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The Influence of Calcium Carbide Residue and Wood Ash on the Properties of Concrete

Olaoyenikan Olajide A.[1], Olajide Olusola D.[2], Adese Akorede J.[3]
[1,3]*(Civil Engineering Department, Federal University of Technology Akure, Nigeria)*
[2]*(Building, Civil and Environmental Engineering Department, Concordia University, Canada)*

Abstract:
Background : *The large amount of space taken on landfills by waste, the constant release of environmental polluting gases like CO_2 into the atmosphere and the high cost involved in cement production has led to the search for alternative binding materials that are cheap, ecofriendly and will help contribute to waste management. This research presents the findings of an experiment, set out to evaluate the performance of calcium carbide residues (CCR) and wood ash (WA) as partial replacements of cement in concrete.*
Materials and Methods*: Mix ratios 1:2:4 and 1:3:6 was used to cast concrete cylinders of sizes 100mm x 200mm and concrete cubes of dimension 150 mm x 150 mm x 150 mm. The percentage replacement of cement with CCR/WA were 0%, 5% 10%, 15% and 20% (by weight of cement) respectively. The water/cement ratio was kept at 0.55. The setting time, slump, compacting factor, compressive and tensile strengths were determined. After 7, 14, 28 and 56 days of curing in a curing tank, the cubes and cylinders were subjected to compressive and tensile strength tests to determine the characteristic strength of the concrete using standard procedures*
Results*: The workability and setting times of the concrete incorporating CCR/WA increases when compared with the conventional concrete. The compressive and tensile strength of the concrete mixes increased as the age of curing increased, however, the 28- and 56-days strengths of the conventional concrete was 24% and 15% respectively higher than the highest strength achieved at similar age in the replaced concrete.*
Conclusion: *Incorporating CCR and WA in concrete helps improves the workability and setting time of concrete and can attain comparable strength to conventional concrete over time. The use of these materials can help reduce the use of cement and its accompanying environmental challenges.*
Key Word*: Calcium Carbide Residue; Wood ash; Supplementary Cementitious Materials; Pozzolanic reaction; CO2 emission.*

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I. Introduction

Concrete has been one of the most important construction materials over the years as it offers a low cost, durable, aesthetic advantage over other materials like wood, bamboo, and steel. One of the constituents of concrete is cement, a material that provides the binding property needed for the solidification of other constituents. The vast use of concrete has directly led to the extensively demand for cement. Today's annual global cement production has reached 2.8 billion tons, and it is expected to increase to some 4 billion tons per year in 2050[1]. The increase in its demand and usage is a huge concern in the bid to meeting the Paris Agreement's temperature goals. Hendriks *et al.*[2], (2004) estimated, that for every 1kg of cement manufactured, an approximate by-product of 0.9kg of CO_2 is emitted, and about 2.52 billion tons of CO_2 is released into the atmosphere around the globe yearly. As a result of present and forecasted release of emission, it is rather important to carryout research on sustainable materials than can either be used partially or fully to control the emissions.

One of the serious problems confronting this present generation is waste and its disposal. Presently, a huge number of industrial by-products, agricultural wastes, and unprocessed materials like calcium carbide residues, slags, rice husk, wood ash, fly ash, animal bones, paper waste etc., litter and take an enormous space on landfills and waterways across the world. These indiscriminate disposal leads to pollution, and some could pose potential hazards to the environment. Much research has been going on the utilization of these materials in construction, an innovation which will help reduce indiscriminate disposal of such waste and reduce the usage of some constituent of concrete. Of significant importance of these constituents is cement due to its environmental impact. Wastes like fly ash, slags, silica fume has been used as supplementary cementitious materials (SCMs) in concrete due to their pozzolanic activity. The microstructure of a freshly placed concrete undergoing hydration consist of components like CSH known as Calcium silicate hydrate and CH; Calcium hydroxide (CH). Other chemical products include ettringite and monosulphate. The CSH represents the strength of the concrete, and this can be increase through the pozzolanic reaction from SCMs. This is achieved by supplying silica to the CH to increase the amount of CSH in the system. Furthermore, the SCMs can help reduce the porosity of the interfacial transition zone (ITZ) by acting as a filler (filler effect) due to their small particle size. Most of these wastes has been researched and confirmed to possess these potentials. Thus, incorporating them in concrete by partially replacing them with cement would help reduce emissions from its production and protect the environment from waste.

There has been recent research on the use of Calcium carbide waste as a replacement for cement in concrete, this is largely due the high Calcium Oxide (CaO) it contained, like that comprised by the ordinary Portland cement. Calcium carbide residues (CCR) is gotten as a waste while producing acetylene gas ($C_2 H_2$). One of the components of this by-product is calcium hydroxide, a component in concrete microstructure product in concrete that can react with siliceous materials to produce CSH. Hence, the possibility of using the material as a replacement of cement in concrete production [3]. This waste is often disposed in landfills and has the tendency of leaching harmful compounds to the surrounding and even contaminate the ground water. According to a work carried out by Aderinola et al.[4] to assess the engineering properties of concrete containing calcium carbide residue and bamboo leaf ash, they reported an increase in the compressive strength of concrete containing the SCMs when compared to conventional when a partial replacement of 10% was made for cement. However, at higher replacement levels, a reduction in the mechanical properties and the consistency of the concrete was observed. As a result, an optimum replacement level of 10% was advised. According to Gora et al. [5], an increase in compressive and flexural strength was observed when up to 2% of cement was replaced with calcium carbide in mortars. The addition of Calcium carbide improves the consistency of the mortar, evident by the increase in slump as the percentage replacement increases. Similar increase in consistency was reported by Ogork & Ibrahim [6]. Also, improvement in other properties of concrete like drying shrinkage, initial and final setting time was documented.

Unused ash from wood burned for fuel or other commercial and household use has posed a problem to the use of wood over time [7]. Wood ash is the residue powder left after the combustion of wood, the ash is commonly disposed in landfills causing environmental pollutions and could also lead to health hazards when inhaled. It can be of great use in construction due to the similarity it has with the class F fly ash, as a result, wood ash poses the potential of usage as a pozzolana in concrete [8]. Wood ash has a high silica and alumina content which is why several research has been ongoing on its assessment as an SCM [9]. Few works exist in the literature regarding the use of wood ash as an SCM, among is the work by Yahia et al.[10], ash was incorporated in concrete cubes and cylinders at varying percentage. A 10% replacement of cement gives 31% increase in compressive strength. A reduction in compressive strength was recorded at higher percentage of replacement. Despite such reduction, the pozzolanic ability of the material was established.

Upon the separate research that has been carried out on the replacement of cement with calcium carbide residue and the pozzolanic reaction by wood ash, this project aims to assess the impact of combining the two materials in concrete to minimize the disposal problems they cause and the reduction in use of cement in construction. Since the mechanical properties is a popular index for assessing the behavior of concrete in service, concrete made by incorporating these materials at different percentage of replacement are to be tested under compression and tension.

II. Material And Methods

Study Location: These study was carried out at the laboratory of the department of Civil Engineering, Federal University of Technology Akure, Ondo State, Nigeria. All the materials used was collected from the community in which the University was situated.

Materials The materials used for this research includes cement, calcium carbide residue, wood ash, coarse and fine aggregates, and water. All of which were obtained in Akure, a city in the south-western part of Nigeria. The ordinary portland cement (OPC) of grade 32 that satisfies the minimum requirement as provided by BS 12 (1996) was used as binder for this project, and it was sieved through a 75 micron sieve before usage. The coarse aggregate used were crushed rock with size range between 4.75mm and 20mm. The coarse aggregate was obtained within Akure metropolis, sieved to required gradation and kept in the saturated surface dry condition. The fine aggregates are made of crushed rock aggregate with size range between 2.36mm and 4.75mm. Sieve analysis was carried out by passing the fine aggregates through a sieve to determine it particle size distribution and the fineness modulus which was found to be 2.85. Calcium carbide samples were collected from panel beaters shops around the city. The waste consists mainly of lime and caustic solid substances, which in pure form is a white crystalline substance. The chemical analysis conducted through the X-ray Florescence Spectroscopy (XRF) showed a high Calcium Oxide (CaO) like that present in ordinary Portland cement (OPC) as shown in Table no 1.

Table no 1: Chemical composition of calcium carbide residue and ordinary portland cement

Oxide	CCR	OPC
Calcium Oxide (CaO)	60.92	66
Magnesium Oxide (MgO)	0.86	1.89
Aluminum Oxide ($Al2O3$)	1.64	5.75
Iron Oxide ($Fe2O3$)	0.21	2.50
Silica Oxide (Si$O2$)	2.72	20.10
Silicon Trioxide (Si$O3$)	0.34	2.75

The wood ash (powdery, amorphous solid) was sourced locally from the bakeries in the city. Table no 2 shows the general composition of the ash. The wood ash contains a high percent of silica and alumina which are important component for a pozzolanic reaction.

Table no 2: Chemical composition of wood ash

Oxides	MASS %
Silica Oxide (Si$O2$)	33.8
Aluminum Oxide ($Al2O3$)	27
Iron Oxide ($Fe2O3$)	2.34
Calcium Oxide (CaO)	10.43
Sodium Oxide (NaO)	6.5
Potassium Oxide ($K2$O)	10.18
Magnesium Oxide (MgO)	9.12

Preliminary tests like the particle size distribution (BS EN 1377-2), soundness test (BS 812-121), aggregate impact value (BS 812-112, 1990), aggregate crushing value (BS 812-110, 1990), moisture content, absorption (BS 812-2) and specific gravity (BS1377-2) was carried out on the materials where appropriate as specified in the respective standards used.

Concrete Mix design

The testing matrix for this project is presented in Table no 3. The phase one was dedicated to determining the compressive strength of conventional concretes and compare them with partially replaced concrete. Two prescribed mix ratios 1:2:4 and 1:3:6 which gives concrete grades of 18MPa and 12MPa respectively after 28 days were used for concrete production at 0.55 water to cementitious material ratio (w/c). Batching of materials was done by weight and 120 concrete cubes with size 150mm × 150mm × 150mm concretes was cast. The phase two of the research were carried out to assess the tensile strength of 120 concrete cylinders (containing conventional concrete and partially replaced concrete) of 100mm x 200mm using the same mix design as specified in phase one. The conventional concrete is made up of cement, fine and coarse aggregates while the cement was replaced with 5%, 10%, 15% and 20% of CCR and WA for the nonconventional concrete as illustrated in Table no 4. The conventional concrete and each replaced concrete samples for each mix ratio were tested after 7, 14, 28 and 56days and the average compressive and tensile strength results from three samples were recorded.

Table no 3: Testing matrix

Phase	Tests	Mix Ratio	Number of Specimens			
			7 days	14 days	28 days	56 days
1	Compressive Test	1:2:4	15	15	15	15
		1:3:6	15	15	15	15
2	Tensile Test	1:2:4	15	15	15	15
		1:3:6	15	15	15	15

For each mix ratios, a total of 15 cubes/cylinders (three per each replacement levels) were cast and three each were tested for both compressive and tensile strengths after 7, 14, 28 and 56 days for conventional samples. Same for other replacement levels.

Table no 4: Conventional and Partially Replaced Concrete

Concrete mix ratios	CCR	WA	Cement
1:2:4, 1:3:6	0%	0%	100%
	2.5%	2.5%	95%
	5%	5%	90%
	7.5%	7.5%	85%

	10%	10%	80%

The batching weas done as specified in the mix design after which they are placed in the moulds. The samples were demoulded after 24 hours and cured in water for complete hydration reaction. The deep-water method of curing was employed and were removed for testing after 7, 14, 28 and 56 days.

III. Results

Physical Properties of materials used

The physical properties of all materials used for producing the concrete are shown in Table no 5. Moisture content, water absorption, specific gravity, aggregate impact value (AIV) and aggregate crushing value (ACV) tests were carried out on the fine aggregates (FA), coarse aggregates (CA), Cement (OPC), calcium carbide residue (CCR) and wood ash (WA) where appropriate.

Table no 5: Properties of materials used

Physical Properties	FA	CA	CCR	WA	Cement
Moisture content (%)	0.24	0.36	0.12	0.10	–
Specific gravity	2.64	2.71	2.47	2.32	3.13
AIV (%)	–	19.21	–	–	–
ACV (%)	–	28.96	–	–	–
Water absorption (%)	0.40	0.82	–	–	–

The particle size distribution results for the aggregates obtained from conducting sieve analysis test on the fine aggregate used for this research. The results shows that higher percentage of the fine aggregate passed through the 4.75mm sieve, while the little percentage of the aggregate left on the retaining pan shows that the silt present in the soil is of minimal quantity. The size of the sieves used ranges between 75µm to 4.75mm and the result shows that the fine aggregate used are well graded.

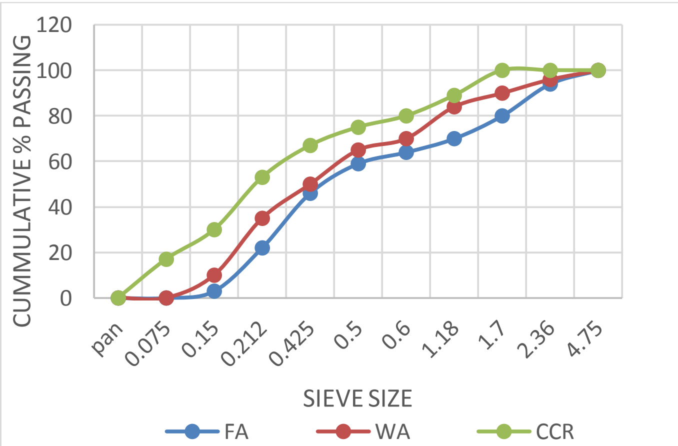

Figure no 1: Particle size distribution curve for fine aggregate

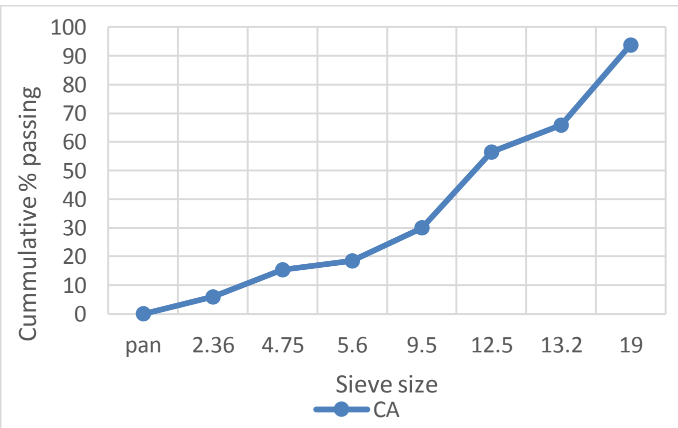

Figure no 2: Particle size distribution curve for coarse aggregates

Slump Test for Concrete Workability

Table no 8 shows a tabular presentation of the slump test carried out on concrete produce at different replacement of cement. The table shows that the slump for the concrete produced at mix ratio 1:2:4 incorporating CCR/WA is higher compared to the conventional concrete. But at mix ratio 1:3:6, the slump height of the CCR/WA blended cement concrete increased at 5% replacement and reduces from 10% to 20%.

Table no 6: Slump test carried out on concrete produce at different replacement of cement.

Percentage Replacement of CCR/WA	Slump For 1:2:4 Mix	Slump For 1:3:6 Mix
0%	20	20
5%	50	50
10%	35	40
15%	40	30
20%	40	20

Compaction test

The results of the partial and full compaction test carried out on the concrete produced are presented in Table no 7. The compactor factor values for CCR/WA concrete are higher than that of normal conventional concrete at the two mix ratios used. It was observed that there is no linear relationship between the increase in the percentage of replacement and the compaction factors recorded at mix ratio 1:2:4 and 1:3:6. The compaction factor values were obtained by using the formulae in equation I.

Compaction factor $C_f = \frac{\text{(Weight of partially compacted)}}{\text{(Weight of fully compacted)}}$ …………………………...(I)

Table no 7: Compaction factor values for various concrete mixes

CCR/WA	Wt. of Partially Compacted CCR/WA	Wt. of Fully Compacted CCR/WA	Compaction factor	Wt. of Partially Compacted CCR/WA	Wt. of Fully Compacted CCR/WA	Compaction factor
	1:2:4 Mix ratio			**1:3:6 Mix ratio**		
0%	19	22	0.86	18.6	22	0.85
5%	18	20	0.90	18.6	20	0.93
10%	18.4	19	0.97	17.8	18.6	0.96
15%	19	20	0.95	18.4	20.4	0.92
20%	19.8	21.2	0.93	20	22	0.91

Setting time test

The setting time test was carried out as recommended in BS EN 196-3 to assess the impact of the varying percentage of Calcium carbide residue and wood ash on the setting times of ordinary Portland cement. It was observed that the OPC has an initial setting time of 78 minutes and final setting time of 570 minutes. CCR/WA blended cement has the highest initial (126 minutes) and final (690 minutes) setting times.

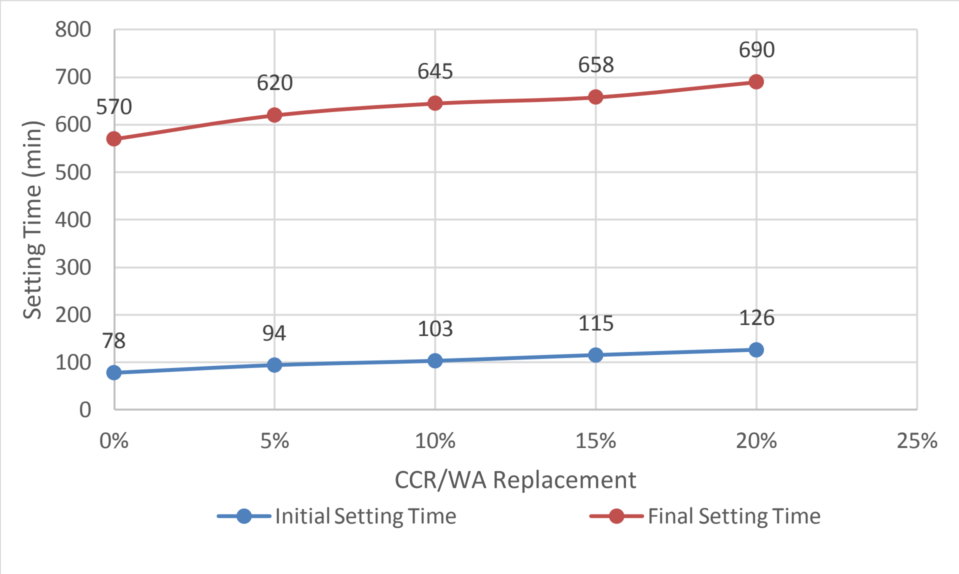

Figure no 3: Setting Time of OPC and CCR/WA and blended cement.

Compressive strength test

Compressive strength test was conducted in accordance with (BS EN 12350: Part 6, 2009) after 7, 14, 28 and 56 days of deep water curing of concrete specimens. This test was conducted to know if the targeted 28-day compressive strengths for both the normal conventional concrete and the concrete produced by partially replacing cement with CCR/WA at varying percentages were achieved. Compressive strength test was carried out on a total sum of 120 concrete cubes (54 concrete cubes per each curing day) to know if the strength of concrete produced is within permissible limits at 7, 21, 28 and 56 days curing ages. The strength characteristics of each cube were determined using a Universal Testing Machine at a loading rate of 13.5 KN/sec. Each strength test result is an average from three identical samples.

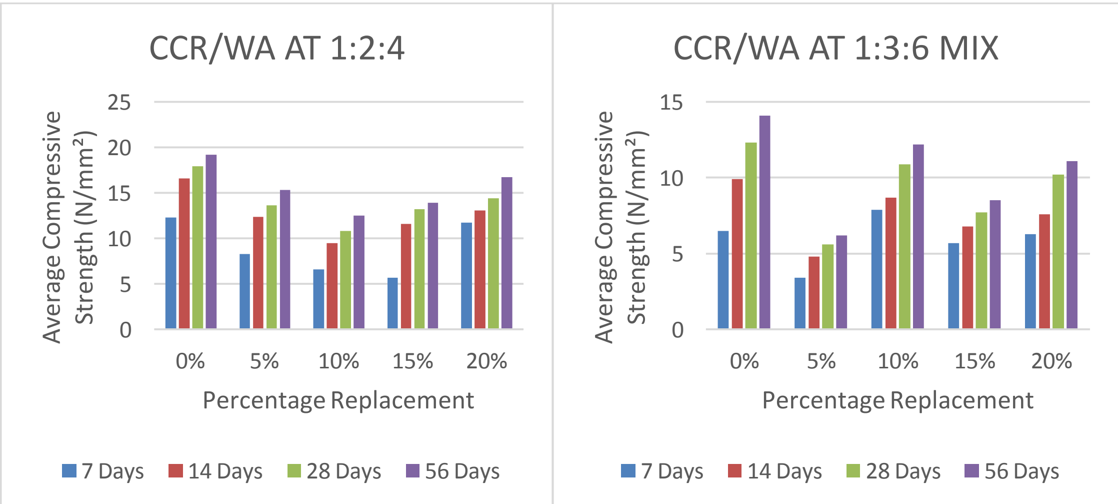

Figure no 4: Compressive strength test results

Tensile Strength test

The tensile strength of cylinders incorporating varying replacement levels of CCR/WA was determined as recommended in BS 1881 117-83. The test which was carried out on 120 concrete cylinders of 100mm by 200mm in dimension was done using the splitting tensile test with the aid of the universal testing machine after 7, 14, 28 and 56 days of curing. The results presented in Figure no 5 shows the average of three cylinders per each replacement level and testing date.

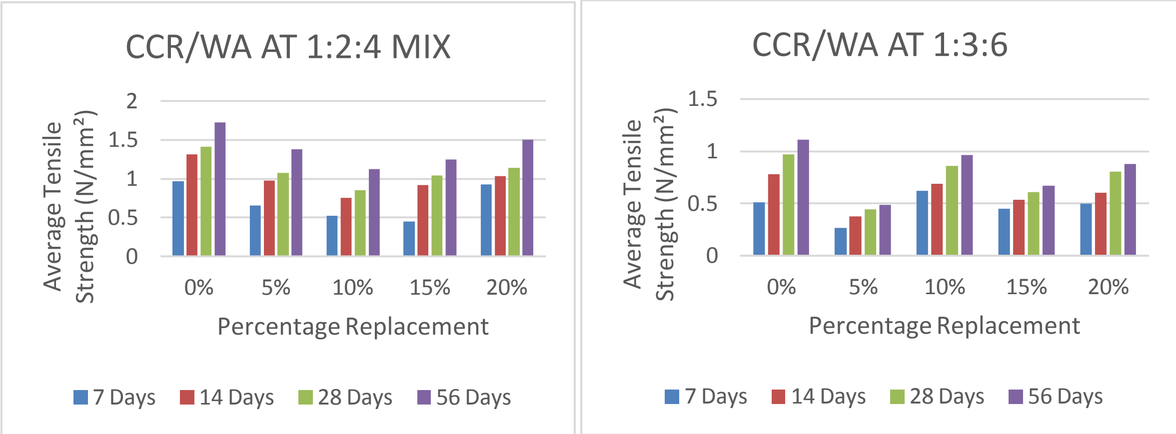

Figure no 5: Tensile strength test results

IV. Discussion

Several tests were carried out in the laboratory on the materials used for this test to determine the engineering properties of the materials to be evaluated, some of which was on the aggregates, cement, concrete; both fresh and hardened. The AIV test was performed on the coarse aggregate to measure its resistance to sudden impact or shock. BS 882 (1992) provides a limit ranging from 30% downward according. A value at or below 30% is regarded be strong and those above 30% would normally be regarded to be too weak for use in construction works. An AIV of 19.21% was recorded for the coarse aggregate, which is within the standard set for concrete production. Also, the ACV which measures the strength resistance of aggregate to crushing under a gradually applied compressive load has a standard of 45% for aggregate. The ACV of 28.96% obtained in this work is within the standard specified by BS 812 (1990). The workability which affects the ease of use of concrete was improved at mix ratio 1:2:4, the slump height for CCR/WA blended cement concrete is greater than that of the 100% OPC concrete and it increases with increase in the percentage of replacement. But at mix ratio 1:3:6, similar slump height was recorded at 0% and 20% replacement of cement with CCR/WA. Also, increase in compaction factors was obtained in both mixes when compared to the OPC. Furthermore, it was observed that the OPC has an initial setting time of 78 minutes and final setting time of 570 minutes. CCR/WA blended cement has a high initial and final settings of 126 and 690 minutes respectively. This could be because of the high carbon content of wood ash. The CCR/WA is thus efficient for concrete production requiring an improved workability and increased setting times.

From the compressive strength results, there was a general increase in concrete strength from 7 to 56 days curing period for the conventional concrete, similar increase in strength over 7 to 56 days was observed in the partially replaced concretes. Although, the maximum strength attained in the partially replacement concrete is lesser when compared to the conventional concrete. However, the difference in strength is less than 20%. For instance, the change in the compressive strength of conventional concrete and 20% replacement of cement with CCR/WA after 56 days is 13%. Thus, their strength could be comparable. Infact, some supplementary cementitious materials (SCMs) are known to gain more strength in late ages due to the slow or late initiation of the pozzolanic reaction. This can be illustrated in the 1:2:4 mix in which the compressive strength of 15% replacement of cement with CCR/WA was 5.7 N/mm^2 at 7 days compared to the 6.6 N/mm^2 obtained for 10% replacement. However, after 56 days of curing, the 15% CCR/WA replaced concrete attained a strength of 13.9 N/mm^2 against the 12.5 N/mm^2 for 10% replacement level. Sound concretes are known to have high compressive strength and durable. However, the properties can be affected due to a poor interfacial transition zone (ITZ), high porosity among other factors. When concrete is tested in compression, failure starts from the ITZ since it is known as the weakest area in concrete microstructure. This zone is majorly made of less calcium silicate hydrate(CSH) which constitutes most of the strength of concrete, and a lot of calcium hydroxide (CH), ettringite and monosulphates. As a result of this weakness, crack is initiated in this zone and as loading prolongs, cracks propagate around the aggregates and subsequently links to each other, and failure of the concrete sample occurred. Several research has been done on improving the ITZ using supplementary cementitious materials (SCM). The alumina and silica in wood ash just like the typical SCMs produces more CSH by reacting with CH in concrete microstructure and thereby increasing the strength of the ITZ. Given the reduction in cement of up to about 20% leading to a comparable strength after 56 days, it could be noted that calcium carbide residue and wood ash has helped to improve the loss of strength caused by reduced cement content through the pozzolanic reaction.

The tensile strength of concrete is governed by fracture mechanics, failure of samples tested in tension is because of a single crack from which other cracks are propagated . The strength is dependent on the stress concentration at the tip of the crack and since concrete is made of flaws that are inherent in its microstructure due to trapped air, voids after hydration and the pulling effects that leads to damage of the existing bonds between molecules in the concrete during tensile strength, all concrete poses a low tensile strength. Same was established in the results obtained for both mixes and all percentage replacement level. The tensile strength results increase with increase in the number of days. This is because of the continued hydration process which leads to the generation of more CSH and the reduction of voids overtime. However, there is no such linear relationship with the percentage of replacement. Nevertheless, the tensile strength for both mix after 56 days poses similar results as compared to those obtained in the conventional concrete.

From tests carried out on fresh and hardened concrete, it can be observed that the combination of CCR and WA can be used to reduce the quantity of cement in construction. Apart from a reduced strength which is largely less than 20% and could even improve in late ages, the materials can promote the workability of concrete and improved setting time. Given the environmental impart of the production of cement through the release of CO_2 , the use of these environmental wastes (CCR and WA) which are mostly disposed of indiscriminately could serve as a cheap and safe alternative to cement.

V. Conclusion

The following conclusions are drawn from the study:

- The compactor factor values for CCR/WA cement blended concrete, are higher than the normal conventional concrete compaction values of 0.86 and 0.85 at 1:2:4 and 1:3:6 mix.
- An increased in slump was obtained when cement was replaced with CCR/WA at a mix ratio of 1:2:4 when compared to conventional concrete.
- The 28- and 56-days compressive strength values (14.4 N/mm^2 and 16.7 N/mm^2) for 20% CCR/WA is comparable to that of OPC (17.9 N/mm^2 and 19.2 N/mm^2) which shows that their results could be comparable.
- The tensile strength results increase with the number of days of curing with the 20% replacement level attaining a strength of 1.5 N/mm^2 at 56 days higher than at 5, 10 and 15%.
- The use of CCR/WA in concrete is sustainable by reducing waste disposal, aiding recycling and also reduce construction cost because the demand for cement in construction industries for construction activities will decrease.

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