Journal of Engineering, Science, and Technology
ISSN: 2714-2396 | Volume 6, Issue 1

INFLUENCE OF OPC:PS:CS TERNARY BLEND ON SOME ENGINEERING PROPERTIES OF CONCRETE

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ABSTRACT
In order to reduce the carbon footing of the cement industry in concrete production, this research investigated the possibility of using a ternary blended cement composed of ordinary portland cement, palm kernel shell ash and coconut shell ash in concrete. The experimental procedure involves employing a mix ratio of 1:2:4 at constant water to binder ratio of 0.63 in casting ternary concrete cubes with varying OPC: PS: CS ash ratios of 100:0:0, 97.5:1.25:1.25, 95:2.5:2.5, 92.5:3.25:3.25, 90:5:5 and 85:7.5:7.5 under research laboratory conditions. Test results show that the workability of the fresh ternary blended concrete diminishes with increase in percent substituted pozzolanic ash using the slump test. At day 7, all the pozzolana containing concrete cubes exhibited early strength compared to the regular concrete, while at 28 days, all the PS: CS ash partly supplemented concrete displayed inferior compressive strength in comparison to the regular concrete. The 2.5% to 10% ternary blended concrete cubes yielded an average of 19. 67N/mm^2 compressive strength which is very close to the target compressive strength of 20N/mm^2, hence 10% is the optimal in producing light weight concrete. Chemical, other mechanical and durability studies are recommended for sustainable green concrete production.

Key words: OPC: PS: CS, Ternary Blend, SCC, Percent substitution

1. INTRODUCTION

For decades, the quest for the innovation of suitable cementitious resources to partially or even totally replace the conventional cement rages on, by both the Civil/Structural as well as the material engineers in order to principally reduce its carbon footing. Agricultural waste(Rice husk ash, corn cob ash and others), industrial waste (Fly ash, ground granulated blast furnace slag, silica fume etc.), and urban waste (cast-off concrete, glass, rubber tyres, plastics, papers and other recovered materials) have been used world-wide as Supplementary Cementitious Constituent (SCC) in the greening of concrete Liew, Sajobi & Zhang [1].

Several investigations have been carried out the world over, through the years in other to find out the possibility of the use of supplementary materials partially or wholly in place of cement in concrete, mortar and sand-crete block making.Binary, ternary and quaternary cements have been introduced as the binder structure in concrete production to reduce the use of Portland cement, improve, modify and balance workability, durability, strength and economy, Yurdakul, Taylor, Ceylan, & Bektas [2]. Due to the economic implications of using sophisticated industrial SCC, the most generally and freely accessible material used in the least developed part of the world, is the agricultural based SCC, Akhionbare [3]. The SCC is otherwise known as pozzolanic material. According to Neville [4], the merits of the use of pozzolanas in conjunction with Ordinary Portland Cement (OPC) include: improvement in workability, water retention, sulphate resistance, alkali aggregate resistance; decrease in bleeding; release of low heat of hydration and superior lasting strength in addition to economy. Protection or conservation of the environment is one other merit that cannot be over emphasized.

Blended Concrete denotesthe part substitution of cement (usually OPC) with one or more pozzolans in concrete production.According to Hameed & Aleyas [5], a ternary blended concrete is developed when dual supplementary cementitious materials are used as part substitution of cement in concrete while a binary blended concrete is composed of a mono-supplementary cementitious material and other concrete constituents. Agreeing with Blezynski, Hooton, Thomas & Rogers [6], huge quantities of mono-SCC (binary blends) may be detrimental to concrete, e.g. protracted setting time and others, depending on the chemical properties of the SCC employed and other variables. In researches where more than two combinations of pozzolanas are blended, the type is called quaternary concrete [7] [8] & [9].

Reviewing some of the researches on binary and ternary concrete, it was documented that:
According to a research carried out by Oyedepo, Olantori & Akande [10], to determine the performance of coconut shell ash and palm kernel shell ash as partial replacement for cement in binary concrete. Their results showed that 20% part substitution of the individual ashes led to a compressive strength suitable for lightweight concrete. However, the highest compressive strength is obtained from the coconut shell ash at 10% replacement. Investigations conducted by Adeala, Olaoye &Adeniji [11], on the effect of coconut shell ash on fresh and hardened concrete properties which include: workability, water absorption and compressive strength, results showed that concrete containing 10% of coconut shell ash has the least water absorption rate, increase in the percent substitution of the ash in the mix led to a stiffer mix (decrease in workability). XRF analysis indicated that the coconut shell ash belongs to class F pozzolanic group. 5-15% part replacement of coconut shell ash with OPC was recommended for average weight production of concrete. In undertaking an experimental program to determine the effect of water-to-binder ratio, air content, and type of cementitious materials on fresh and hardened properties of binary and ternary blended concrete, Yurdakul *et. al* [2] found out that ternary blends trailed the developments of their individual materials. Binary and ternary mixtures containing Class C fly ash and slag cement exhibited higher compressive strength than the regular mixture.

The surface resistivity and shrinkage outcomes of binary and ternary mixtures were equal to or better than the regular combination. They recommended additional tests on other mechanical and durability properties of the different blends. Ghrici, Kenas & Said-mansour [12], investigated the effect of combining silica fume on the mechanical properties and durability of cements containing natural pozzolana, test results confirm that the use of ternary cements contributes to the enhancement of strength at an initial phase. Improved resistance to sulphate and acid attacks and low chloride ions permeation likewise enhanced durability. Obute *et. al.*[9], studied, a ternary mixture of OPC, Cassava Peel Ash (CPA), and Rice Husk Ash (RHA) which were used as the cement in concrete production. The concrete mix was prepared to set CPA at 5% for all combinations while the RHA was replaced at 0 to 25% of the total blend. With a 0.65 water/binder ratio, an optimal strength was attained at 20% substitution of CPA (5%) and RHA (15%).

The part substitution of cement with CPA – RHA in concrete also clearly influencedthe concrete's water absorption characteristics. Summarizing the experimental investigations on Strength characteristics of concrete containing fly ash and micro silicaternary blends in the last decade, Harishav, Mukesh & Sohit [13], stated that most of the studies were of the view that the materials (fly ash and micro silica) are thoroughly safe for use in any environment and they complement each other in blends. Saleh *et. al.*[14], reported the laboratory study to establish the prospect of using Palm Oil Fuel Ash (POFA) and Rice Husk (RH) in developing green unfired bricks where 2% - 10% of POFA and 1% - 5% RH were used in brick production. Addition of POFA was intended to lessen the cement usage and RH was meant to be part substitution of sand in the blend. Their result showed that adding POFA and RH led to the reduction of the density of the bricks while the compressive strength also decreases in comparison to the conventional brick.

It can be concluded from the literature above that numerous researches involving binary and ternary blends had been performed experimentally in order to determine some mechanical and durability properties of concrete, which revealed that the ternary blends are superior to the dual combinations.

One of the Author's in this research reported a study on the use of binary blends of palm oil husk ash and coconut shell ash, with cement individually in green concrete production, where Danjuma & Amamat [15] found out that their binary blend of palm oil husk ash indicated a compressive strength close to that of their regular concrete at 28 days while the coconut shell ash blend did not measure up. Hence, the idea of a ternary blend was born. Envisaging the possibility of a synergistic combination where the ternary mixture/blend properties will be superior to that of the binary blend. It is hoped that this will minimize the demerit of any of the individual constituents and in the same vein maximize their collective strengths.

The focus of this research is to determine the effect of a ternary blended cement comprising Ordinary Portland Cement, Palm-kernel Shell ash and Coconut Shell ash(OPC: PS: CS) used at various levels of substitution of the components,on the workability and compressive strength of concrete and suggest an optimum amount of the ternary cement to be used for concrete production

2. MATERIALS AND METHODS

2.1 MATERIALS

The materials used for this experimental work are: Cement, Palm kernel shell ash, coco nut shell ash, Sand, gravel, and water; with the deliberate exclusion of an admixture, hence, a fairly high water binder ratio of 0.63 was adopted to make the mix suitably workable.

Cement

In this study, the Ordinary Portland Cement (OPC) type 1(42.5N), produced by Dangote Cement Limited, Obajana, being one of the Nigeria largest cement producer and as such easily accessible in almost every part of Nigeria was used for all the mixes required. This cement conforms to the requirements of the British Standard Code, [16]. To prevent the cement from being exposed to moisture and hardened before usage, it was kept in air tight packages and stored inside the laboratory store.

Palm-kernel Shell ash (PS ash)

The palm kernel shell burnt to ash in this research work was obtained from Zaria city, Zaria Local Government Area of Kaduna State, Nigeria. Though Zaria does not locally grow palm fruits, but the oil, fruits and kernels are in abundance because it is a metropolitan area that enjoys trade between the northern and southern part of Nigeria. The ash was sieved using sieve number 200 (75µm) in order to make sure it is of suitable uniformity and only ash particles that pass through sieve was used in the concrete preparation.

Coconut Shell ash (CS ash)

The coconut shells were obtained from a coconut seller in Zaria metropolitan area, Zaria local Government Area of Kaduna state. It was sun dried for 4 days, in order to reduce its moisture to the barest minimum and burned thoroughly in open air. The dust retrieved from the burning was sieved using sieve number 200 (75µm) and then collected for use.

The palm kernel shell ash (PS ash) and coconut shell ash (CS ash) were then blended in equal proportion (i.e. in same ratio 1:1) to produce the PS: CS ash used in the study.

Journal of Engineering, Science, and Technology
ISSN: 2714-2396 | Volume 6, Issue 1

Fine aggregates, coarse aggregates and water

The Fine Aggregate used was sourced from Gobirawa community in Zaria, Kaduna state, Nigeria. It was thoroughly washed with water to reduce the level of impurities and organic matter, and later sun dried. The fine aggregates (sharp sand) particle sizes ranges from 0.10mm-6.0mm in diameter which conforms to the requirements of BS 1881-108 [17]. The gravel was obtained from Danmagaji along Kano-Kaduna express-way, Zaria, Kaduna state Nigeria having a maximum size of 20mm which also conforms to [17]. The water used for the study was obtained from a borehole close to the material's laboratory of School of Engineering, Nuhu Bamalli Polytechnic, and Zaria. The water was clean and free from any visible impurities. It suitability was based on BS 882 [18] requirements.

2.2 METHODS

The various tests carried on the materials used for the experiment are: sieve analysis for fine aggregate and pozzolanes (ash), aggregate impact value test, aggregate crushing value test., cement soundness, Initial and final setting time of cement and ash mixture, etc.

Mix proportions

The total amount of materials needed for each mix was determined in accordance to BS 3148:1993 [19] by the assumption of light weight concrete of density 2000kg/m^3. For the purpose of this study, a concrete cube of 150 x 150 x 150mm was produced under laboratory condition. The mix ratio used was 1:2:4 (one-part cement to two parts of sand to four part of coarse aggregate) at constant water cement ratio of 0.63. The ternary concrete was casted using varying OPC: PS: CS ash ratios of 100:0:0, 97.5:1.25:1.25, 95:2.5:2.5, 92.5:3.25:3.25, 90:5:5 and 85:7.5:7.5 respectively, i.e. 8 cubes for each percent substitution. The 100: 0: 0 served as the regular (control) sample for the study. To prevent deficiency due to waste, compaction and bulking of aggregates, 10% was permitted on the materials. The concrete materials used for each batch of eight cubes is as shown in Table 1.

Table 1: Concrete Materials for Production of a Batch of Eight Cubes

Concrete Materials (Kg)	PS:CS 0%	PS:CS 2.5%	PS:CS 5%	PS:CS 7.5%	PS:CS 10%	PS:CS 15%
Cement	9.60	9.36	9.12	8.88	8.64	8.16
PS:CS ash	0.00	0.24	0.48	0.72	0.96	1.44
Fine Aggregate	18.60	18.60	18.60	18.60	18.60	18.60
CoarseAggregate	38.00	38.00	38.00	38.00	38.00	38.00
Water	5.96	5.96	5.96	5.96	5.96	5.96
Water/Binder	0.63	0.63	0.63	0.63	0.63	0.63

Mixing process

Hand mixing was adopted in producing the samples as it is possible to make concrete on a small scale without a concrete mixer. Hand mixing may be advantageous when considering that the amount of concrete required is not much though it may limit production and not always be thorough.The blendingfor each batch was done on the floor. All the materials were weighed precisely prior to blending. The surface of the floor was moistened before putting the materials to minimize water losses through the floor. Fine aggregate, coarse aggregate, PS: CS ash and cement were placed on the floor accordingly and mixed well with a shovel before water was poured and mixed thoroughly. Slump test was then undertaken on the fresh mix in order to determine the workability of the concrete. Workability is one of the primary characteristics of any concrete material; for practical purposes, it largely indicates the ease with which a blended concrete can be controlled from the mixer to its final compacted form. Its main characteristics are consistency, mobility and compact-ability. The slump test is widely used due to its simplicity amongst others, to determine workability; its values depends to a large extent on the concrete constituent materials. In the absence of admixtures, such as super-plasticizers, pozzolanic cement blends demands high water to binder ratio for their concretes to be reasonable workable.

Production of Concrete and Curing

48 moulds of (150 x 150 x 150) mm were used in concord with BS 8500 [20]. They were lubricated with engine oil in order to reduce friction and enhance removal of cubes from the moulds. They were then filled with concrete in three layers and each layer was tamped 25 times. The moulds containing the cubes were left for 24 hours under the laboratory temperature for the cubes to set before removing the moulds. Plate I shows the process of concrete production. The cubes were removed after 24 hours and were taken to curing tank were they were totally immersed in water as shown in Plate II

Plate I: Concrete Production

Plate II: Curing

The most important engineering property of concrete is its compressive strength. It is the maximum compressive load it can sustain for each unit area, in concrete constructions. It is generally affected by type of cement, mix proportions, modes of compaction and curing circumstances.

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ISSN: 2714-2396 | Volume 6, Issue 1

The compressive tests of the hardened, cured concrete cubes were undertaken in accordance to [21] as captured in Plate III

Plate III: Compression Testing Machine

3. RESULTS AND DISCUSSION

The pattern of variation of the slump value of the concrete blends with part substitution of ashes is as shown in Figure 1, it can be seen that the workability of the concrete with the part substitution of cement decreases with increase in percent substitution. According to Neville [4], any slump value ranging from 15 to 30 is low, so all the slumps are very low also BS 12390-3 [22] classifies all the slump value between 10 and 40 as S1. This may be attributed to the larger porous particles of the PS:CS ash supplement as documented by [22] [23] & [24], hence, the mixes with such supplements due to higher specific surface, need more water to be workable.

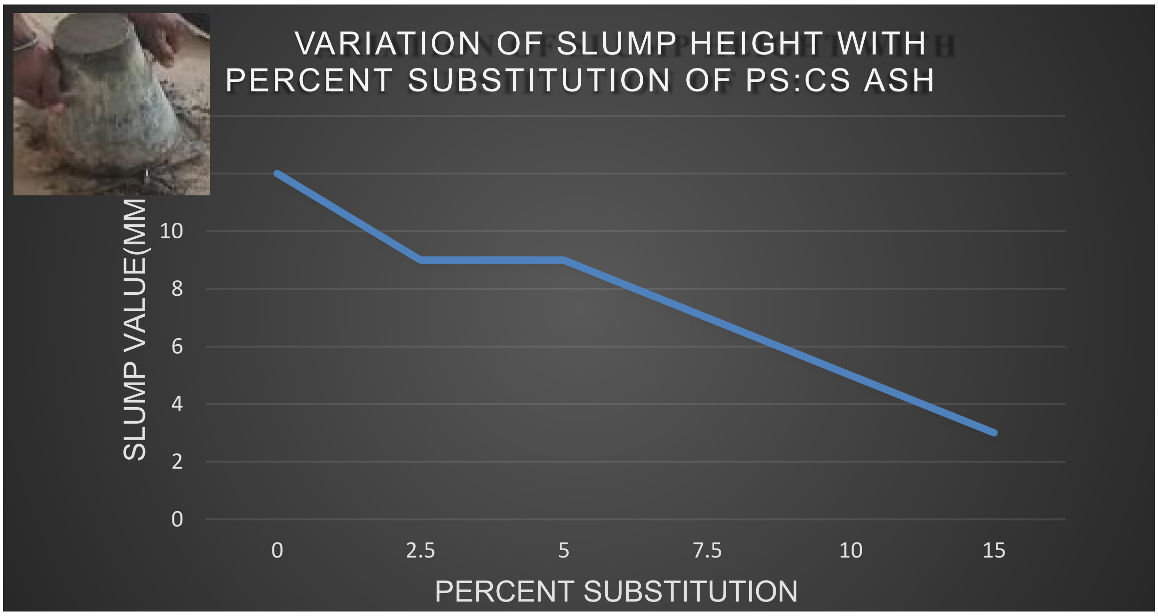

Figure 1: Variation of Slump Value with Percent Substitution in the OPC: PS: CS Concrete

The weight of each cured cube and the average compressive strength for all substitution is depicted in Table 2 and Figure 2

Journal of Engineering, Science, and Technology
ISSN: 2714-2396 | Volume 6, Issue 1

Table 2: Average weight and Compressive Strength at Curing ages

Percent Substitution (%)	Average Weight of each Cured Cube (Kg)				Average Compressive Strength (N/mm^2)			
	7days	14days	21days	28days	7days	14days	21days	28days
0	8.23	8.71	8.66	8.63	10.10	20.70	18.90	27.90
2.5	8.25	8.64	8.43	8.56	18.20	18.50	25.30	20.60
5	8.40	8.45	8.34	8.43	15.80	23.40	16.60	19.40
7.5	8.52	8.29	8.33	8.30	11.50	22.10	16.40	13.30
10	8.45	8.20	8.28	8.30	13.70	20.10	17.20	19.00
15	8.18	8.10	8.25	8.30	12.20	11.00	16.10	15.70

Generally, the pattern of compressive strength development is as shown in Figure 2. At day seven, all percentages of substitution showed significant early strength development than the regular (0% substitution) concrete. This has been the pattern with agricultural pozzolanic materials used in partial substitution and could be of advantage especially in structures where early strength development is required as recognized by Ogunwemimo, Salami & Familusi [25], this, they stated could be ascribed to the pozzzolana acting as void filler during hydration; thus, positively affecting the early age strength gained.

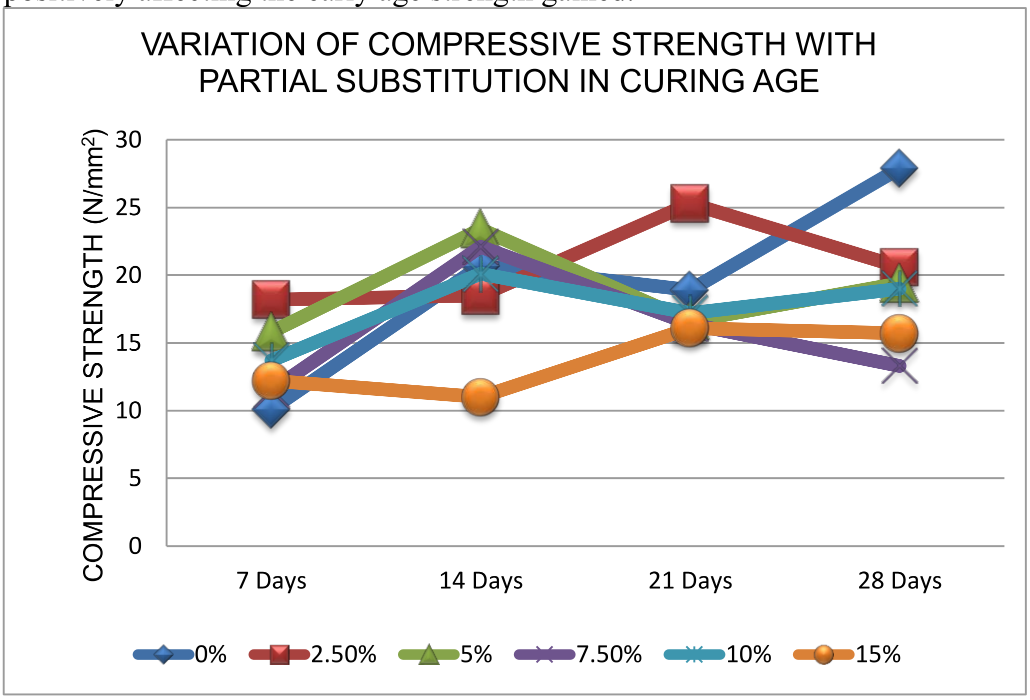

Figure 2: Variation of Compressive Strength with Curing ages at different PS: CS Part Substitution.

Also all percentages of substitution yielded an increase in strength at day fourteen with the exception of 15 per-cent substitution whose compressive strength dropped. At twenty-one days all substitutions saw a decrease in compressive strength, with the exception of 2.50per-cent and 15per-cent substitutions that increased. At 28days only the regular exceeded the targeted strength of $20N/mm^2$ with a compressive strength of $27.9N/mm^2$ while 2.5, 5, and 10 per-cent partial substitution followed closely with an average of $19.67N/mm^{2.}$ According to Danjuma & Amamat [15], the reduction in compressive strength of the part substituted concrete may be due to a low proportion of Calcium Oxide in the PS ash, and low calcium oxide and silicate oxide in CS ash, because the dual oxides are the main components of OPC cement and are principally answerable for its strength progression.

So, as the cement content is gradually substituted by the ash, the amount of cement for hydration is reduced, therefore, the strength of the concrete declines. This implies that PS: CS ash fractional replacement of a maximum of 10per-cent could be used as a SCC of cement in concrete successfully, especially lightweight concrete. The decrease in strength observed at 28 days should not be considered as a drawback in the use of pozzolanic blended cements as it has been documented by other researchers such as Olowe & Adebayo [24], that beyond 28 days, their strengths even exceeds those made from of the regular OPC cement.

The researchers attributed the strength gain to the continuation of cement hydration or the reaction of the pozzolana with lime or even the slowing of rate of hydration allowing the development of heavier hydrates of strength enhancing C_2S. Jonida *et. al*. [26], attributed the later age strength gain in pozzolanic concrete to the reaction of SiO_2 present in the pozzolana with free lime $Ca(OH)_2$ acquired through cement hydration in an additional reaction as time passes to form calcium silicate hydrate (C-S-H).

4. CONCLUSION AND RECOMMENDATIONS

The workability of the fresh ternary blended concrete decreases with increase in percent substituted pozzolanic ash.

At 7 days all the pozzolana containing concrete exhibited early strength compared to the regular Concrete

At 28 days, all the P S: CS ash partly replaced concrete displayed lower compressive strength in comparison to the regular concrete

The least amount of the ternary cement for usage in concrete is 2.5% while the optimum amount is 10%

More research and development in order to better understand the chemical and other mechanical properties of such ternary cements and their concretes should be undertaken. Such mechanical tests may include: tensile strength, corrosion and abrasion resilience; drying shrinkage, microstructure etc.

Longstanding studies on the development of strength as well as durability aspect of concrete containing ternary mixtures and other green concrete is necessary.

ACKNOWLEDGEMENT

The Authors do acknowledge the contribution of the Technologists of the Civil Engineering Materials Laboratory in carrying out the laboratory tests.

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