food, clothing, and shelter. These, from the general point of view, are the three necessities of man. Shelter from the weather elements is not just leisure but a core necessity as well. Over the years, a great diversity of construction techniques and construction materials have been employed to meet this need. These structures have evolved with time from temporary and straightforward structures like huts, tents, and containers to more permanent and sophisticated structures such as skyscrapers, canals, and dams. Likewise, the early and perishable construction materials such as leaves, straws, tree branches, and animal skin were replaced with more durable materials like clay, stone, and timber. Synthetic materials such as brick, concrete, metal, and plastic have been developed for construction [1].

From the aforementioned, concrete is the single most widely used construction material in the world. With an annual production of over ten billion tons worldwide, it ranks second only to water in the list of human consumables [2]. Concrete is defined as a composite material that comprises a mixture of Portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without admixtures [3]. When fresh, it is highly workable and can be fashioned into a variety of shapes. On the other hand, it possesses a very high compressive strength when hardened. This strength is a function of age and can reach between 20 and 40 Mpa in commercially produced concrete. These two properties make concrete the most desirable construction material. However, if loaded in tension, the material fails at a stress typically of the order of 10% of the compressive strength. Because of this low (and unreliable) tensile strength, concrete is usually reinforced with steel bars [4].

Nonetheless, concrete does have its downsides. One of these is the negative impact inflicted on the environment when mining its aggregates and manufacturing Portland cement. For example, world cement production now contributes about 5 percent of annual anthropogenic global CO_2 output [5]. Also, cement production is costly, making it difficult for the masses in developing countries to afford modest housing. For example, in Nigeria, it was estimated by the United Nations Agency for Human Settlement UN-HABITAT that the housing deficit was 17 million as of 2006. The market value for this deficit was estimated at $363 billion [6].

The pollution of the environment is not entirely the fault of the construction industry alone, other sectors like the agricultural and power sectors also contribute, and are equally deserving of urgent attention. For instance, pollution studies in the Sagamu and Ewekoro environs in Ogun state revealed that many are suffering from health challenges due to the pollution from the cement factory close by [7]. Also, Nigeria is among the top producers of cassava and rice globally is bedeviled by tons of agricultural wastes, which loiters most of her towns and villages. CPA – RHA in cement will reduce the environmental pollution from cement production (by reducing the amount of cement needed per concrete mix) and provide a sustainable and economical way of managing the agricultural wastes from such crops.

This study investigates the strength of concrete containing Cassava peel ash and Rice husk ash as partial replacement of cement (5% CPA and varying percentage of RHA ranging from 5% - 25%) in the concrete of 1:2:4 mix ratio and 0.6 water binder ratio. Cassava peel ash (CPA) is produced after the combustion of cassava peel (CP), which is a byproduct from the processing of cassava, either for domestic consumption or industrial use [8]. The plant thrives in the Nigerian climate and is mostly cultivated in the country's southern and middle belt [9]. This has placed the country in a good light as the highest cassava producer, producing about 38 million tones (MT) per annum. It is expected that this value will double by the year 2020 [10]. This makes it suitable that adequate attention is given to finding effective ways of disposing or recycling waste. Salau [8] wrote that the cassava plant's major waste is the peelings and ranges between 20 – 35% by weight of the tuber, especially if it is peeled using the hands. From the estimate, using 20% by weight of the tuber, about 6.8 million tonnes of cassava peels are generated annually, and 12 million tonnes are expected to be produced in the year 2020. Failure to deal with this waste will inevitably lead to a serious environmental hazard. The reality of this is already dawning on some communities in the country. In Ado Ekiti, for example, a previous field survey revealed that the volume of cassava peel heaps around some factories had more than doubled within just three years. The resultant effect of this is the production of noxious and offensive odour and the emission of heat and gases, which attract flies and other vectors [11].

Oryza sativa – the botanical rice name - ranks next to maize as the most popular cereal in the world [12]. With an estimated 3.8 million tons production, Nigeria is the largest rice producer in West Africa and the second-largest in Africa after Egypt [13]. However, this falls below the yearly consumption of 5 million tons. About 365 billion nairas is spent yearly on rice importation. In essence, a higher production rate is expected, as the government's goal is to meet its local demand from local production.

There are two major wastes from rice: the husk, which constitutes about 20% of rice weight; the straw, which is almost the same weight as the rice grain. It is estimated that global rice production generates about 10^8 tonnes of rice husk annually [14]. The husk is sometimes burnt as fuel for cooking, heating air in rice driers, or power milling plants. However, just a small fraction is used for such purposes as most of it is dumped and burnt in the open [15]. Many refuse heaps have been formed in different country locations where they are dumped and posing as an environmental nuisance [14].

Rice husk ash (RHA) is a pozzolan produced after the burning of rice husk [12]. For the best pozzolans, the husk should be burnt at a controlled temperature below 700^0C and under the supply of adequate air to minimize carbon creation. This is because burning at temperatures above 700^0C produces a less reactive crystalline silica compared to the much more reactive amorphous silica formed at lesser temperatures. As a pozzolan, RHA is considered to possess the greatest potential due to its widespread availability and the large proportion of ash (containing about 90% silica) produced after burning. It is already being produced commercially in countries like Thailand, India, and Columbia for use as pozzolans [16].

2. Ternary Blending of Pozzolans

Blended cement refers to the partial replacement of cement (usually ordinary Portland cement) with one or more pozzolans. When OPC is partially replaced with a particular type of pozzolan, it is called a binary blended cement. However, when partially replaced with two different pozzolans, it is referred to as a ternary blended cement [17]. As earlier discussed, the aim of using pozzolans is because of its advantages, which include economic benefits, ecological benefits, and the improvement of concrete properties [18]. And when these pozzolans are used in ternary blends, research has shown that they often produce better results than binary blends. It is observed that the addition of a second pozzolan helps in overcoming the shortcomings of the first. However, it must not be assumed that the improvement is due to their properties' superimposition as the pozzolans could react with each other. The properties found in their ternary blend could be different from those found in their binary blends [19].

Quite a several researchers have looked into the ternary blend of pozzolans. In 2018, Datok et al. [17] investigated the behavior of binary and ternary blends of binding material in concrete. To achieve this, they blended OPC with 20% Acha Husk Ash (AHA), 10% Corn Cob Ash (CCA), and then the range of 5-15% was used for the ternary blend of OPC/AHA/CCA. Results from their research revealed that after 28 days of curing, the ternary blend of 5% developed a strength of 24.60 N/mm^2. This is about 96% of the control and higher than the highest strength developed by OPC/AHA and OPC/CCA's binary blends. In 2007, Ghrici et al. [20] blended Portland cement, limestone, and natural pozzolana. They then proceeded to test their resultant effect in concrete and compared them with the test results gotten from control mixtures of ordinary Portland cement, Portland cement and limestone, and Portland cement and natural pozzolana. The test results showed that the ternary blend not only offered more resistance to sulfate and chloride ion ingress than the control mixtures they also showed better early age and long-term compressive strength [19].

3. Materials and Methods

3.1 Materials

The materials used for the experiment were Ordinary Portland Lime cement, clean and dry river sand (fine aggregate), and crushed granite (coarse aggregate) of maximum nominal particle size. The water used was clean portable water. Cassava peels used were collected from cassava peels dumpsite at Oju Local Government, Benue State, Nigeria. The Cassava Peels were initially burnt to ash through open-air burning before being subjected to control burning in a kiln at a temperature of 650^{o}C for 90 minutes. It was ground into finer particles using local milling machine and then sieved through 150µm sieve upon cooling down to room temperature. The analysis of its chemical composition was carried out using X-ray Fluorescence Analytical Method.

Rice husk was collected from Sabon Gari Local Government and subjected to -air burning at temperature, reaching up to 1000^{o}C for seven days. The ash was sieved through a 450µm sieve to rid it of dirt and ground into finer particles using a local milling machine upon cooling down to room temperature. Next, the milled RHA was sieved through 75µm, and analysis of its chemical composition was carried out using X-ray Fluorescence Analytical Method.

3.2 Methods

The tests employed in this research work are; oxide composition analysis using XRF, sieve analysis, specific gravity, crushing test, and impact value test. Others were consistency, setting time, soundness, Absolute Volume Method of concrete mix design, slump test, and compressive strength test All the tests were conducted in conformity with relevant standards.

Table 1: Physical Properties of Materials for Concrete

Materials	Specific Gravity	Moisture Content (%)	Bulk Density (Kg/m^3)
Cement	3.14	0.53	-
Fine Aggregate	2.56	7.50	1465.00
Coarse Aggregates	2.70	0.20	1795.00
Cassava Peel Ash	0.98	-	-
Rice Husk Ash	1.05	-	-

3.2.1 Tests on Concrete

The slump test is conducted on fresh concrete to determine how workable the concrete is. It was carried out following BS EN 12390 part 2 [21]. Compressive strength is a measure of the concrete's ability to resist the crushing load being applied directly. In essence, it reveals the maximum compressive load that the concrete can bear per unit area. This test was conducted following BS 1881, part 116 [22](1983). A total of one hundred and twenty cubes (120) were cast using 100mm × 100mm × 100mm steel moulds and cured in water for 3, 7, 14, 28, and 56 days, respectively tests.

Water absorption test, which is a test carried out to determine the level or rate at which concrete specimens absorb/retain water it, was done according to ASTM 140 [23]. The concrete cubes were surface dried after curing before being oven-dried at 100^{o}C for 24 hours. After the samples were removed from the oven, they were cooled and weighed before they were immersed in water for 24 hours and weighed again after removing them from water. Increases in mass as a percentage of initial mass is expressed as its water absorption and can be mathematically expressed as shown in equation (1);

$$\text{Water absorption} = \frac{\text{New Weight} - \text{Air dry weight}}{\text{Air dry weight!}} \times 100 \quad (1)$$

Where;

New weight = weight of saturated concrete cubes

Air dry weight = weight of oven-dried concrete cubes

3.2.2 Mixture Proportion

A Water-cement ratio of 0.60 was adopted for the mixes throughout the research work. The actual concrete mix proportions are presented in Table 2.

Table 2: material proportion used for producing concrete cubes (100× 100 × 100mm)

S/no	Description	Water (kg)	Cement (kg)	CPA (kg)	RHA (kg)	Fine aggregate (kg)	Coarse aggregate (kg)

1	C0%R0%	5.431	9.053	0.000	0.000	18.106	36.212
2	C5%R0%	5.431	8.600	0.453	0.000	18.106	36.212
3	C5%R5%	5.431	8.148	0.453	0.453	18.106	36.212
4	C5%R10%	5.431	7.695	0.453	0.906	18.106	36.212
5	C5%R15%	5.431	7.242	0.453	1.359	18.106	36.212
6	C5%R20%	5.431	6.790	0.453	1.812	18.106	36.212
7	C5%R25%	5.431	6.337	0.453	2.265	18.106	36.212

4. Results and Discussion

4.1 Oxide Composition of Cement, CPA, and RHA

Table 3 Oxide Composition of Cement, CPA, and RHA

Oxide (%)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO
OPC	0.710	1.690	5.700	14.98	-	2.670	-	0.100	68.30
CPA	0.421	4.726	11.323	51.755	4.890	2.173	O.660	6.434	6.890
RHA	0.061	2.400	1.814	79.864	7.428	0.880	0.102	2.976	2.898
Oxide (%)	TiO_2	Cr_2O_3	Mn_2O_3	Fe_2O_3	ZnO	SrO			
OPC	0.220	0.010	-	4.100	-	-			
CPA	2.419	0.020	0.308	7.863	0.082	0.034			
RHA	0.198	0.002	0.236	1.065	0.058	0.017			

The chemical composition analysis of Cassava peel Ash (CPA) and rice husk ash (RHA) using XRF is presented in Table 3. It can be observed that the combined SiO_2, Al_2O_3, and FeO_3 content for CPA and RHA are 67.178% (class C pozzolana) and 82.743% (Class F pozzolana), respectively. This shows that the RHA is a very reactive pozzolan, having more than the 70% recommended in ASTMC618, [24] for good pozzolan. The CPA, however, is considered less reactive. The pozzolans' chemical composition also indicated that the K_2O content for CPA was 6.434% and 2.976% for RHA, higher than the 1.2% limit recommended in cement [25]. The high K_2O content may cause a delay in the setting time of concrete. It is also observed that the value of MgO for both pozzolans is lower than the 5% limit specified by ASTM C618-12 [24]. This indicates the possibility of improved soundness and hardness when they are used in concrete.

4.2 Sieve Analysis of a Coarse Aggregate

Coarse aggregate is crushed granite of nominal size of 20mm with a specific gravity of 2.7. The particle size grading curve shown in Figure 1 indicates that the coarse aggregate's particle size is majorly medium size granite.

The particle size distribution test for fine aggregates is shown in Figure 2. The test was carried out following BS EN 933-1 [26], and the fine aggregate was found to fall within zone 1 by BS 882 [27] classifications.

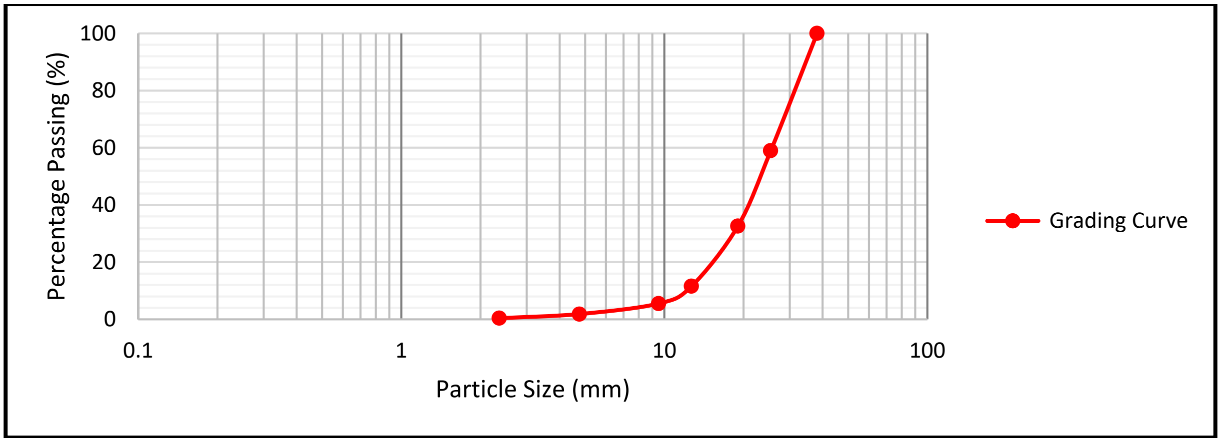

Figure 1: Particle Size Distribution Curve of coarse aggregate

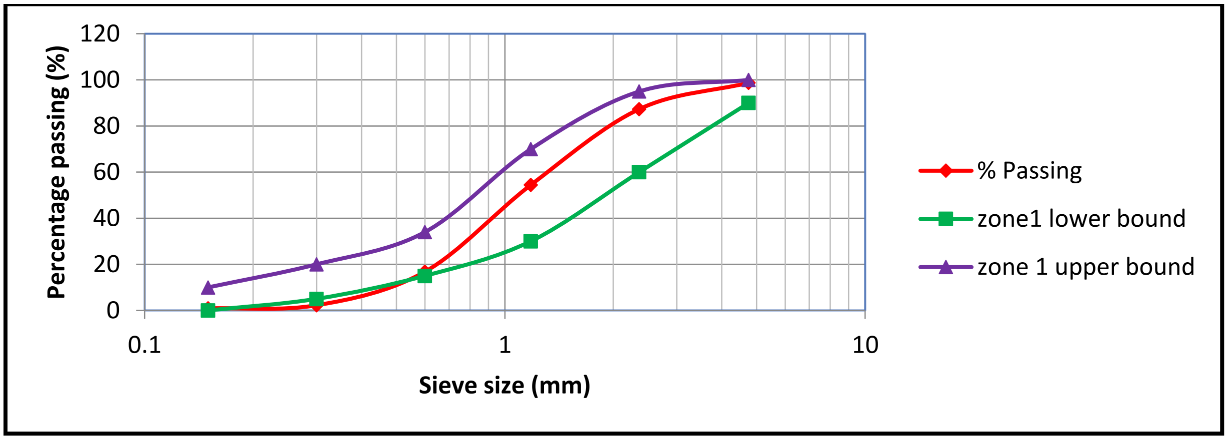

Figure 2: Particle Size Distribution Curve of Fine aggregate

4.3 Slump Test on Fresh Concrete

The slump values used to measure the fluidity, softness, or wetness of a batch of concrete as per ASTM C 143[28] are represented in Figure 3. As can be observed from the graph, the research results reveal that the slump decreased upon CPA - RHA inclusion as a partial replacement of ordinary Portland cement. It goes on to say that to attain the required workability, mixes containing CPA – RHA will require more water than the corresponding conventional mix.

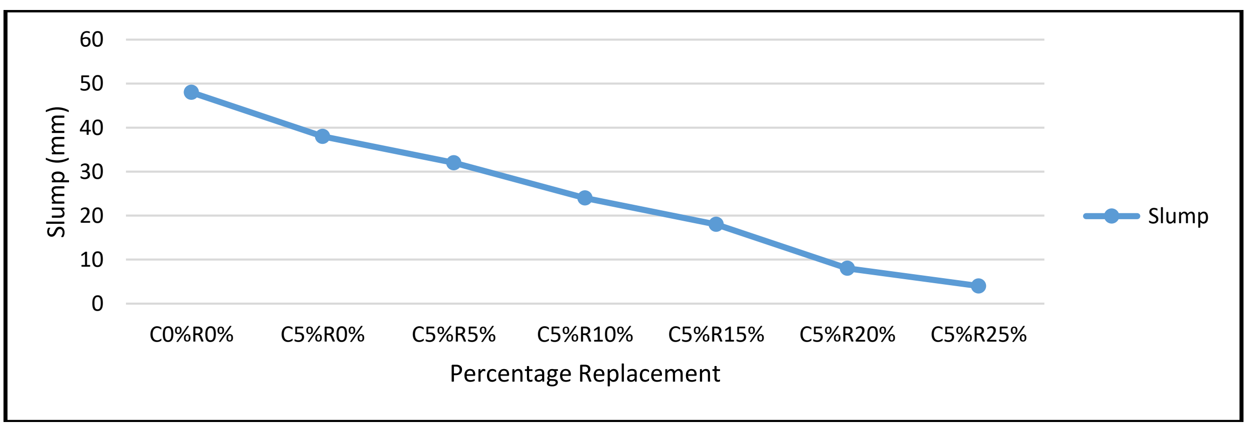

Figure 3: Slump Test of CPA - RHA Concrete

4.4 Compressive Strength of CSA-GSA Concrete

The compressive strength results shown in Figure 4 indicate that compressive strength increased with curing age and decreased with increased blended CPA - RHA content. The results show that the 3 days compressive strength decreased from 13.5N/mm^2 for OPC to 9.3N/mm^2 for 30% replacement with CPA – RHA. Similarly, after 28 days of curing, the strength decreased from 28.7N/mm^2 for OPC to 20.2N/mm^2 for 30% replacement with CPA – RHA. The optimal 28 and 56 days strength for CPA - RHA concrete is recorded at 20% replacement, i.e., 24.12N/mm^2 and 25.2N/mm^{2,} respectively. These results show that the ternary blend of OPC/CPA/RHA has a positive impact on concrete strength, especially at the later stages, and agrees with the previous works [17].

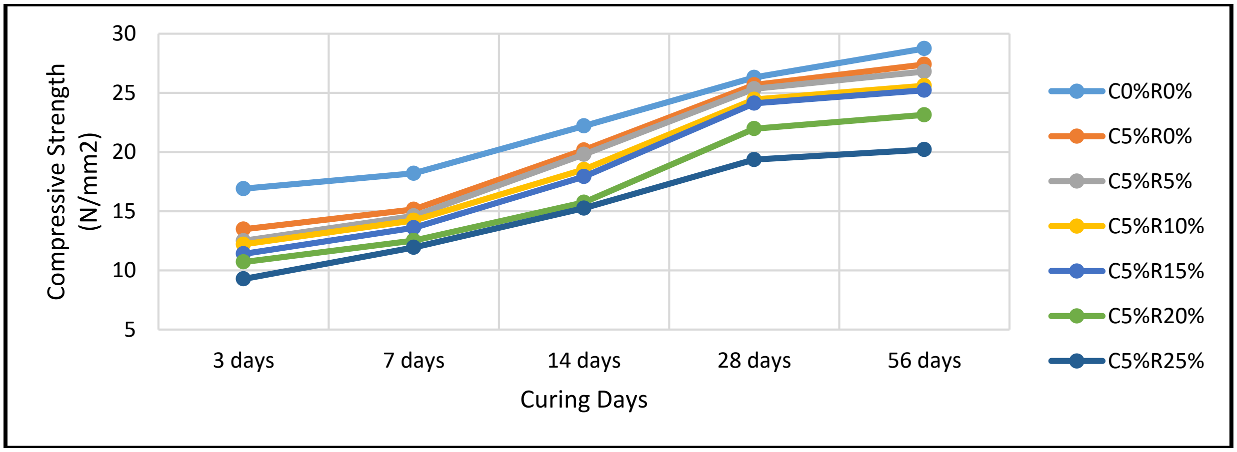

Figure 4: Compressive Strength of CSA-GSA Concrete

4.5 Water Absorption

The graph shows that the percentage water absorption of concrete reduced progressively as the percentage with CPA – RHA increased. The control it is observed had the highest percentage water absorption of 5.59%, while 5%CPA – 25%RHA had the least water absorption value of 3.25%. This is in line with the report by Malhotra and Mehta [29]. This decline in water absorption could be attributed to the fineness of CPA - RHA as reported by Pande and Makarande,[30]. Another explanation for this might also be due to the pore's extensive refinement in the matrix and the interface layer [31].

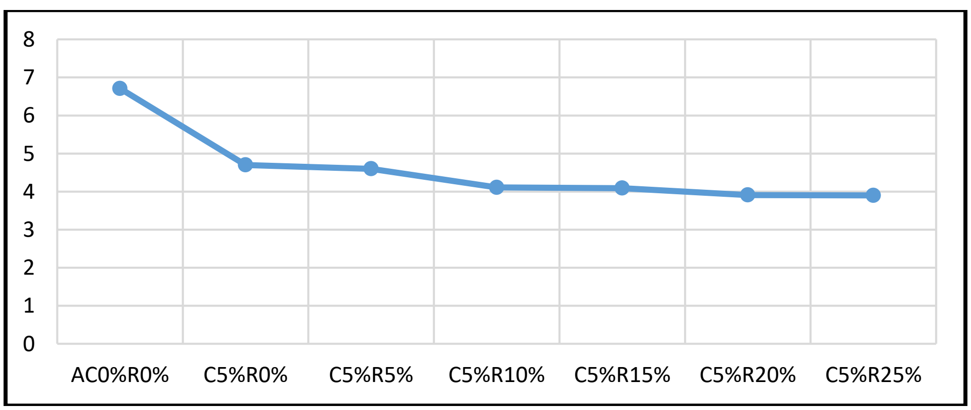

Figure. 5: Water Absorption of CPA - RHA Concrete (%)

5. Conclusions

This study looked into the effects of cement's partial replacement with cassava peel ash and rice husk ash on concrete. CPA is a class C pozzolan having combined SiO_2, Al_2O_3, and Fe_2O_3 content of 67.178 % (which is less than the recommended 70% for pozzolans). It is less reactive than RHA, a class F pozzolan having combined SiO_2, Al_2O_3, and Fe_2O_3 content of 82.743%. However, the ternary combination of CPA with RHA is complementary, producing a CPA – RHA concrete with satisfactory compressive strength. An increase in percentage replacement of cement with CPA – RHA results in a decrease in the compressive strength. However, an increase in curing age increases the compressive strength, with CPA – RHA concrete gaining a compressive strength comparable to that of the control when cured for 28 days or more. Hence, CPA – RHA concrete will be suitable for construction projects where early strength gain is not a major concern. A slump test carried out on fresh blended CPA – RHA concrete reveals that the workability of concrete reduces as the CPA – RHA percentage in concrete increases. Hence, more water will be required to maintain the fluidity of fresh CPA – RHA concrete than ordinary Portland cement concrete. An increase in percentage replacement of cement with CPA- RHA results in a decrease in the resulting concrete percentage water absorption.

Acknowledgment

The authors wish to acknowledge the staff and management of the concrete laboratory, Civil Engineering Department, Ahmadu Bello University, Zaria for their contribution to this work.

Conflict of Interest

The authors declare no conflict of interest.

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