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EFFECT OF INCORPORATION OF CASSAVA PEEL ASH (CPA) IN CEMENT PASTE AND CONCRETE

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Abstract

In this research study, Cassava Peel Ash (CPA) which is an agricultural/industrial waste was incorporated in the concrete mixture as a supplementary cementitious material (SCM) thereby encouraging recycling and reuse of solid waste derivatives in construction works to achieve sustainable engineered infrastructural development and eco-efficient environment. The cementitious portion of the concrete mix were partially replaced by varying proportions of CPA ranging from 0-40% while tests were carried out on the concrete samples at fresh and hardened state to derive its workability, setting time, compressive and flexural strength behavior. The concrete's mechanical strength was determined at hydration periods of 3, 7, 28, 60 and 90 days respectively; to produce a concrete mixture of coarse and fine aggregates, water, cement and CPA. The physiochemical properties of CPA were obtained so as to characterize the elemental chemical composition the admixture and the results indicated a good pozzolanic behavior with Al_2O_3 + SiO_2 + Fe_2O_3 summing to 81.83%. the mechanical strength test results indicate rise in [redacted] percentage difference as CPA replacement ratio increased from 5-40% with a score of 7.2 – 46.2% and 18.18-86-19% for the compressive and flexural strength property respectively. Similarly, the workability and setting time test result showed increase in percentage difference as CPA replacement ratio increased from 5-40% with a score of 17.08-54.2%, 5.6-81.14% and 0.84-28.57% for slump, initial and final setting time properties respectively. Furthermore,

Keywords: Cassava Peel Ash, Cement Past, Concrete.

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the concrete's mechanical properties were observed to increase generally with relative increase in the concrete hydration period. The Pozzolanic Activity-Index (PAI) of CPA is 75.8% which is an indication that it has high pozzolanic properties. From the results, the optimum combination level of 5-10% replacement of the cement by CPA can be used to produce a better and more desirable concrete. Correlation analysis were deployed to statistically assess the mechanical properties response with the control results; the analysis results showed a consistent decrease in the correlation value from 0.9988-0.9678 and 0.9942.0.97594 for 5-40% replacement of the cement by CPA for the compressive and flexural strength respectively.

Introduction

Concrete is a composite manmade material which possesses similar mechanical properties to the naturally derived lime stone rocks. Its major ingredients are fine aggregate, coarse aggregate, water and cement; and it also develop required mechanical strength through cement hydration reaction (Shafigh *et al.,* 2019). Concrete's utilization in infrastructural development sector is on the increase especially in developing countries which causes relative increase in its demand and also resulting to more consumption of the ingredients. The incorporation of waste mateirals in concrete production helps to solve satisfactorily environmental and waste management challenges. This becomes essential because during the process of production and use of cement in concrete, large quantity of CO_2 emission as a result of fuel combustion and industrial processes which are major drivers of global warming are recorded. To tackle these challenges, the use of supplementary cementitious materials to substitute cement use in order to reduce the total construction cost and also achieve environment efficient, environment friendly, and sustainable development in terms of infrastructure (Lothenbach *et al*., 2019; Onyelowe *et al*., 2020).

Cassava peel which is a waste (by-product) from cassava processing and these materials are generated either on domestic level (household) or industrial level. The cassava peel consists of about 20% to 35% of the total tuber weight especially by hand peeling. This agricultural waste is heated through control incinerating system to thermally decompose into ash which is observed to possess pozzolanic characteristics (Salau *et al*., 2019). Pozzolans are considered to contain silica and alumina which in finely divided state reacts with calcium hydroxide in the presence of water to produce cementitious compounds such as calcium silicates hydrates,

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calcium sulfo-aluminate hydrates and calcium aluminate hydrates (Talero and Rahhal, 2018). Pozzolanic material utilization as a building construction material is nearly as old as ancient civilization where these pozzolanic materials are used to enhance the characteristics of lime; many of these structures are still intact as a confirmation of the durability property of pozzolanic-lime concrete mixture (Olusola et al., 2018). The physicochemical and mechanical character of natural pozzolans is derived from their behavior when situated or placed in a very aggressive environment. The pozzolans composed primarily of aluminic content are majorly chloride resistant while the silicic pozzolans serve well as sulphate resistant (Hewayde et al., 2018). The pozzolanic activity is a measure of the reaction rate between calcium hydroxide or Ca_2+ and a pozzolan in the presence of moisture. The intrinsic properties of the pozzolans namely; the active phase content, the surface area and the chemical composition affects the rate of pozzolanic reaction while the adsorption of physical surface is not considered due to the fact that no molecular irreversible bond are generated in the process. The pozzolanic reaction rate can be affected by externally related factors like the quantity of water, mix proportion, hydration product growth and reaction temperature (Benezet et al., 2018).

The utilization of solid wastes and its derivatives which possesses alumino-silicates content with pozzolanic property in the production of concrete helps to improve its durability property as it is being situated at the environmental severe conditions (Alaneme, et al., 2019). The need to obtain more sustainable cementing products in concrete makes it essential for researchers to indulge in the assessment of the pozzolanic activity of supplementary cementitious material so as to determine the safe combination level of these additives in concrete (Massazza, 2019). The importance of saving cost of construction and also to mitigate environmental degradation challenges due to indiscriminate disposal of various agricultural/industrial wastes and also oxides of carbon emission from both industrial plants and cement hydration as well as the enhancement of concrete durability performance, has led to increasing research into the utilization and re-cycling of various solid wastes and its derivatives which can be used as pozzolans (Mikuleie et al., 2020). Raheem et al., (2020), in their research study, the cement was partially replaced in concrete by CPA of varying proportions from 0% to 20% by cement weight at 5% interval using a mixture ratio of 1:2:4 and cured for 7 days to 28 days. The strength development and slump were observed and it was concluded that the concrete strength increases with increased hydration period

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but decrease with increase quantity of the CPA. Also, Ofuyatan et al., (2018), investigated cassava peel ash which is locally available is utilized as a supplementary cementitious material to partially replace conventional cement in concrete at varying ratio from 5% to 25%. The strength properties of the CPA concrete cured for 7 days to 180 days is determined in terms of compressive strength, flexural strength, porosity, durability, slump, water absorption and shrinkage from the results summary 10% to 15% produced the optimal results for the response parameters.

In this research, the characterization of cassava peel ash which is a solid waste derivative to substitute cement in concrete partially at varying ratios from 0-40% in terms of setting time, workability, flexural strength, compressive strength and pozzolanic activity index; the strength development of the concrete is also evaluated. This investigation will add to existing knowledge on concrete mixture using pozzolanic materials. The expected gains from this study will provide good decision making on grade and batching of concrete mixed with supplementary cementitious materials (SCM) required for sustainable construction works based on intended use (ONyelowe, et al., 2019).

Cassava peel (CP) is a by-product of cassava processing, either for domestic consumption or industrial uses. Adesanya et al., (2020) reported that cassava peel constitutes between 20-35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, about 8.7 million tonnes of cassava peel is generated annually and 26 million tonnes is expected to be produced in the year 2025. Indiscriminate disposal of cassava peels due to gross underutilization as well as lack of appropriate technology to recycle them is a major challenge, which results in environmental problem. Thus, there is need to search for alternative methods to recycle them (cassava peels). Salau and Olonade (2020) studied the pozzolanic potential of Cassava Peel Ash (CPA) and their results showed that cassava peel ash possesses pozzolanic reactivity when it is calcined at 700^{o}C for 90 minutes. At these conditions, CPA contained more than 70 percent of combined silica, alumina and ferric oxide. Thus, the aim of this paper is to find out the workability, flexural strength, compressive strength, setting time, pozzolanic activity index of concrete with Cassava Peel Ash (CPA) used as partial substitute for cement.

Cement Compound

Portland cement is made up of four main compounds:

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i. Tricalcium silicate ($3CaO\ SiO_2$)
ii. Decalcium silicate ($2CaO\ SiO_2$)
iii. Tricalcium aluminate ($3CaO\ Al_2O_3$) and a
iv. Tetra-calcium aluminoferrite ($4CaO\ Al_2O_3Fe_2O_3$)

In an abbreviated notation differing from the normal atomic symbols, these compounds are designated as C_3S, C_2S, C_3A, and C_4AF, where C stands for calcium oxide (lime), S for silica, A for alumina, and F for iron oxide. Small amounts of uncombined lime and magnesia also are present, along with alkalis and minor amounts of other elements.

Properties of Cement-Physical and Chemical

Cement, a popular binding material, is a very important civil engineering material. This article concerns the physical and chemical properties of cement, as well as the methods to test cement properties.

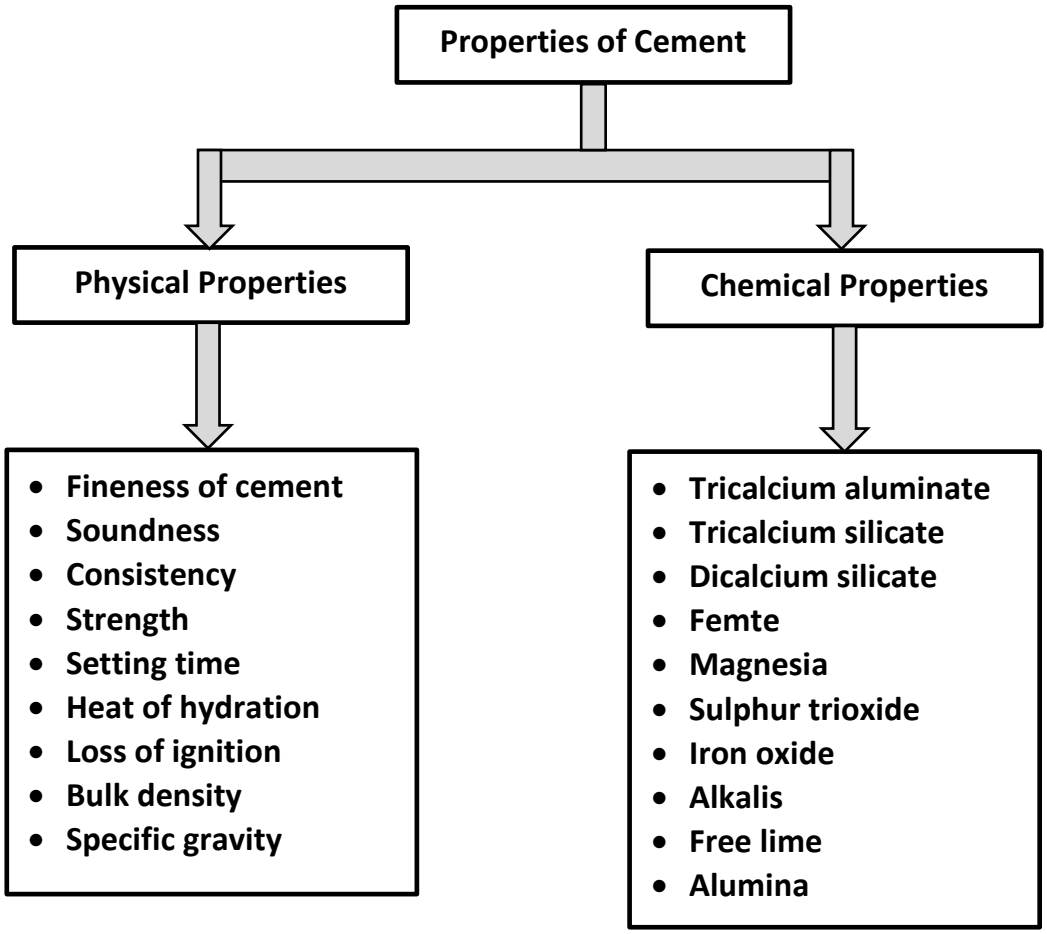


Figure 1: Properties of Cement

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METHODOLOGY

The materials that will be use for the study are:

i. Cement
ii. Fine aggregate (sand)
iii. Coarse aggregate (gravel)
iv. Water
v. Super plasticizer
vi. Cassava Peel Ash (CPA)

RESULTS

Test Mixture Proportion

The mix proportion of the mixture constituents comprising of cement, Cassava Peel Ash (CPA), water and aggregates (coarse and fine) is shown in Table 9 below.

Table 1: Mix proportion of the mixture constituent

Mixed	% replacement of cement	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	CPA (kg/m^3)	Water (kg)	Curing (days)
Mix - 1	0	290	766.35	1198.65	0.00	115	3,7,28,60, 90
Mix-2	5	275.5	766.35	1198.65	14.50	115	3,7,28,60, 90
Mix-3	10	261	766.35	1198.65	29.00	115	3,7,28,60, 90
Mix-4	20	232	766.35	1198.65	58.00	115	3,7,28,60, 90
Mix-5	30	203	766.35	1198.65	87.00	115	3,7,28,60, 90
Mix-6	40	174	766.35	1198.65	115.00	115	3,7,28,60, 90

Physical Properties of Constituents' Aggregates

The aggregates sieve analysis graph presents the particle size distribution of the fine and coarse aggregates used in the concrete mixture, From the results, 94.2 % and 1.2 % is passing sieve size 2mm and 75µm respectively for the fine aggregate and 97.66 % and 11.41 % passing sieve size 12.7mm and 2mm respectively for coarse

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aggregate, For the cassava peel ash CPA, 75.45 % and 35.18 % are passing sieve size 0.15 mm and 75µm respectively. The semi-log graph is shown in Table 10 and Fig. 4 below.

Table 2: Particle size distribution of the fine and coarse aggregate and CPA

	Sieve sizes	% passing
Fine aggregate	2mm 75µm	94.2 1.2
Coarse aggregate	12.7mm 2mm	97.66 11.41
CPA	0.15mm 75µm	95.45 35.18

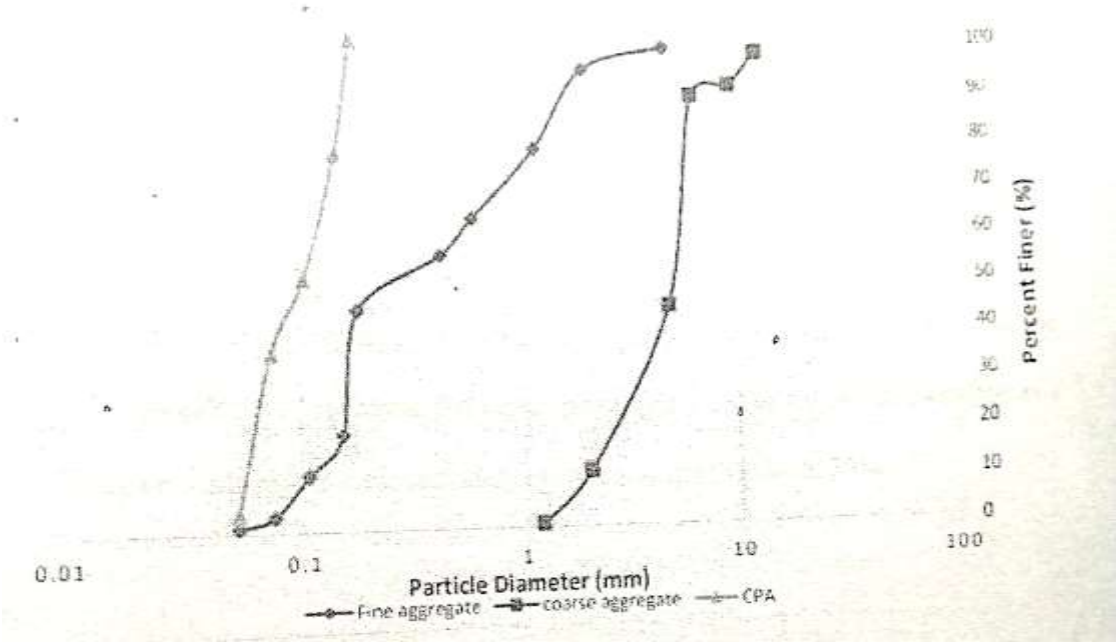


Fig. 1: Grain size distribution of test aggregates

Fineness Modulus (FM)

Fineness modulus of the aggregates used which is the index number that represents the mean size of the aggregate particles gotten after performing sieve analysis with standard sieves obtained from the sieve analysis graph. The cumulative weight retained divided by 100 gives us the fineness modulus computed from the table 11 below; the smaller the value of FM, the finer the

aggregates and vice versa. FM values ranging from 2.0 to 4.0 can be classified as a fine aggregate while higher value indicates coarse aggregates (Vashisth, 2018).

Table 3: Fineness Module (FM)

Sieve size	Weight retained (g)	% weight retained	Cumulative % retained	Cumulative % finer	Fineness modulus
4.75	12.3	1.23	1.23	98.77	
2.36	45.7	4.57	5.80	94.20	
1.18	161.8	16.18	21.98	78.02	
0.6	187.8	18.78	40.76	59.24	3.18
0.425	191.2	19.12	59.88	40.12	
0.15	300	30.00	89.88	10.12	
0.075	89.2	8.92	98.80	1.20	
	994	99.40	318.33		

Chemical Composition of Cement and CPA

The chemical composition results of Cassava Peel Ash and test cement are presented in Tables 12—13. From the result presents that the Cassava Peel Ash has a combined ratio of $A1_2O_3$ + SiO_2 + Fe_2O_3 totalled 81.83 % which is more than 70 % and that shows a good pozzolanic material according to the requirements of ASTM C618 (1991). The Cassava Peel Ash contains by percentage; 55.93, 19.88, 9.85 and 6.02 for SiO_2, $A1_2O_3$, CaO and Fe_2O_3, respectively. The specific gravity and loss on ignition for the Cassava Peel Ash is 0.35 and 12.5 respectively. The Si02 and A1203 which is supplied by the Cassava Peel Ash reacts with cement hydration products Ca $(OH)_2$. The hydrated lime (Ca $(OH)_2$) will then react with SiO_2 and $A1_2O_3$ to develop a binding property which is made possible by a process known as pozzolanic reaction. Calcium alumino silicate hydrate is formed which is responsible for gain of strength in concrete. The surface area of the Cassava Peel Ash is 31 Og/m^2 (Salau et al., 2019; Ikponrnwosa and Olonade, 2020; Owolabi et al., 2021).

Table 4: Chemical Composition of the Test Samples

Oxidation composition	Percentage by weight (%)
MgO	3.2
Fe_2O_3	6.02

SiO_2	55.93
CaO	9.85
Al_2O_3	19.88
Na_2O_3	0.98
ZnO	1.4
MnO	1.55
Specific gravity	0.35
Loss of ignition	12.5
SO_4	Nil
CuO	Trace
TiO_2	Trace
CdO	Trace

Source: Mbadike et al., (2021).

Table 5: Chemical Analysis of Dangote cement

Oxidation composition	Percentage by weight (%)
K2O	0.46
MgO	1.25
Fe2O3	4.301
SiO2	53.2
CaO	11.52
Al2O3	21.4
Na2O	1.04
Specific gravity	3.1
Loss on ignition	6.78
Physical analysis of dangote cement	
Moisture content (%)	2.4
Specific gravity	3.15
Bulk density (g/cm^3)	2.95
Fineness Modulus	0.88
pH	8.8

Source: Mbadike et al., (2021).

Test on Fresh Concrete

Workability Test Result (Slump)

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The obtained workability property of the concrete matrix indicates that value of the slump test reduces with increase in the cassava peel ash content in the concrete mixture by requiring more water in order to make the mixture more workable. The high requirement of water is as a result of the presence of silica and increased surface area for the ash sample. This is because of silica-lime reaction require more water in addition to the water presented for the cement hydration reaction process (Salau et al., 2019). The obtained result is presented in table 14 and Figs. 5 for the concrete cubes respectively.

Table 6: Workability test (Slump)

% replaced	Curing age	Slump for concrete cubes (mm)
0%	3d	8.1
	7d	8.4
	28d	7.9
	60d	8.0
	90d	8.9
5%	3d	7.1
	7d	7.2
	28d	6.0
	60d	7.2
	90d	6.8
10%	3d	6.8
	7d	6.8
	28d	6.7
	60d	7.0
	90d	6.5
20%	3d	5.3
	7d	5.0
	28d	4.9
	60d	5.2
	90d	4.9
300%	3d	4.1
	7d	4.3
	28d	4.0
	60d	4.3

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	90d	4.2
40%	3d	3.0
	7d	3.2
	28d	3.1
	60d	3.0
	90d	3.4

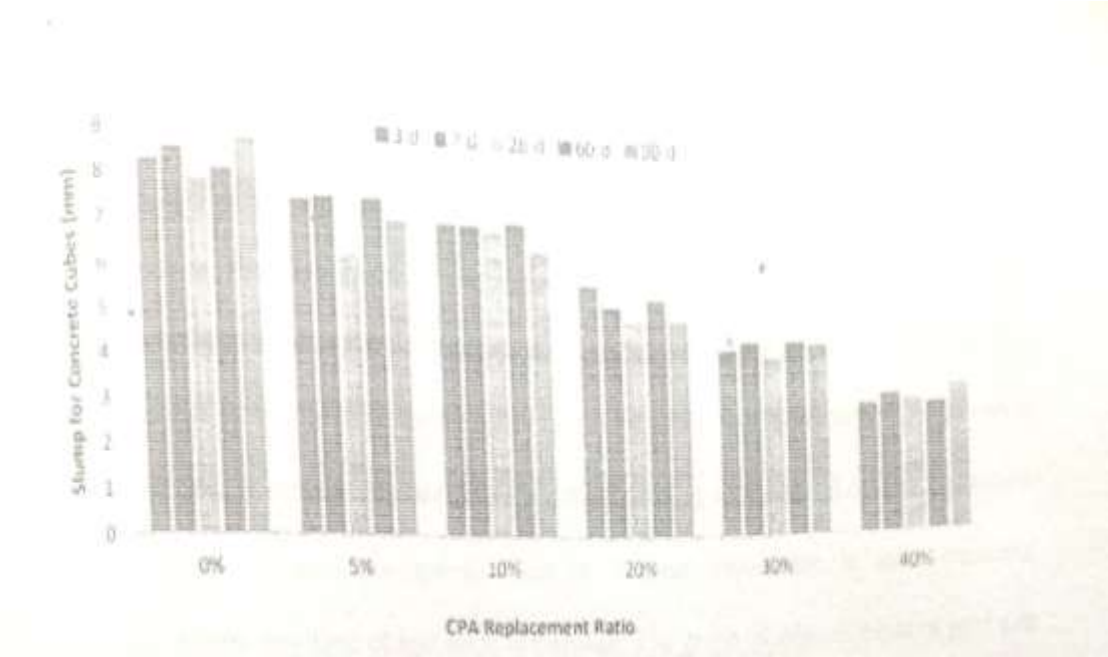


Fig. 2: Slump test result for cubes

Setting Time Results

From the obtained results, it was observed that the addition of CPA effected the increase of the initial setting time from 52 to 123 minutes; while that of final setting time also rose from 591 to 788 minutes from 0-40% respectively. This is because the addition of Cassava Peel Ash reduces the surface area of the cement paste to be added in the mixture. This causes a slowdown in the hydration process causing setting time to increase. The slow hydration means low rate of heat development. This is of great importance in mass concrete construction where low heat of hydration is required. The graph of cement/cassava peel ash paste setting time versus % replacement is presented in Table 15 and Fig. 6. The result shows that the increase in cassava peel ash content leads to increase in both initial and final setting time of the cement-CPA paste (Ogbonna et al., 2020).

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Table 7: Initial and final setting time result

% Replaced	Initial setting time (Min)	Final setting time (Min)
0%	52	591
5%	52	595
10%	98	645
20%	99	689
30%	110	700
40%	123	788

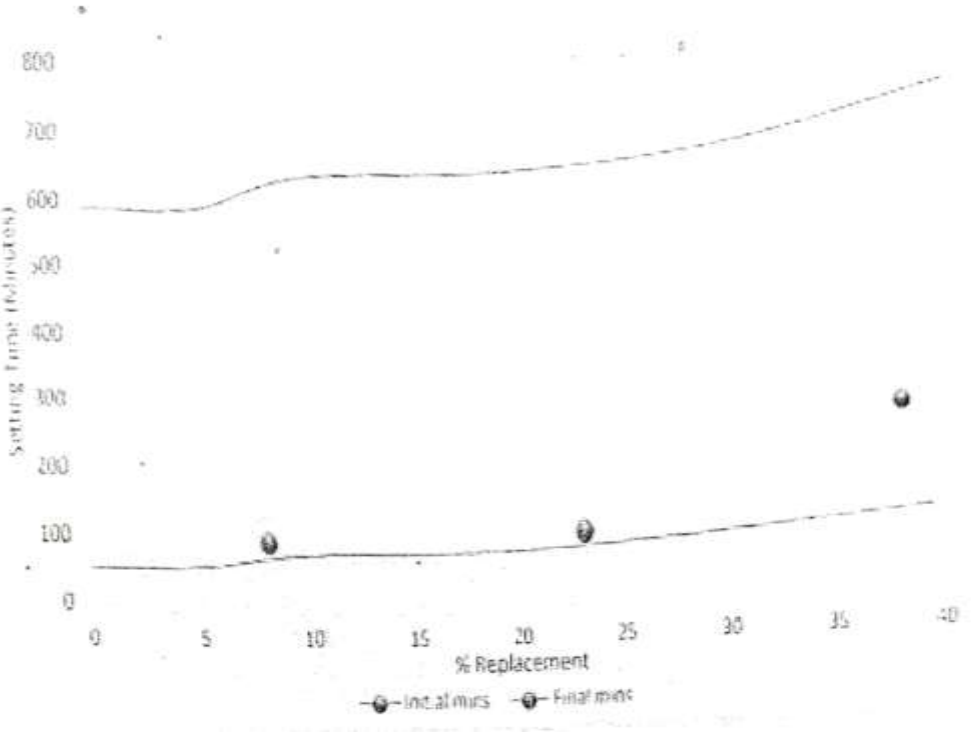


Fig. 3: Setting time versus % replacement of CPA

Mechanical Property of the Hardened Concrete

The concrete's compressive strength with respect to the different hydration periods and ratio of cement replacement by CPA indicates that the compressive strength results for the CPA- cement blended concrete mixture is relatively low at early hydration period but the strength development improves rapidly with longer curing period. However, the strength decreases with higher ratio of CPA in the concrete mix. Similarly, the concrete's flexural strength is minimum at early period of hydration while the strength improves rapidly with prolonged curing period, while the result also decreases with higher ratio of CPA in the concrete mix.

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Compressive and Flexural Strength vs Concrete Hydration Period

The graph of average compressive and flexural strength of concrete versus hydration period of concrete were presented in Table 16-17 and Figs. 7-8. The plotted results showed that the compressive and flexural strength value obtained for the control samples (0% replacement) were very low and minimum at 40% replacement for the earlier period of hydration of the concrete (i.e., 3 -7 days). At moderate period of hydration (i.e., 28 days), relative increase in the strength properties were recorded for the unblended groups with the blended samples having slight increment in strength behaviour. However, at longer curing periods (i.e., 60 - 90 days), there is also relative increase in the strength values obtained for the control samples while the blended mixture showed significant rise in strength properties which represents the Commencement and effects of pozzolanic action due to the reaction of the CPA with the calcium hydroxide liberated during hydration of cement. Moreover, the strength gain can be attributed to the cementitious products formed as a result of hydration of cement and those formed when lime reacts with the pozzolan incorporated which happens at longer period of hydration of the concrete samples (Lai and Sera, 1997; Alaneme et al., 2020).

Table 8: Compressive strength vs Hydration period to % replaced

% replaced	Hydration period (days)	Compressive strength (N/mm^2)
0%	3d	14
	7d	23
	28d	27
	60d	32
	90d	34
5%	3d	13
	7d	19
	28d	27
	60d	31
	90d	33
10%	3d	10
	7d	16
	28d	25
	60d	29
	90d	30

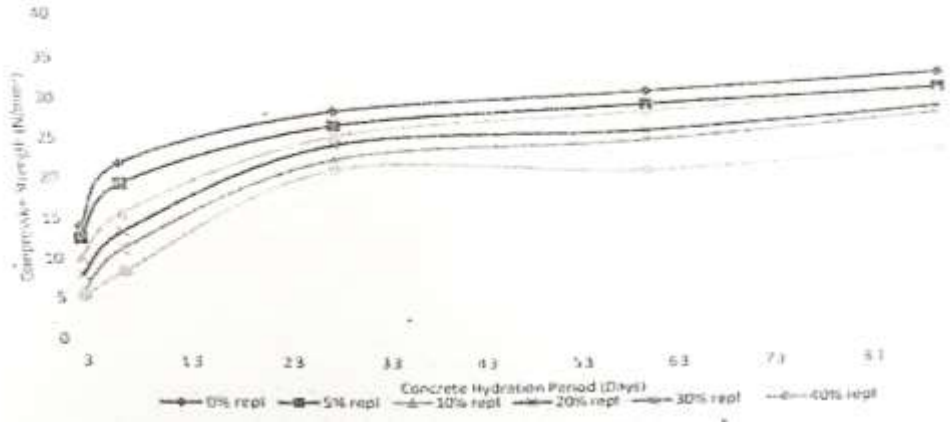
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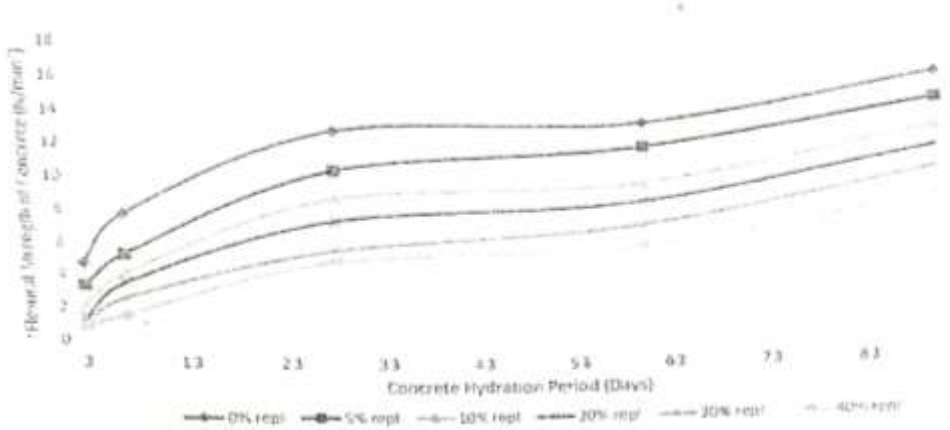
20%	3d	7
	7d	14
	28d	24
	60d	27
	90d	29
300%	3d	5
	7d	13
	28d	23
	60d	26
	90d	29
40%	3d	5
	7d	7
	28d	20
	60d	19
	90d	20

Table 9: Flexural strength vs Hydration period to % replaced

% replaced	Hydration period (days)	Flexural strength (N/mm^2)
0%	3d	5
	7d	7
	28d	13
	60d	13
	90d	17
5%	3d	3
	7d	5
	28d	9
	60d	12
	90d	14
10%	3d	2
	7d	4
	28d	8
	60d	9
	90d	12
20%	3d	1
	7d	5

	28d	7
	60d	8
	90d	11
300%	3d	1
	7d	3
	28d	5
	60d	6
	90d	9
40%	3d	1
	7d	2
	28d	4
	60d	5
	90d	7





Pozzolanic Activity Index (PAI)

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For the evaluation of pozzolanic activity of the CPA with cement, ASTM standard C618-78 prescribed the measurement of a pozzolanic activity index. This is established by the determination of strength of mixtures with a specific replacement of cement with pozzolana PAI.

$$\frac{\text{Crushing Strength of 35\% repl. of cement with Cassava Peel Ash at 28 days}}{\text{Crushing Strength at 28 days for the control test}} = \frac{20.22}{29.33} \times 100 = 75.8\%$$

Pozzolanic activity index is approved as a direct parameter for assessing pozzolanic activity of pozzolan. The pozzolanic activity index score of 75.8% meet the requirements of ASTM C618-00 Standard Specification. Therefore, the CPA is mechanically suitable for use as pozzolan in cement-based composite (Price et al., 2019).

Statistical Analysis and Validation of results

Correlation Analysis

The statistical analysis was carried out using Minitab 18 Software, to assess the relationship strength between quantitative variables. To achieve this, the control mixture was compared with the mixture replaced partially by varying ratios of CPA ranging from 5% to 40% so as to obtain the relationship between these results and determine statistically the mix ratio whose performance is closely associated with that of the control mixture. The correlation result with respect to the compressive and flexural strength is presented in the Table 18 below.

Table 10: Correlation analysis result

Compressive strength result	0% repl	5% repl	10% repl	20% repl	30% repl	35% repl	40% repl
0% repl	1						
5% repl	0.998838	1					
10% repl	0.992269	0.996988	1				
20% repl	0.989473	0.994601	0.998559	1			
30% repl	0.979094	0.994404	0.999043	0.999607	1		
35% repl	0.987102	0.990632	0.993797	0.989628	0.992967	1	
40% repl	0.967866	0.976693	0.986412	0.99304	0.99102	0.969559	1
Flexural strength results							
	0% repl	**5% repl**	**10% repl**	**20% repl**	**30% repl**	**35% repl**	**40% repl**
0% repl	1						
5% repl	0.994248	1					
10% repl	0.994008	0.99796	1				

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20% repl	0.992173	0.9961	0.998928	1			
30% repl	0.97395	0.986435	0.991464	0.994622	1		
35% repl	0.974731	0.987999	0.991618	0.99479	0.999734	1	
40% repl	0.975946	0.98929	0.993896	0.9932	0.996331	0.995682	1

The result shows a consistent and slight decrease in the correlation value from 0,9988 for 5 % to 0.9678 for 40 %replacement of the cement by CPA for the compressive strength while for the flexural strength, 0.9942 was obtained for 5 % and the correlation value decreased consistently to 0.97594 for 40 %replacement of the cement by CPA, From the results, it is observed that concrete with 5 %replacement of the cement by CPA performed better than the rest and thus the optimum combination level is between 5 % to 10 %replacement of the cement by CPA (Alaneme et al., 2020).

CONCLUSION

This research work investigated the effect of incorporation of Cassava Peel Ash (CPA) in cement paste and concrete which studies workability, flexural strength, compressive strength, setting time, pozzolanic activity index (PAI) of concrete with Cassava Peel Asha (CPA) used as partial substitute for Ordinary Portland cement (OPC) ranging from 0 – 40% of the partial replacement. The strength development of concrete is also evaluated. The investigation also adds to existing knowledge on concrete mixture using pozzolanic material.

RECOMMENDATION

This study demonstrate how the use of appropriate technology can transform abundantly available, cheap agricultural waste which could be potential environmental hazards into a natural resource and hence, can be used in the construction.

Based on the research work carried out, the following recommendation were drawn:

- ✓ The general physical behavior of the concrete aggregates sieve analysis, fineness modulus and specific gravity was obtained to assess the gradation parameters and from the chemical analysis of the CPA samples, the total sum of Fe_2O_3, SiO_2, and Al_2O_3 is greater 70% which indicates a good pozzolanic material.
- ✓ The slump test carried out to assess the impact of cassava peel ash replacement ratio on the workability of the concrete. The results indicate that there is an indirect proportionality between the slump value and the replacement ratio.
- ✓ The setting time results shows that the addition of CPA increases the initial and final setting time of the partially replaced cement paste.
- ✓ The compressive strength was carried out for varying hydration periods to investigate the effect of CPA on early strength gain in concrete at prescribed replacement levels by cassava peel ash. It was observed that CPA concrete's strength is minimum at early stage but grows with longer hydration period.

However, the concrete's compressive strength diminishes when the replacement ratio is increased from 5-40%. Also the flexural strength result shows a better performance for the 5% replacement while the flexural strength reduces with increased replacement ratio as observed in the compressive strength test results. This property also decreases with increased level of CPA content.

- ✓ The pozzolanic activity index which is a direct parameter for assessing the pozzolanic activity of pozzolan is adapted in this study in accordance with ASTM standard C618-78%; and an index score of 75.8% indicates satisfactory pozzolanic activity performance for cassava peel ash sample.
- ✓ The statistical analysis results show a consistent decrease in the correlation value from 0.9988 – 0.9678 and 0.97594 – 0.9942 for 5-40% replacement of the cement by CPA for the compressive and flexural strength responses respectively.

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