Laboratory Experiment on the Effect of Carbibe Waste and Metakaolin on Strength and Durability Properties of Blended Concrete

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Abstract:
The versatility of concrete makes it the most desirable construction material in the construction industry. The increase in global population growth and urbanization leads to a high demand for more basic infrastructure. The high cost of concrete structures is largely influenced by cost of the constituent materials and it is an important constituent in the making of concrete There are other cementing materials which have shown the ability to improve the properties of concrete and also presents both environmental sustainability and economic benefits. For this study investigation into the suitability of using calcium carbide waste and metakaolin in concrete production, this investigation involves the replacement of cement with blend of calcium carbide waste and metakaolin in an increment of 0, 5, 10, 15 and 20%. Concrete cube containing CCW-MK was tested for strength at 3, 7, 14, 28 and 56 days of curing age. The optimum compressive strength was recorded at 10% CCW-MK content. 5% concentration of H2SO4 was used to cure the concrete for 28 days. Oxide composition test was done on the CCW and MK. The results revealed that CCW had a CaO content of 86.43% and MK had a sum of Al2O3, SiO2 and Fe2O3 as 98.6%. The workability of CCW-MK increases with increase as the dosage of CCW-MK increase. The compressive strength of CCW-MK concrete increased with an increase in the dosage of CCW-MK and curing period respectively. The retained compressive strength of CCWMK concrete cured in H2SO4 with an increase in the dosage of CCW-MK. Furthermore, the water absorption increases with an increase in the dosage of CCW-MK. Microstructural analysis of CCW-MK concrete was done with the aid scanning electron microscope equipment. The microstructure of the maximum compressive strength sample shows a denser, more homogenous and compact hardened concrete with respect to the control. It was concluded that blended concrete with sufficient strength can be achieved with the addition of CCW and MK blends can as supplementary cementing materials in concrete production.
Keywords: Calcium Carbide Waste, Metkaolin, Cement, Concrete, Compressive Strength, Durability

1. Introduction

In an effort to minimize environmental degradation and to reduce cost of construction while not compromising standard, researchers are of the view that there is need to incorporate into concrete other materials that have shown cementing potential, especially waste materials or natural occurring materials, which in the process saves the environment and generates employment for the locals, such materials already existing in the body literature are Metakaolin (MK), Limestone Dust. Industrial waste like Calcium Carbide Waste (CCW), Blast Furnace Slag (BFS), Silica Fume (SF), Coal Ash (CA) etc. and agricultural waste such as Rice husk Ash (RHA), Palm Oil Fuel Ash (POFA), Cassava Peel Ash (CPA), Cocoa Pod Ash (CPA) [1].
Calcium Carbide Waste (CCW) is one of the industrial by-product. It is also known as lime hydrate or carbide lime sludge [2,3]. The reaction between calcium carbide and water produces what is known as acetylene gas (C2H2), as shown in equation (1).

$CaC_2(s) + 2H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$ eq.1
(Calcium Carbide) (Water) (Acetylene) (Calcium Carbide waste)

Acetylene (C_2H_2) gas has numerous industrial application which include but not limited to heating applications such as flame, spraying, gauging, hardening and heating [4-6]. In Nigeria, acetylene gas (C2H2) is majorly used for welding in local panel beating workshops across cities [28]. After the utilization of acetylene (C_2H_2), the resulting by-product is called calcium carbide waste (CCW) and it is disposed indiscriminately into the environment, chemicals from this calcium carbide waste leeches into environment which impacts the environment negatively [8-10].

Nwachuku et al. [11] stated that, the Nigerian Automobile Technicians Association (NATA) has about twenty-five thousand (25,000) registered members with each person producing an average of 30kg calcium carbide waste daily. Calcium carbide waste generated annually is about 274, 000 tons except. Calcium carbide waste Ca(OH)2 constitutes more than 92% calcium hydroxide mass fraction and is highly alkaline (pH>12), it also contains Fe2O3, SiO2, Al2O3 metal oxide, hydroxide (OH) and a small amount of organic matter [12]. The colour of the calcium carbide waste is grayish when dried, it has a fine and uniform

Thermally activated natural occurring material like kaolin which is converted to metakolin after thermal treatment is considered as source of supplementary cementing material to reduce dependence on Portland limestone cement therby reducing the CO2 emissions associated with cement production [13,14]. During calcination process the unreactive kaolinite changes to an amorphous state resulting in a metakaolin product, the process of this conversion is called dehydroxylation as expression by the following reaction in equation 2. After this thermal treatment of kaolin to metakaolin, the material which is now a pozzolana can react with calcium hydroxide ($Ca(OH)_2 + H_2O$) in the presence of water to form a cementing compound during the hydration process [15].

$$\underset{\text{Kaolin}}{2Al_2Si_2O_5 + (OH)_4} \rightarrow \underset{\text{Metakaolin}}{2Al_2Si_2O_7} + 4H_2O \qquad \text{eq.2}$$

Metakaolin is a reactive aluminosilicate pozzolana formed by purified Kaolinite clays at a temperature range mostly between 650°-850° and by grinding it to a high fineness [15]. Calcium Carbide Waste (CCW) is one of the industrial by-products, commonly disposed of improperly in landfills, as a result, it poses a threat to the environment [16, 17]. The high cost of concrete structures is largely influenced by the high cost of the constituent material and cement is an important constituent material in the production of concrete [18, 19, 20]. Literatures exist on the use of Calcium Carbide Waste (CCW) separately and likewise Metakaolin (MK) as partial replacement of cement in concrete, but no works have been reported on the blend of Calcium Carbide Waste (CCW) and Metakaolin (MK) as partial replacement of cement in concrete. Thus, this experiment seeks to further investigate the suitability of using Calcium Carbide Waste (CCW) and Metakaolin (MK) as suitable replacements of cement in concrete and whether it will lead to enhanced or acceptable properties. These materials have both shown prospects when used individually and it appears to complement each other in terms of chemical composition, CCW and MK will be used for this study.

2. Materials and Methods

2.1 Materials

Materials used for this experiment include the following: grade 42.5 cement and calcium carbide (CCW) waste obtained from the waste dumps created by commercial welding artisans in Zaria, Kaduna State, Nigeria. Metakaolin (MK), by calcination of kaolin was obtained from Kankara Katsina State Nigeria. Coarse aggregates and fine aggregate was sourced from a quarry site within Zaria. Portable water was sourced from Ahmadu Bello University, Zaria.

2.2 Methods

2.2.1 Mix design

Mix design used for this experiment was 1:1.5:3 for grade 25 concrete. The CCW and MK were used to replace part of the cement by weight in the concrete mix, water cement ratio of 0.55 remained unchanged throughout the mixes. Table 1 shows the mix proportion of the concrete.

Table 1: Proportion material used for concrete cubes production (100× 100 x 100mm)

S/N	Description	Water (kg)	Cement(kg)	CCW (kg)	MK (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
1	CCW0%MK0%	3.03	6.045	0.000	0.000	10.08	19.16
2	CCW5%MK5%	3.03	5.441	0.302	0.302	10.08	19.16
3	CCW10%MK10%	3.03	4.836	0.605	0.605	10.08	19.16
4	CCW15%MK15%	3.03	4.232	0.907	0.907	10.08	19.16
5	CCW20%MK20%	3.03	3.627	1.209	1.209	10.08	19.16

3. Results and Discussion

3.1 Test on portland limestone cement

The cement used in this research was sourced from the open market at Sabon Gari Zaria. Table 2 and 3 shows the chemical and physical properties respectively. From the results presented in Tables 2 and 3. The cement fell within the ranges specified by the relevant standard code, hence considered good for concrete production.

Table 2: Chemical composition of pc with standard requirement

Oxide Composition	Percentage (%) of oxide composition	BS EN 196-2 2013) Recommendation
CaO	74.24	Limit not specified
SiO2	8.73	Max. 35.5%
Al2O3	5.08	Max. 6.3%
Fe2O3	3.24	Max. 6.5%
MgO	2.40	Max. 4.0%
SO3	2.34	Max. 3.0%
Alkalis	0.65	Max. 1.5%
Loss of ignition	1.44	Max. 5.0%

Table 3: Physical properties of the pc with standard requirement

Test conducted	and BS codes	Min	Max	Results	Remark
Soundness (mm)	BS EN 196-3 (2016)	0.5	-	10	Satisfactory
Soundness (mm)	BS EN 196-3 (2016)	0.5	-	10	Satisfactory
Initial and final setting time (mm)	BS EN 196-3 (2016)	96/223	45	600	Satisfactory
Consistency	BS EN 196-3 (2016)	30	26	33	Satisfactory
Fineness (%)	BS EN 196-6 (2013)	3	≤10	-	Satisfactory
Specific gravity	BS EN 1097 3 (1998)	3.13	2.6	3.15	Satisfactory

3.2 Test on aggregates

The physical test carried out on the fine and coarse aggregate are presented in Table 4. All the preliminary tests done on the aggregates are in compliance with the relevant code specifications. The result of the sieve analysis of fine and coarse aggregate is presented in Figure 1. The test was done in accordance with [12]. From the result it was observed that the aggregate are within the zone 2 limit. The aggregate of zone 2 is recommended because it tends to have a balance size gradation for effective interlocking in concrete. An aggregate of zone 2 is used to achieve a specific mechanical properties in concrete[12].

Table 4: Results of physical properties of the fine and coarse aggregate

Test Conducted	ASTM/BS Code	Test Results	Code Specification Min	Code Specification Max	Remark
Specific gravity	ASTM C127, (2015)	2.71	2.4	3.0	Satisfactory
Silt content (%)	ASTM C40 (2004)	3.77	-	8	Satisfactory
Impact Value (%)	BS 812 part111, (1990)	12.63	-	30	Satisfactory
Crushing Value (%)	BS 812 part112 (1990)	18.97	-	30	Satisfactory
Flakiness Index	ASTM D4791 (2019)	13.88	-	25	Satisfactory
Elongation Index	ASTM D4791 (2019)	15.5	-	25	Satisfactory
Water Absorption (%)	BS 812 part 2, (1995)	5	-	15	Satisfactory

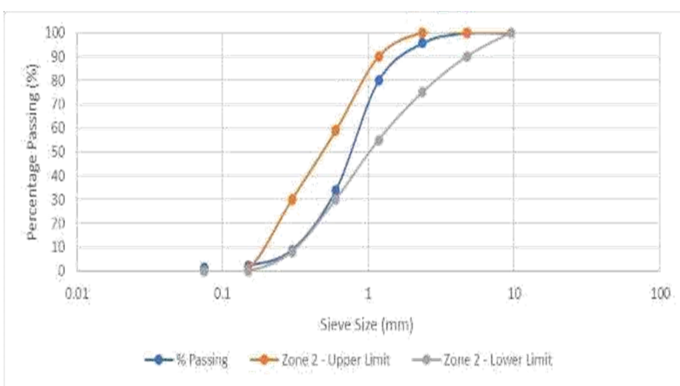

Figure 1: Particle Size Distribution (Sieve Analysis)

3.3 Oxide composition of calcium carbide waste (CCW) and metakaolin (MK)

X-ray fluorescence (XRF) analysis of calcium carbide waste and metakaolin was carried out in accordance with [21] Table 5 shows the various oxide concentration detected for calcium carbide waste and metakaolin respectively and the recommended specifications from [22]. From the results obtained the metakaolin can be classified as Class F pozzolana as the combination of $SiO2 + Al2O3 + Fe2O3 \geq 70\%$, also $SO3 \leq 5$ while calcium carbide waste could be classified as Class C having $CaO > 50\%$ and $SO3 \leq 5$. Oxide composition present in pozzolanic materials play an important role in cement-pozzolana reaction as they react with Ca(OH2) and C3A in the cement-pozzolana system during hydration and strength development of concrete . Similar results were obtained by [23, 24].

Table 5 Chemical composition of calcium carbide and metakaolin

Oxide Composition	CCW concentration (%)	MK concentration (%)	BS EN 196-2 (2013) recommendation
CaO	86.43	0.66	Limit not specified
SiO2	2.71	55.0	Max. 35.5%
Al2O3	4.99	35.20	Max. 6.3%
Fe2O3	3.24	1.66	Max. 6.5%
MgO	2.78	0.21	Max. 4.0%
SO3	0.42	0.37	Max. 3.0%
K_2O	0.08	1.18	Limit not specified

3.4 Test on Cement Paste

3.4.1 Consistency of cement paste

Consistency test of cement paste is used to determine the water content needed to for a given cement to achieve a standard consistency. The result of the consistency of CCW/MK/Cement paste is shown in Figure 2. The result showed that consistency of the cement paste increased with increment of CCW/MK content, this is because the introduction of CCW/MK in the mixture required extra amount of water due to the surface area of the material [25].

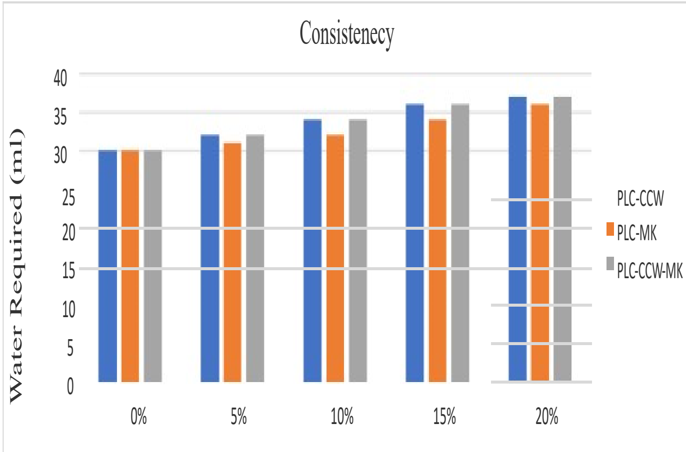

Figure 2: Consistency of CCW-MK-cement paste

3.4.2 Setting time of cement-paste

The setting tine of cement paste refers to period cement paste changes from fluid to rigid. Results of the initial and the final setting time of cement is presented in Figure 3 and 4 respectively. The results revealed that setting time of CCW/MK-cement paste increased with increase in the CCW/MK dosage. This is due to the high content of potassium oxide (K_2O) which introduced impurities in the form of Barium Sulfate ($BaSO_4$) and Barium Aluminum Oxide ($BaAlO_4$). Similarly high content of Magenesium Oxide (MgO) promote the hydration of $C_{2.75}$ $B_{1.25}$ A_3 because of the lattice distortion and defects [26] these impurities alter the selective hydration of tricalcium silicate (C3A) and dicalcium aluminate (C_3S) in cement altering the time frame in the setting time of cement.

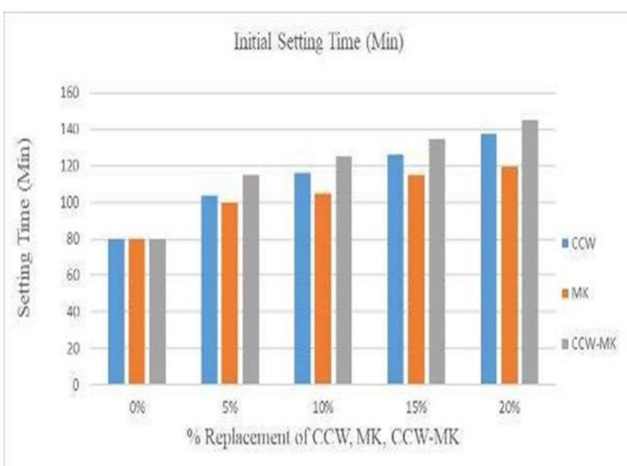

Figure 3: Initial Setting Time of Cement Paste

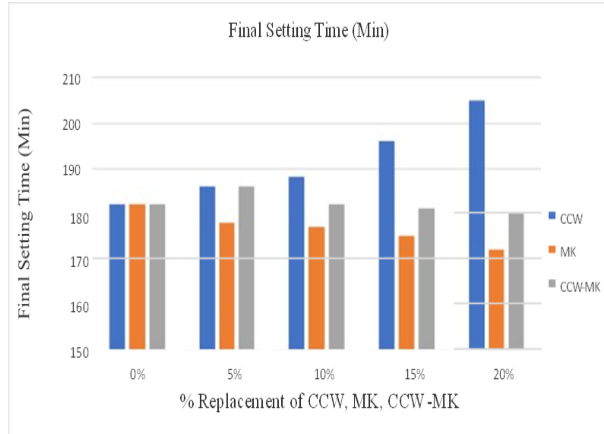

Figure 4: Final setting time of cement paste

3.4.3 Soundness of cement-paste

The soundness test result is presented in Figure 5. Form observation, the soundness of cement increased as the CCW/MK dosage increased. The values of soundness for each replacement is within the acceptable limit specification according to [27] which stipulates that the expansion of cement should be ≤10mm.The result demonstrates that the inclusion of CCW/MK did not adulterate or expand the cement excessively.

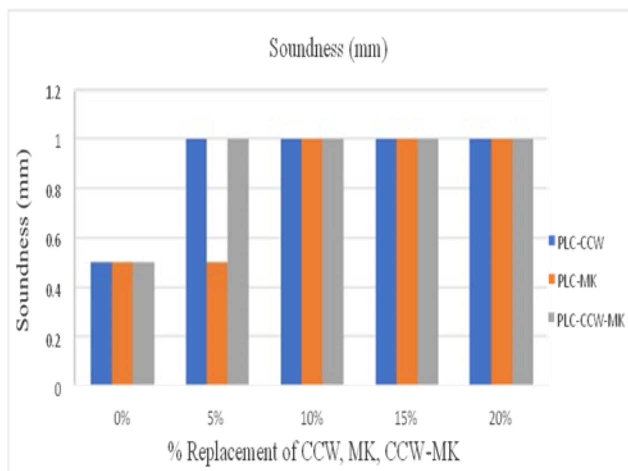

Figure 5: Soundness of CCW-MK-cement paste

3.5 Test on Concrete

3.5.1 Result of Concrete Slump

Workability (slump) test result is used to measure the uniformity and consistency of a given batch of concrete mixes. The result of slump test conducted on the concrete with variation in the percentages of CCW and MK content is presented in Figure 6. For slump of cement and CCW it was observed that as CCW dosage increases there is a corresponding increase in the slump value, same increment trend was also observed for cement and MK. Furthermore the slump test of cement and CCW-MK the results showed an increase in slump values with increase in CCW/MK dosage. All the slump test for blended cement are classified as S1 (that is slump values within 10–40mm) according to [28] and are within the acceptable limit of two different slump results as specified by [28, 29]. This means that the concrete maintained a good workability at constant water -cement ratio.

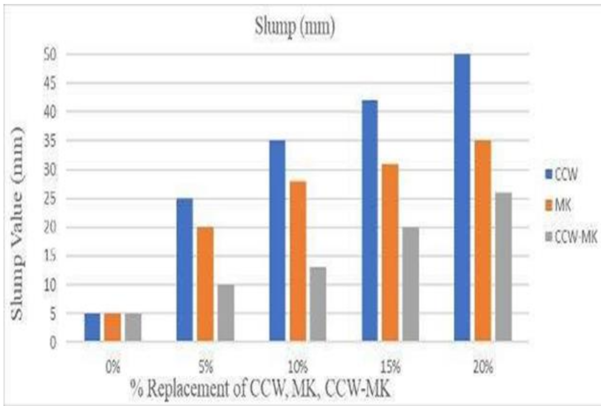

Figure 6: Slump of CCW-MK Concrete

3.5.2 Compressive Strength of Calcium Carbide Waste-Cement Concrete

The compressive strength test result of the CCW-Cement concrete is presented in Figure 7. The result of test for CCW concrete showed a decreased with increase CCW dosage. The results revealed that at the age of 3days, the compressive strength reduced by 0.76% from control (0%) to 20% replacement with CCW. Similarly, the strength also reduced by 0.47, 0.82, 0.36, and 0.35% for 7, 14, 28 and 56days respectively, the decrease in compressive strength is connected to the high dosage of Magnesium Oxide (MgO) present in the CCW. Borhan [30] stated that high MgO content in cement causes reduction in the strength of concrete. The optimum strength for the blended CCW/Cement concrete was recorded at 10% replacement with 27N/mm2 similar result was obtained by [31].

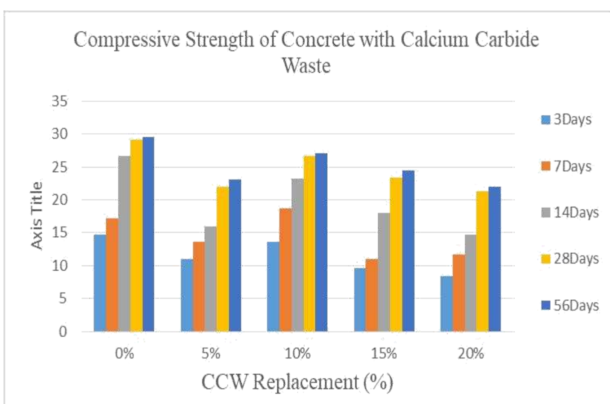

Figure 7: Compressive strength of CCW-cement concrete

3.5.3 Compressive Strength of Metkaolin-Cement Concrete

The compressive strength result are shown in Figure 8. The result obtained from compressive strength test of MK concrete depicted a decreased in strength with increase MK content. The strength result test showed that the 3 days compressive strength reduced by 0.63% from control (0%) to 20% replacement with MK. Similarly, the strength also reduced by 0.36, 0.25, 0.21, and 0.20% for 7, 14, 28 and 56days respectively. According to [32] potassium oxide (K2O) > 1.0% causes a reduction of compressive strength at the early ages and late ages respectively, this is in agreement with [33] opined that two factors are responsible for the general decline in strength, first, is the partial replacement of cement which leads to decrease in the quantity of tri-calcium silicates (C3S) available for reaction which is the major compound responsible for strength gain in concrete, second is physical properties of MK which delays the hydration of cement. Similar results were reported by [34].

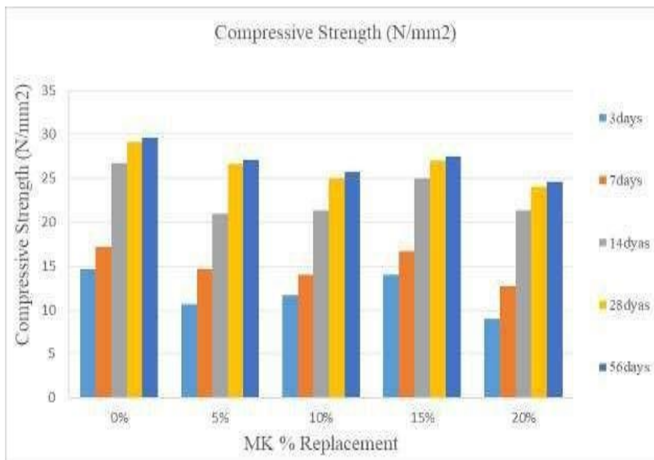

Figure 8: Compressive strength of MK-cement concrete

3.5.4 Compressive Strength of Calcium Carbide Waste-Metakaolin Concrete

The compressive strength of the ternary blend of PLC/CCW/MK is shown in Figure 8. The result of the strength test of PLC/CCW/MK concrete showed that the strength of the concrete increased as the curing age of the concrete increased. The compressive strength values reduced with 5% addition of CCW/MK at. 56days. A further increase above 5% CCW/MK content showed a decreased in the strength of concrete. The reason for the increase in strength of concrete with increase in curing age is due to the combined effect of high content of CaO in CCW and high sum of Fe2O3, SiO2 and Al2O3 in MK producing more Calcium Silica Hydrates (CSH) bonds which contributes to increase compressive strength while the decrease could be as a result of saturation from cement blends which created weak interface zone between aggregate and cement paste. Aïtcin [35] as cited in [36] stated that adding pozzolans contributes to the strength enhancement at later ages only and the strength would be comparable to the PLC concrete. Kaura et al. [37] in their research also confirmed that compressive strength of concrete is improved with introducti on of highly reactive pozzolanic materials. Similar result was also obtained by [38].

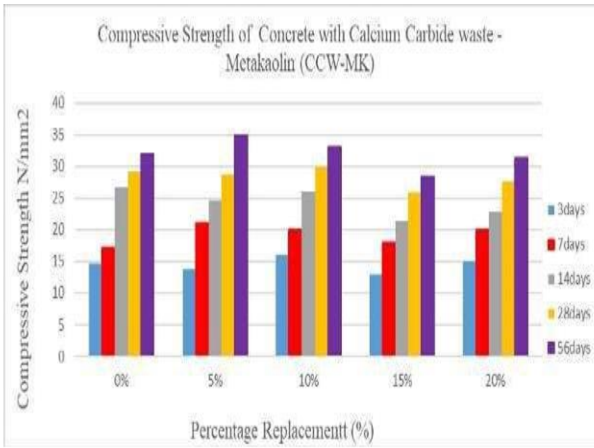

Figure 9: Compressive strength of CCW – MK concrete

3.5.5 Acid Test

Acid test is done to determine the extent of reaction between an acid (H2SO4) and calcium hydroxide Ca(OH)2 in a given cement. Figure 9 shows the result of CCW-MK concrete after 28days immersion in 5% H2SO4 solution. Form the results it was observed that the blended concrete recorded 18, 13, 10, 18 and 9% reduction in compressive strength for the CCW/Mk concrete for 0, 5, 10, 15 and 20% replacement respectively. The values of the acid test collaborates the statement from [39] which states that "The reaction between H2SO4 and cement constituents of concrete results in the conversion of Ca(OH)2 and C-S-H to calcium sulphate (gypsum), this type of formation involving calcium sulphate (CaAl2O4) results in the softening of the concrete and that calcium sulphate (gypsum) further reacts with calcium aluminate to form calcium sulfoaluminate (ettringite). These ettringite further reacts with the acid to form silica gel. This silica gel can be easily disintegrated."

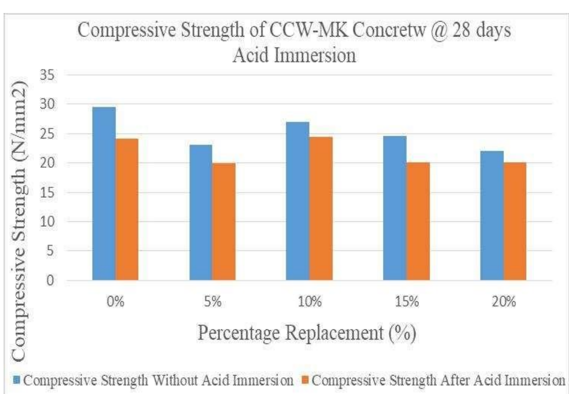

Figure 10 Acid Resistance of CCW – MK concrete

3.5.6 Water Absorption

The results of water absorption are shown in Figure 11. Babak [40] as cited in [41] opined that water absorption in concrete is influenced by paste pores, capillarity, surface energy, surface tension and concrete sorptivity, this is in consonance with research from [42] which states that the water absorbed by concrete is chiefly due to the total paste phase present in the concrete. It was observed from the results that with the increase in the CCW/MK dosage there is a corresponding increase in the water absorbed by the concrete, this is mostly caused by the deficiency in the C-S-H gel formation, resulting in higher pore sizes within the concrete mixture. However the average water absorption recorded met the criteria recommended by [43] which states that maximum water absorption should be less than 10%.

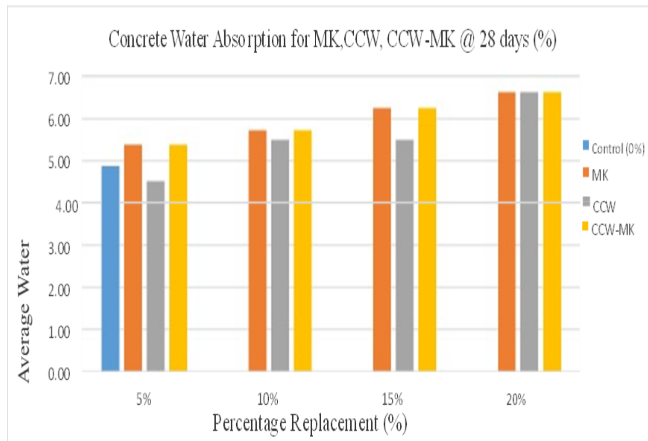

Figure 11 Water absorption and CCW–MK concrete

3.5.7 XRD Analysis of Concrete Samples

The XRD mineralogy analysis of calcium carbide waste/metakaolin concrete is presented in Figure 12. The XRD mineralogy pattern generated 100% matching recorded at 2-theta (deg) the presence of tobernite (C-S-H) at 61%, calcium carbide (CaC2) 19.3%, larnite (CaSiO2) 16.9%, alite (Ca 3SiO5) and porlandite (Ca(OH)2) 0.4%.

3.5.8 Microanalysis of Concrete Sample

The microstructure and morphology of the control and CCW/MK concrete are shown in plate I and II respectively. The scanning electron microscope of the concrete was done in accordance with ASTM standards [45] using a magnification of 1000µm after 56days of curing in water. Figure 13 shows a rough, irregular shape of the aggregate, it also shows a compact and cohesive C-S-H gel sheet coating of aggregate which contributes in the pore blockage yielding in good compressive strength of the concrete. On the other hand Figure 14 shows the microstructure of 5% CCW/MK content for the blended concrete. The inclusion of CCW/MK content improved the interlocking and packing ability of aggregate in the hardened concrete matrix with respect to the control. Figure 14 also shows particles of CCW/MK that remained unreactive or partially reactive within the matrix. Similar observation was reported in a study [20].

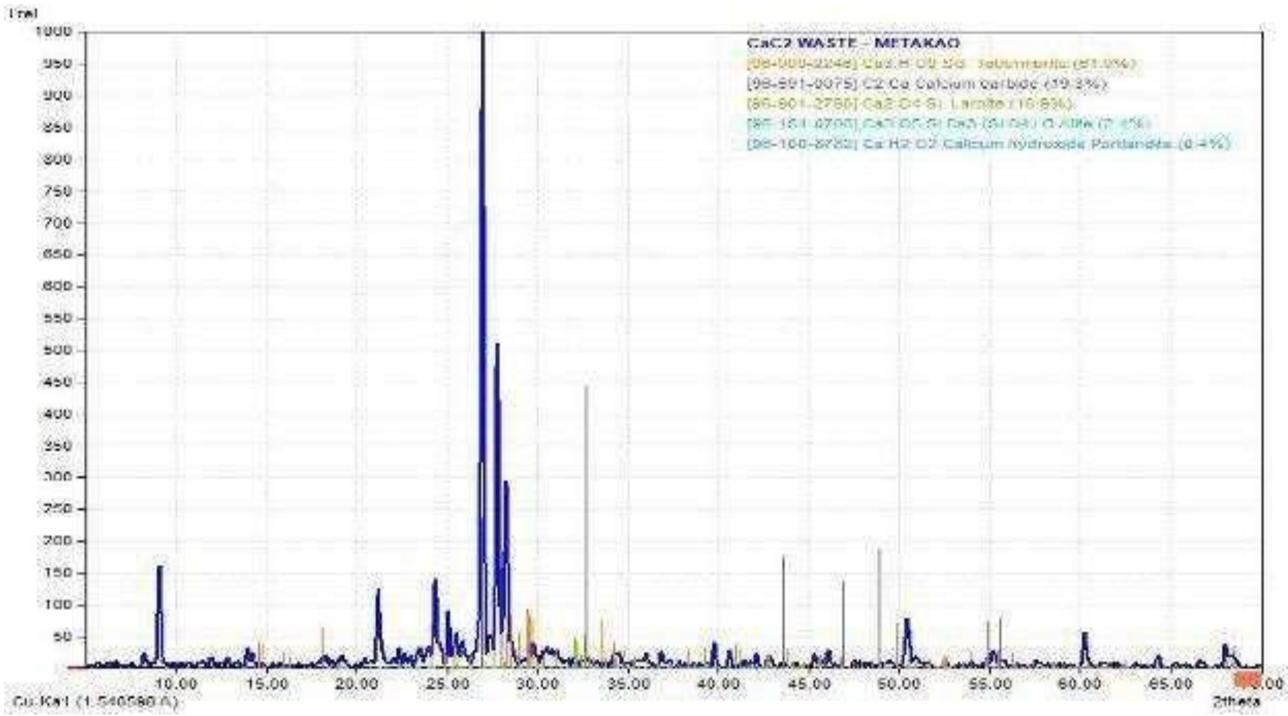

Figure 12: XRD mineralogy Analysis of Concrete Sample

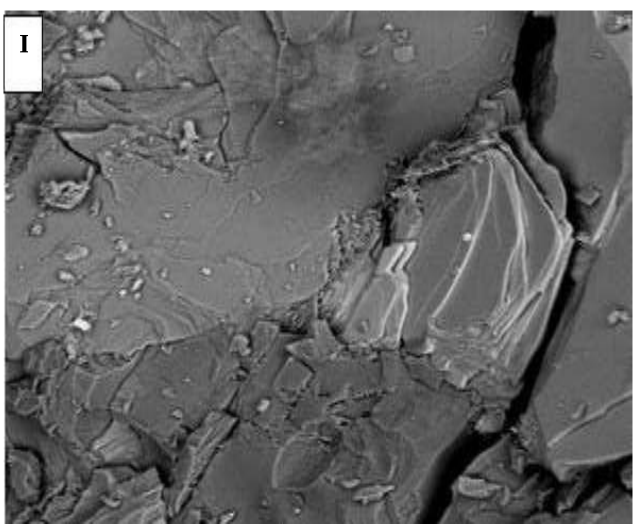

Figure 13. Micrograph of concrete produced with Portland Limestone Cement as control. At 1000µm magnification.

Figure 14. Micrograph of concrete produced with calcium carbide waste and Metakaolin. At 1000µm magnification.

4. Conclusions and Recommendations

The following are the conclusions drawn from the study:

i. MK is classified as class F pozzolana having a combined SiO2 + Al2O3 + Fe2O3 ≥ 70% and SO3 ≤ 5 while CCW is classified as class C pozzolana CaO > 50% and SO3 ≤ 5 according to ASTM standard.

ii. The physical test such as consistency, setting time and soundness carried out on CCW/MK blended cement showed satisfactory performance as stipulated by relevant codes.

iii. Workability (slump) of the fresh concrete increase continuously with an increase in the CCW/MK quantity.

iv. The ternary blend of CCW/MK concrete showed a satisfactory compressive strength. An increase in calcium carbide waste/metakaolin content resulted in a reduction in the compressive strength. However, as curing age increases there is a resulting increase in the compressive strength of CCW/MK concrete. Hence CCW/MK are considered good for concrete structures.

v. Acid test on the concrete resulted in a reduction in the retained strength of the concrete.

vi. An increase in water absorption was observed with increase in CCW-MK content after 28 days curing.

vii. Microstructure of the concrete resulting in a denser and more homogenous mixture

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Conflict of Interest
The authors declare that there is no conflict of interest in this paper.

References

[1] Busari, A., Dahunsi, B., and Akinmusuru, J. (2019). Sustainable Concrete for Rigid Pavement Construction using De-hydroxylated Kaolinitic Clay: Mechanical and Microstructural Properties. Construction and Building Materials, 211, 408-415.
[2] Makaratat, N., Jaturapitakkul, C., Namarak, C., and Sata, V. (2011). Effects of Binder and Cacl2 Contents on the Strength of Calcium Carbide Residue-Fly Ash Concrete. Cement and Concrete Composites, 33(3), 436-443

[3] Ndububa, E.E. and Omeiza, M.S. (2016). Potential of Calcium Carbide Waste as Partial Replacement of Cement in Concrete. Nigerian Journal of Tropical Engineering, ISSN: 1595-5397, 9(1-2), 1-9.
[4] Tuleun, L. Z., and Jimoh, A. A. (2018). Laboratory Evaluation of the Performance of Calcium Carbide Waste (Hydrate Lime) In Concrete.
[5] Liu, X., Zhu, B., Zhou, W., Hu, S., Chen, D., and Griffy-Brown, C. (2011). CO2 Emissions in Calcium Carbide Industry: An Analysis of China's Mitigation Potential. International Journal of Greenhouse Gas Control, 5(5), 1240-1249.
[6] Sun, H., Li, Z., Bai, J., Memon, S. A., Dong, B., Fang, Y., and Xing, F. (2015). Properties of chemically combusted calcium carbide residue and its influence on cement properties. Materials, 8(2), 638-651.
[7] Nwachukwu, M. I., Njoku-Tony, R. F., Ihejirika, O. C., Enwereuzoh, U. O., and Imo, E. O. (2014). Impact of calcium carbide waste dumpsites on soil chemical and microbial characteristics.
[8] Abiya, S. E., Odiyi, B. O., and Salau, I. O. (2015). Effect of calcium carbide waste on the growth and biomass of Okra (Abelmoschusesculentus l. Moench). IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), e-ISSN, 2319-2402.
[9] Jaturapitakkul, C., and Roongreung, B. (2003). Cementing material from calcium carbide residue-rice husk ash. Journal of Materials in Civil Engineering, 15(5), 470-475.
[10] Tanalapsakul, A. (1998). Document from M Thai industrial company limited. M Thai Industrial Company Limited. Samutsakorn, Thailand.
[11] Nwachukwu, M. I., Njoku-Tony, R. F., Ihejirika, O. C., Enwereuzoh, U. O., and Imo, E. O. (2014). Impact of calcium carbide waste dumpsites on soil chemical and microbial characteristics.
[12] Jiang, M., Huang, X. F., Liu, H. P., Zhan, F. D., He, Y. M., & Li, B. (2016). Research progress on resource utilization of carbide slag. Bulletin of the Chinese Ceramic society, 35(12), 4025-4031.
[13] Tironi, A., Trezza, M. A., Irassar, E. F., and Scian, A. N. (2012). Thermal treatment of kaolin: effect on the pozzolanic activity. Procedia Materials Science, 1, 343-350.
[14] Lv, P., Liu, C., and Rao, Z. (2017). Review on clay mineral-based form-stable phase change materials: preparation, characterization and applications. Renewable and Sustainable Energy Reviews, 68, 707-726.
[15] Salvador, S. (1995). Pozzolanic properties of flash-calcined kaolinite: a comparative study with soak-calcined products. Cement and concrete research, 25(1), 102-112.
[16] Tuleun, L. Z., and Jimoh, A. A. (2018). Laboratory Evaluation of the Performance of Calcium Carbide Waste (Hydrate Lime) In Concrete.
[17] Ndububa, E.E. and Omeiza, M.S. (2016). Potential of Calcium Carbide Waste as Partial Replacement of Cement in Concrete. Nigerian Journal of Tropical Engineering, ISSN: 1595-5397, 9(1-2), 1-9.
[18] Palou, M. T., Kuzielová, E., Novotný, R., Šoukal, F., and Žemlička, M. (2016). Blended cements consisting of Portland cement–slag–silica fume–metakaolin system. Journal of Thermal Analysis and Calorimetry, 125(3), 1025-1034.
[19] Kad, N., and Vinod, M. (2015). Review research paper on influence of rice husk ash on the properties of concrete. International Journal of Research, 2(5), 873-877.
[20] Neville, A. M. (2000). Properties of Concrete, Pearson Education Asia Publishing Limited. England, Produced by Longman Malaysia, VVP.
[21] ASTM E1621-13. (2013). Standard Guide for Elemental Analysis by Wavelength Dispersive X-Ray Fluorescence Spectrometry. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org
[22] BS EN 196-2 (2013). Method of Testing Cement Chemical Analysis of Cement. British Standard Institution, London, United Kingdom. (BSI)
[23] Samson, D., Abdullahi, M., and Mohammed, A. (2016). Effect of metakaolin on compressive strength of concrete containing glass powder. International Journal of Research and Engineering Technology, 5(1). 137-142
[24] Dinakar, P., Sahoo, P. K., and Sriram, G. (2013). Effect of metakaolin content on the properties of high strength concrete. International Journal of Concrete Structures and Materials, 7(3), 215-223.
[25] Babako, M., and Apeh, J. A. (2020). Setting time and standard consistency of Portland cement binders blended with rice husk ash, calcium carbide and metakaolin admixtures. In IOP Conference Series: Materials Science and Engineering 805(1) 12-31 IOP Publishing.
[26] Weibo, S., Yun, Z., Chenchen, G., & Jibao, X. (2017). Effect of K2O and MgO on the Formation and Hydration Activity of Ba-Bearing Calcium Sulfoaluminate. Ceramics– Silikáty, 61(1), 6-13.
[27] BS EN 196-2 (2013). Method of Testing Cement Chemical Analysis of Cement. British Standard Institution, London, United Kingdom. (BSI)
[28] BS EN 206 (2021). Concrete Specification, Performance, Production and Conformity. British Standard Institution, London, United Kingdom. (BSI)
[29] ASTM C143/C143M – 10 (2010). Standard Test Method for Slump of Hydraulic-Cement Concrete. West Conshohocken, Philadelphia.PA: American Society for Testing and Materials (ASTM)

International. Retrieved from www.astm.org

[30] Borhan, T. M., & Al-Rawi, R. S. (2016). Combined Effect of MgO and SO3 Contents in Cement on Compressive Strength of Concrete. Al-Qadisiyah Journal for Engineering Sciences, 9(4). 516-525

[31] Makaratat, N., Jaturapitakkul, C., Namarak, C., and Sata, V. (2011). Effects of Binder and Cacl2 Contents on the Strength of Calcium Carbide Residue-Fly Ash Concrete. Cement and Concrete Composites, 33(3), 436-443.

[32] Weibo, S., Yun, Z., Chenchen, G., & Jibao, X. (2017). Effect of K2O and MgO on the Formation and Hydration Activity of Ba-Bearing Calcium Sulfoaluminate. Ceramics– Silikáty, 61(1), 6-13.

[33] Samson, D., Abdullahi, M., and Mohammed, A. (2016). Effect of metakaolin on compressive strength of concrete containing glass powder. International Journal of Research and Engineering Technology, 5(1). 137-142

[34] Ramezanianpour, A. A., and Jovein, H. (2011). Metakaolin as Supplementary Cementitious Materials on Strength and Durability of Concretes. Construction and Building Materials, 30(28): 470-47

[35] Aïtcin, P.C (1998), High-Performance Concrete, London, UK: E and FN SPON.

[36] Tiamiyu, I. A. (2006). Effects of Curing Methods on the Properties of Hardened Rice Husk Ash And Sugarcane Bagasse Ash Concrete. An Unpublished Dissertation, Ahmadu Bello Univerity, Zaria.

[37] Kaura, J. M., Lawan, A. and Ocholi, A. (2020) Effect of Nanosilica on the Mechanical and Microstructural Properties of A Normal Strength Concrete Produced in Nigeria.Nigerian ournal of Technology (NIJOTECH) Vol. 39, No. 3, July 2020, pp. 710 – 720

[38] Smith, A. S. J., Xu, 1, G., Garba, M. J. and Aliyu, M. Y. (2020). Pozzolanic and Mechanical Properties of Date Palm Seed Ash (DPSA) Concrete. Nigerian Journal of Technology (NIJOTECH). 39(3). 680 - 686

[39] Lawan A., Dugguh L. N., Ejeh S. P. and Amartey Y. D. (2021). Investigation of Concrete Strength Made with Nanoparticles and Metakaolin in Acid and Sulphate Solution. Nigerian Journal of Engineering, 28(2). 39 - 47

[40] Babak, M. (2017) Development of Concrete Water Absorption Testing for Quality Control https://spectrum.library.concordia.ca/978086/1/Full_Text%2C_Master_Thesis%2C_Babak_Mohammadi_%286200532%29.pdf, Accessed on March 14,

[41] Smith, A. S. J., Xu, 1, G., Garba, M. J. and Aliyu, M. Y. (2020). Pozzolanic and Mechanical Properties of Date Palm Seed Ash (DPSA) Concrete. Nigerian Journal of Technology (NIJOTECH). 39(3). 680 – 686

[42] Ramamurthy, K., Kunhanandan Nambiar, E.K., and Indu Siva Ranjani, G. (2009). A classification of studies on properties of foam concrete. Cement and Concrete Composite, 31: 388-396.

[43] Neville, A. M. (2011) Properties of Concrete, 5th Edition. Wiley, New York.

[44] Liu, X., Zhu, B., Zhou, W., Hu, S., Chen, D., and Griffy-Brown, C. (2011). CO2 Emissions in Calcium Carbide Industry: An Analysis of China's Mitigation Potential. International Journal of Greenhouse Gas Control, 5(5), 1240-1249.

[45] ASTM E986-04. (2017), Standard Practice for Scanning Electron Microscope Beam Size Characterization, West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org