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Assessment of Calcium Carbide Waste Powder and Bamboo Leaf Ash Blended Cement Concrete as Sustainable Engineering Materials for Construction

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Abstract:- The high cost and environmental damage of cement has led researchers into searching for alternative binders that are friendly and contribute to waste management. This research is set out to investigate the use of the mix of an industrial waste, Calcium Carbide Waste (CCW) and an agricultural waste, Bamboo Leaf Ash (BLA) as incomplete replacement of Portland cement (OPC) in concrete, determine the compressive strength and the workability properties of the concrete. Oxide composition analysis of Calcium Carbide Waste Powder (CCWP) and Bamboo Leaf Ash (BLA) confirmed their status as non pozzolanic material rich in Calcium oxide (CaO) component and pozzolanic material rich in Silicon oxide (SiO_2), respectively using X-ray fluorescence spectrometer. The effect of Bamboo Leaf Ash (BLA) and Calcium Carbide Waste Powder (CCWP) on concrete was investigated for the replacement by addition of 5.0%, 10.0%, 15.0% and 20.0% respectively by weight of Portland cement to concrete at 7, 28 and 56 days as well as analyze the microstructural property at 28 days. The tests established CCWP and BLA as capable of successfully replacing cement in concrete production with added advantages in the properties in terms of chemical composition, strength and microstructural property.

Keywords:- *Admixtures, Chemical Composition, Production, Compressive Strength, Microstructure.*

I. INTRODUCTION

The feasibility of reusing waste products from industries or agricultural products in the construction industry is carried out to yield sustainable materials for construction. This could be done by looking for or inserting waste materials and products that are more sustainable towards the reduction of carbon dioxide (CO_2) emission into the environment [1].

Numerous studies trends in development of materials that focused on contributing alternatives demanded by the high cost of construction materials, and problems in getting funds for construction development, amongst several reasons. The alternatives to conventional materials include use of pozzolanas as replacements to ordinary Portland cement (OPC) or as mineral admixtures and use of other cementitious materials from farm wastes and by-products from industries as additives. In advanced countries, the demand for building and construction materials such as Portland cement and admixtures is high to meet the infrastructure needs of the country's residents [2].

Agricultural and industrial byproducts known as wastes materials in a technologically and infrastructurally underdeveloped communities can be used as replacements of ordinary Portland cement (OPC) to achieve this aim. Endless attempts have just been focused on such substitutes in producing composites of cement such as concrete, sandcrete etc. [3]. Partially replaced cement concrete is currently used in many parts of the world for concrete works [4]. When pozzolans are mixed with ordinary Portland cement (OPC), it chemically reacts with the lime to produce additional calcium-silicate-hydrate (C-S-H), which is one the main cementing compound required for cementing. Thus, the pozzolanic material reduces the quantity of lime and increases the quantity of C-S-H. Therefore, the cementing quality is enhanced if a pozzolan is blended in suitable quantity with ordinary Portland cement (OPC) [5].

According to [6], calcium carbide waste power (CCW) is a byproduct gotten from the acetylene gas (C_2H_2) production process as shown in Equation (1).

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \qquad (1)$$

Research findings have indicated that Calcium Carbide Waste, when it is blended with some pozzolanas containing high content of silicon dioxide (SiO_2), iron oxide (Fe_2O_3) and aluminum oxide (Al_2O_3) can due to pozzolanic activities yield final products that are similar or close to those derived from cement hydration [7]. More research are still being conducted on use of Calcium Carbide Waste in construction works.

$$CaO + SiO_2 + H_2O \rightarrow C{-}S{-}H \qquad (2)$$

(Calcium Carbide Waste Powder) + (Bamboo Leaf Ash) ⟶ Calcium Silicate Hydrate.

From Equation (2), it is observed that calcium carbide waste (CCW) contains some cement chemical composition. X-Ray Fluorescence (Chemical composition) Spectrometer is a non-destructive method of analyzing the elements and oxides composition of materials [8]. Compressive strength is a measure of the concrete's ability to resist coming load which tends to crush it. Compressive and tensile strength tests are the two major strength tests carried out on concrete for reliable. Strength normally gives an overall view of the quality of a concrete because it is directly related to the structure of the cement paste. Compressive strength of concrete specimen is a widely used test, to measure its strength [9]. This method was concurrently utilized in this research work to ultimately picture the features and interlocking behavior of these wastes in concrete for construction.

This research study is set out to investigate the use of the mix of an industrial waste, Calcium Carbide Waste Powder (CCWP) and an agricultural waste, Bamboo Leaf Ash (BLA) as a replacement of cement in concrete partially, determine the compressive strength and workability property of concrete containing BLA and CCWP. The usage of these two wastes in concrete may be a lesser substitute to conventional admixtures, which may lead to a reduction in the cost of construction. This will also be a way of addressing the environmental pollution caused with the accumulation of these wastes in landfill.

II. MATERIALS AND METHODOLOGY

Research materials used in this work were Calcium carbide waste powder (CCWP), Bamboo leaf ash (BLA), sand (fine aggregate), chipping (coarse aggregate), cement (Dangote type, 42.5 grade) and durable water as mixing agent and curing.

A. Sample Collection

Calcium carbide waste was collected from panel beaters' workshops within Akure metropolis, sun-dried, grinded and sieved through British sieve 0.075mm to produce the calcium carbide waste powder (CCWP) and Bamboo leafs was obtained from standing bamboo trees. The bamboo leafs was dried and burnt to a temperature of 600°C for 1hour to produce BLA.

B. Physical Analysis of Samples

Size distribution analysis on particles (with minimum sieves size 75µm) was done with the hygrometer test for the fine aggregate obtained, Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) tests were carried out on course aggregate. The size distribution curve for the fine aggregate was gotten.

➢ *Aggregate Crushing Value*

To determine the ACV for the course aggregate, the course aggregate was sieved through 12.5 mm BS sieve and got retained on 10 mm British Standard sieve. The coarse aggregate sample was dried in the oven at a temp. of 100-110°C for 3 hours and 30 minutes. The cylindrical mould was filled in three layers, each layer was tamped with 25 strokes of the tamping rod. The weight of the course aggregate was measured and recorded as X. The surface of the coarse aggregate was then levelled and the plunger inserted. The apparatus was then placed in the compression testing machine and loaded at a steady rate until the coarse aggregate sample fails. The sample was then sieved through a 2.36 mm BS sieve and the portion passing through the sieve was measured as Y. The ACV was calculated using Eq. 3.

$$\text{ACV}\ (\%) = \frac{\text{Y}}{\text{X}}\ \text{X}\ 100 \qquad (3)$$

➢ *Aggregates Impact Value*

The AIV was carried to know the impact value of coarse aggregates in accordance to [10] [11]. The coarse aggregate sample was oven-dried for about 360 minutes at a temp. of 100-110^{oC} and allowed to cool. The cylindrical mould was filled with the coarse aggregates in three layers and tamped with 25 strokes of the tamping rod at each filling. The total weight (kg) of the coarse aggregates was recorded as P. The cup of the impact testing machine was tightened firmly in position on the base of the machine and the whole of the test sample (coarse aggregate) were placed in it and compacted with 25 strokes of the tamping rod. The hammer was raised to about 0.385 m above the upper surface of the coarse aggregates-sample in the cup and allowed to fall freely onto the coarse aggregates. The test sample (coarse aggregate) underwent a total of 15 blows, each being done at an interval of not less than two second. The sample (crushed coarse aggregate) was collected and sieved through a 2.36 mm BS sieve. The fraction passing through was weighed (in kg) as Q. The ratio of the weight of the fines formed to the total sample was expressed as a percentage as shown in Eq. 4. The test was repeated and conducted three times, recorded and the mean value was gotten and calculated.

$$AIV\ (\%) = \frac{Q}{P}\ X\ 100 \qquad (4)$$

C. Chemical Analysis of Samples

Some Chemical analyses were done on CCWP and BLA to evaluate the chemical properties. The chemical analyses were conducted with X-ray-fluorescence (XRF) spectrometry (XRF machine-Model Xsupreme 8000 by Oxford instrument) and the various percentages of oxides present in the ash and powder were displayed on the screen. Moisture content (Mc), Soundness and Loss of Ignition (LOI) tests were also carried out on CCWP and BLA wastes.

➢ *X-ray Fluorescence Analysis*

A MiniPal 4 Energy dispersive X-ray fluorescence (XRF) bench-top spectrometer was used in carrying out the non-destructive chemical analyses of elemental oxides present in the two wastes that was used. The CCWP and BLA samples were put into the sample mould and placed in the appropriate tray. The analysis was done by bombarding the samples (CCWP and BLA) with very high energy X-rays which led into emission of secondary X-rays. By using silicon drift detector, the elemental analysis and oxide composition were determined and copied out via the connected computing device and printing accessories.

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➢ *Scanning Electron Microscopy Analysis*

During SEM analysis, the specimens in paste form (of about one-inch diameter) were arranged to fit into the specimen chamber and they were inserted rigidly on the specimen stub. The specimen outer surfaces were carbon-polished to a fine-smooth surface. Secondary electron detectors were used and the data were displaced by a computing component.

1. *Loss on Ignition (LOI) Analysis*

LOI was carried out by subjecting CCWP and BLA to a temp. between 850-1000ºC so as to obtain a constant weight. This test was done to determine the organic matter present in the two samples. The weight (g) of the each sample due to heating was then determined and recorded using Eq. 5.
Where; W_1= Weight of empty crucible (g), W_2= Initial Weight (g) of crucible and Sample before heating and W_3= Final weight (g) of crucible and sample after heating for 25 minutes and cooling for 20 minutes.

$$\text{Loss on Ignition (\%)} = \frac{W2-W3}{W2-W1} X\, 100 \qquad (5)$$

D. Physical and Chemical Tests on Concrete Specimens

The concrete cubes of 0.150 m x 0.150 m x 0.150 m were partially done by replacing OPC with CCWP, BLA and CCWP-BLA at 0%, 5%, 10%, 15% and 20% replacements. After, the caste concrete cubes were cured for 7, 28 and 56 days in water and then brought out to be used for compressive strength test in accordance to [12]. A concrete design ratio of 1:2:4 was used for the production of all the concrete cubes at water-cement ratio (c/w) of 0.60. Also, various cement paste with mix ratio 1:6 (cement : sand) of 0.050 m x 0.050 m x 0.050 m dimension were produced with the cement partially replaced with CCWP and BLA at 0%, CCWP10%, BLA10% and CCWP-BLA10%. Paste samples were cured in water for 28 days duration and then analysed using SEM.

E. Analyses of Variance (ANOVA) and Least Significant Different (LSD) Tests

The compressive strength values were compared using ANOVA and LSD as post hoc test. ANOVA is the table that shows the output of the ANOVA analysis and whether we have a statistically significant difference between our group means while LSD post hoc test shows which groups differed from each other.

III. RESULTS GOT AND DISCUSSIONS

The size distribution and the hygrometer test of sand (fine aggregate) is shown in Figure 1. This result showed that the sand was well graded. The results of ACV and AIV for coarse aggregate were 30.48% and 19.78% respectively as shown in table 1, which are adequate for concrete of good impact resistance. This means that aggregates of higher impact values are weaker than aggregates with lower AIV. Therefore, the coarse aggregate used in the study is averagely adequate to produce concrete of good impact resistance. Aggregate Impact Value also indicates the degree to which the aggregates absorb shock. The result obtained from aggregate impact value test conducted on the coarse aggregate used in this research shows that the aggregate is impact resistance according to [13] [14] as its average AIV is less than 25%. The result obtained from aggregate crushing value test conducted on the coarse aggregate (granite) used in this study shows that the average ACV of 30.48% falls almost within the standard of 25% to 30% as specified by [14] [15]. The recommended maximum ACV stipulated in [14] for aggregates for concrete production is 30%.

The chemical analysis of CCWP and BLA carried out using EDXRF is presented in Table 2. The result was compared with the standard specified and presented in Table 3. The chemical composition for these two wastes presented in Table 2 shows that BLA is pozzolanic material and CCWP is not; BLA satisfies the requirements specified by ASTM C618 (1999) while CCWP does not. BLA satisfies three of the requirements; it has 70.6% as the sum of the percentages of SiO_2 + Al_2O_3 + Fe_2O_3, no SO_3, and 5.33% loss on ignition. CCWP does not satisfy the requirements in Table 2, addition of Silicon dioxide (SiO_2) plus Aluminium Oxide (Al_2O_3) plus iron oxide (Fe_2O_3) is 9.29% which is less than 50% minimum requirement and loss on ignition of 16.62% are not all within the specified range for a pozzolan as presented in Table 3 [16] [17].

Also, if magnesium oxide (MgO) present in the samples is in excess of 4%, it would make the pozzolan or any other substitute to be unsound but was 1.18% in Bamboo Leaf Ash (BLA) which implies that it's far less than 4% and not detected in Calcium Carbide Waste Powder (CCWP), which implies that MgO could only be present in traceable quantity. The LOI of pozzolan (BLA) is less than the maximum permissible value of 10% as specified by ASTM. This shows that there is little unburnt carbon, which reduces the pozzolanic activity of bamboo leaf ash if present in a quantity greater than 10%.

The Effect of replacing OPC with CCWP, BLA and CCWP-BLA partially in the compressive strength values of concrete was investigated using at 0%, 5%, 10%, 15% and 20% replacements. The compressive strength values of concrete gotten for 7 days, 28 days and 56 days are plotted in Fig 2, 3 and 4 respectively. It can also be observed from the result that the compressive strength values increase with an increase in the percentage of replacement of BLA, CCWP and CCWP-BLA at 7, 28 and 56 days of curing with water. The maximum compressive strength value lies in 10% Ordinary Portland Cement (OPC) replacement for CCWP, BLA and CCWP/BLA while almost the same value of strength was obtained for OPC and the CCWP and BLA with 15% replacement. At 20% replacement of cement with BLA, CCWP and BLA-CCWP, there is a drastic reduction in the compressive strength values of the concrete samples. These values show that the strength forming reactions takes place when these wastes were partially used to replace OPC from 0% to 20% of these wastes, after which the chemical reactions reduced and the compressive strength values dropped. The phases of the percentage replacement with 10% BLA, 10% CCWP and 10% BLA-CCWP were studied by SEM studies.

Properties of all materials used	**Fine Aggregate (Sand)**	**Coarse Aggregate (Granite)**	**Calcium Carbide Waste Powder (CCWP)**	**Bamboo Leaf Ash (BLA)**	**Ordinary Portland Cement (OPC)**
Moisture content (%)	0.47	-	-	-	-
Bulk Density (g/cm^3)	1.788	-	-	-	-
Silt/Clay Content (%)	5.56	-	-	-	-
Fineness content (%)	-	-	100	100	99.72
Soundness (mm)	-	-	< 10	< 10	< 10
Specific Gravity	2.64	2.61	2.93	2.32	3.13
AIV (%)	-	19.78	-	-	-
ACV (%)	-	30.48	-	-	-
Water Absorption (%)	-	0.93	-	-	-
Loss on Ignition (%)	-	-	16.62	5.23	-

Table 1: - Properties of Materials Used (Physical)

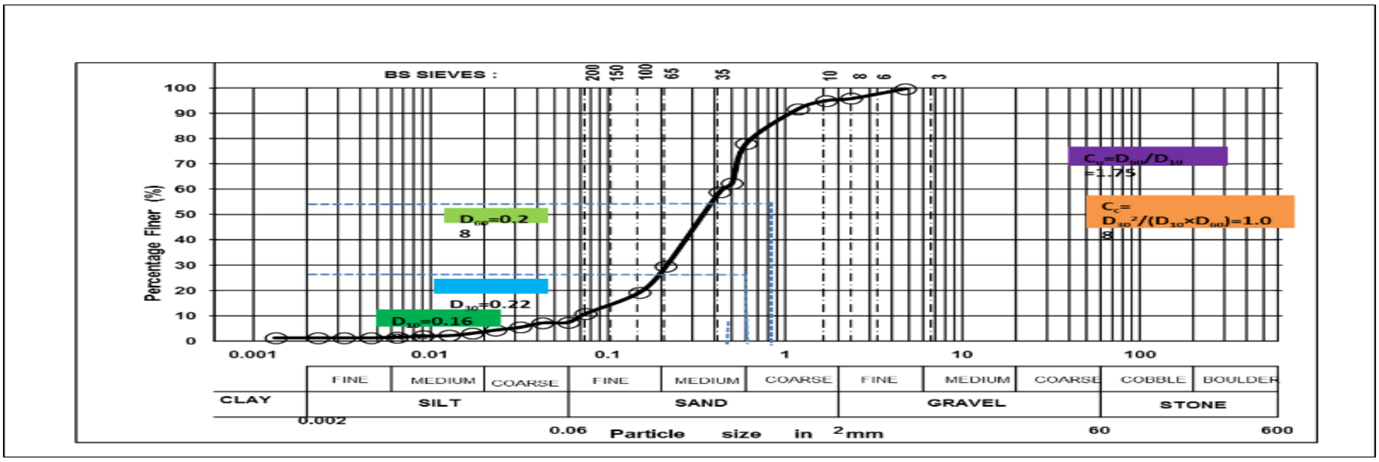

Fig 1:- Particle size distribution and hydrometer analysis chart for sand

Oxide	**Chemical formula**	**Percentage composition (%) of BLA**	**Percentage composition (%) of CCWP**	**Percentage composition (%) of OPC**
Silica	SiO_2	67.41	6.69	22.00
Alumina	Al_2O_3	1.95	2.30	3.11
Ferric oxide	Fe_2O_3	1.24	0.30	4.65
Calcium oxide	CaO	16.99	89.76	62.00
Magnesium oxide	MgO	1.18	ND	2.06
Manganese oxide	MnO	0.19	ND	0.32
Zinc oxide	ZnO	1.18	ND	0.86
Potassium oxide	K_2O	1.27	0.09	0.40
	LOI	5.33	16.62	-

Table 2:- Chemical Composition of Major Oxides of Pozzolans

Oxide required for a Pozzolan	**Group**				
	N	F	C	CCWP	BLA
$SiO_2 + Al_2O_3 + Fe_2O_3$, (min %)	70.0	70.0	70.0	9.29	70.6
SO_3, max %	4.0	5.0	5.0	0.57	0.22
Moisture content, (max %)	3.0	3.0	3.0	-	-
Loss on Ignition, (max, %)	10.0	6.0	6.0	16.62	5.33

Table 3:- Oxide requirements for pozzolanic composition

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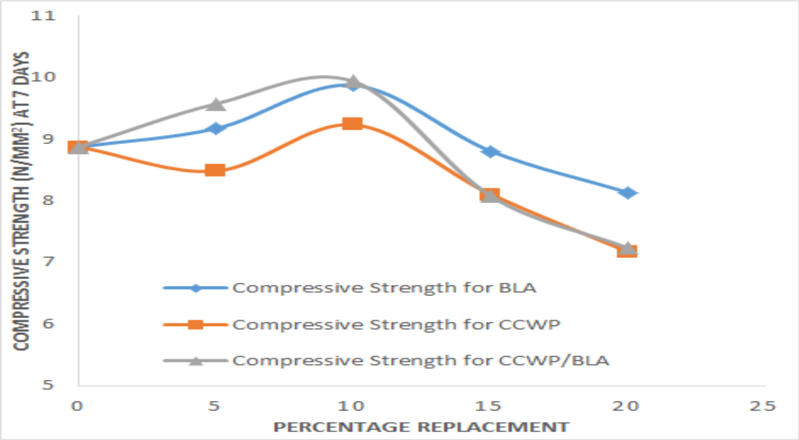

Fig 2:- Tread of the Compressive Strengths of CCWP, BLA and CCWP/BLA Blended Cement Concrete at 7 days

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Strength	40.184	12	3.349	15.811	.000
Error	5.507	26	.212		
Total	45.691	38			

Table 4:- Analysis of Variance (ANOVA) table for the compressive strength values for 56 days crushing

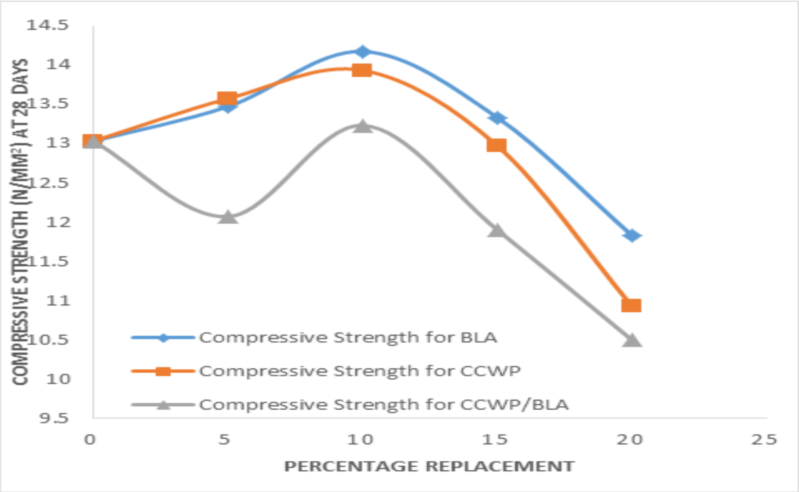

Fig 3:- Tread of the Compressive Strengths for CCWP, BLA and CCWP/BLA Blended Cement Concrete at 28 days

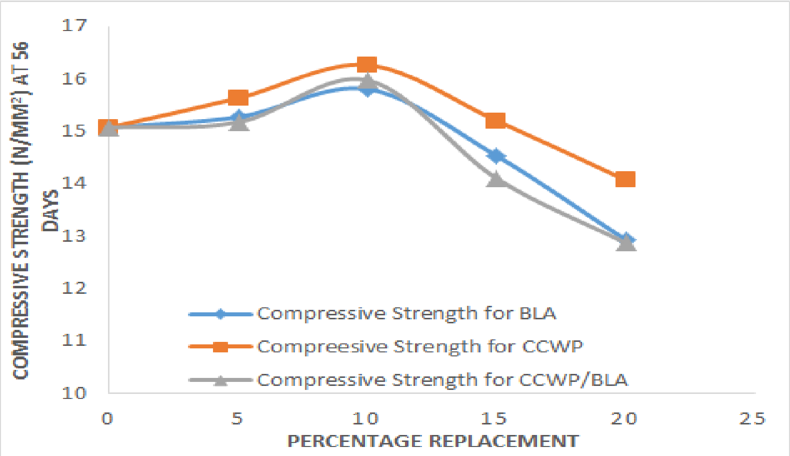

Fig 4:- Tread of Compressive Strengths for CCWP, BLA and CCWP/BLA Blended Cement Concrete at 56 days curing

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The compressive strength values of 56 days were analysed with ANOVA and Least Significant Difference (LSD) and the outputs are tabled as Table 4 and 5 respectively. The compressive strength values showed that there were significant difference in the compressive strength values obtained for Ordinary Portland Cement (OPC) when compared and analysed with CCWP5%, CCWP10%, CCWP15%, CCWP20%, BLA5%, BLA10%, BLA15%, BLA20%, 8% and CCWP/BLA5%, CCWP/BLA10%, CCWP/BLA15% and CCWP/BLA20% replacements. CCWP10%, CCWP/BLA10%, BLA10%, and CCWP15% showed a significant strength increment while BLA (15%) and CCWP/BLA (15%) showed a significant strength reduction. These results further showed that CCWP15%, CCWP/BLA15% and BLA15% will replace OPC in concrete production without altering the compressive strength significantly while the reduction in the compressive strengths with BLA15% and CCWP/BLA15% are insignificant.

Replacement(s)	N	Subset(s)					
		1	2	3	4	5	6
CCWP/BLA 20%	3	12.8667^{f}					
BLA 20%	3	12.9333^{f}					
CCWP 20%	3		14.0667^{e}				
CCWP/BLA 15%	3		14.1000^{e}				
BLA 15%	3		14.5333^{d}	14.5333^{d}			
OPC	3			14.9667^{c}	14.9667^{c}		
CCWP 5%	3			15.1000^{b}	15.1000^{b}	15.1000^{b}	
CCWP/BLA 5%	3			15.1667^{b}	15.1667^{b}	15.1667^{b}	
CCWP 15%	3			15.2000^{b}	15.2000^{b}	15.2000^{b}	
BLA 5%	3			15.2667^{b}	15.2667^{b}	15.2667^{b}	
BLA 10%	3				15.7667^{a}	15.7667^{a}	15.7667^{a}
CCWP/BLA 10%	3					15.9667^{a}	15.9667^{a}
CCWP 10%	3						16.2667^{a}
Sig.		.861	.252	.096	.070	.050	.020

Table 5:- LSD test for 56 days Compressive Strengths

The interlocking micrographs for hydrated samples of OPC, CCWP 10%, BLA 10% and CCWP/BLA 10% after 28 days curing are presented in Fig 5, 6, and 8. The SEM results show that the micrograph of CCWP 10% is closely packed compared with that of OPC and BLA 10%, while micrograph of OPC gives a better parking. This result further shows that blending of pozzolanic material (OPC) and non-pozzolanic material (CCWP) with cement in concrete will enhance the interlocking property of such concrete, improve other properties like compressive strength, density, durability etc. The optimum percentage replacement of 10% BLA, 10% CCWP and 10% BLA/CCWP should strictly be adhered to for effective performance.

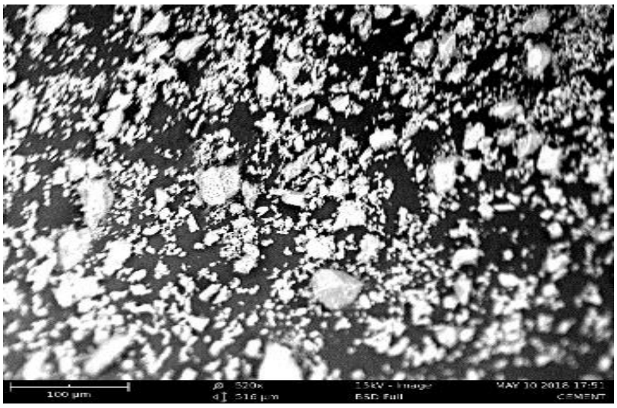

Fig 5:- Micrograph of developed sample of OPC (0%) with 520 magnification

Fig 6:- Micrographs of developed sample of OPC/BLA (10%) with 520 magnification

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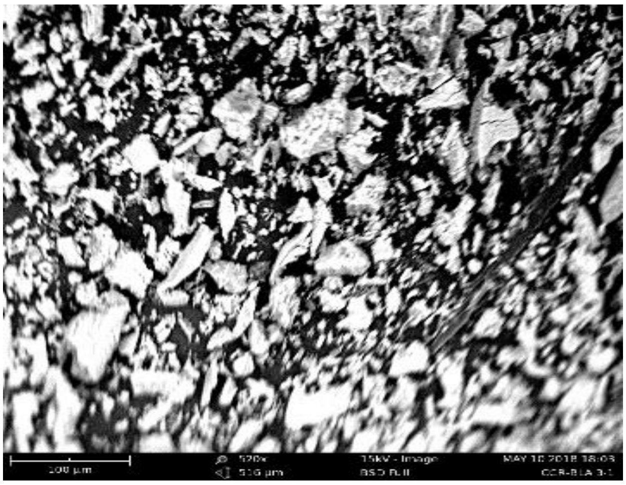

Fig 7:- Micrographs of developed sample of OPC/CCWP (10%) with 520 magnification

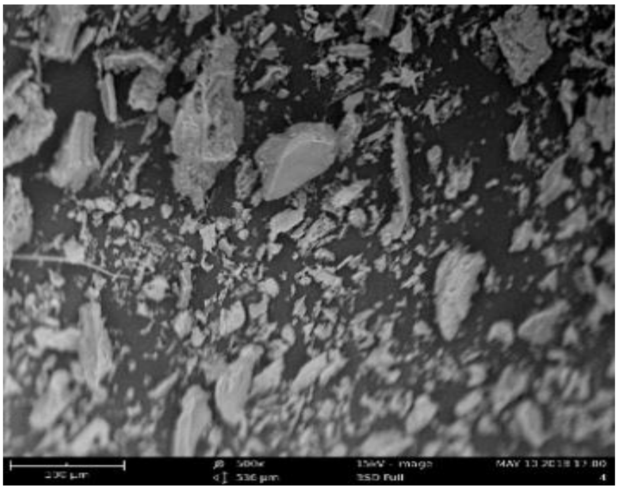

Fig 8:- Micrograph of developed sample of OPC/CCWP/BLA (10%) with 520 magnification

IV. CONCLUSION

From the research, the following were drawn as conclusions:

- Oxide composition analysis of Calcium Carbide Waste Powder (CCWP) shows that CCWP is a non pozzolanic material with high Calcium Oxide (CaO) content, and low Silicon Oxide (SiO_2) content, while bamboo leaf ash (BLA) is a pozzolanic material rich in silicon oxide (SiO_2) component.
- The compaction ability, slump, soundness and setting time of CCWP, BLA and CCWP/BLA binary cement concrete are similar to that of the OPC concrete.
- Compressive strength results shows that Calcium Carbide Waste Powder (CCWP) and Bamboo Leaf Ash (BLA) both have positive impact on the strength of concrete when partially replaced.
- Recommendation of a 10% BLA, 10% CCWP and 10% binary for use in concrete production and mass construction, because peak compressive strengths at this replacement levels are comparable with result obtained with the use of only cement as binder.

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