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EFFECTS OF CALCIUM CARBIDE WASTE ON THE DURABILITY OF CONCRETE

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ABSTRACT

This paper presents the findings of an investigation on calcium carbide waste (CCW) as additive in concrete and its effect on durability. The CCW used was sourced from a local panel-beating workshop. It was sundried and sieved through a 75 µm sieve and characterized by X-Ray Fluorescence (XRF) analytical method. The compressive strength of CCW-Concrete was investigated at CCW additions of 0, 0.25, 0.5, 0.75 and 1.0 %, respectively by weight of cement. A total of sixty number 150 mm cubes of CCW-Concrete of 1: 2: 4 mix and water-cement ratio of 0.5 were tested for compressive strength at 3, 7, 28 and 56 days of curing in accordance with standard procedures. Fifteen number 150 mm cubes were also tested for water absorption after curing for 28 days in water. Fifteen number 150 mm cubes were also cured in clean water for 28 days before exposed to attack from 10 % concentration of sulphuric acid and hydrochloric acid solution, respectively for 28 days and tested in compression. The concrete compressive strength in acidic solution was also modeled using Minitab statistical software. The results of the investigations showed that CCW was predominantly of calcium oxide (95.69%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 3.14%. Addition of up to 0.5% CCW increased the compressive strength of concrete. CCW addition however decreased the resistance of concrete exposed to acidic environment and water ingress. The models of compressive strength for CCW-concrete in acidic environment were developed with R^2 values of 0.816 and 0.807, and could be used to predict concrete compressive strength exposed to acidic environment.

Key words: Additive, Calcium carbide waste, Concrete, Durability, Model

1. INTRODUCTION

Research trends in construction materials development have been that of sourcing for alternatives necessitated by the high cost of conventional materials, difficulties in accessing fund for construction/building development, amongst many other reasons. In a similar vein, the possibility of using wastes from industrial or agricultural processes in the construction industry is borne out of the need to provide sustainable materials for construction. This is achieved either by searching for or incorporating new materials and products that are more environmental friendly and/or contributing towards the reduction of carbon dioxide emission into the atmosphere (Hardjito *et al.*, 2012 and Sun *et al.*, 2015). In many developing countries the demand for construction materials such as ordinary Portland cement and admixtures is high to meet the infrastructure needs of the citizens. The production of these products requires capital intensive plants and expertise, with consequent high cost in addition to increase in the prices of traditional building materials to the common man due to inflation. To reduce the cost of material and construction to affordable rate, many research works have been directed towards utilization of cheap and readily available local materials such as industrial and agricultural by-products as substitutes for aggregate or binder in infrastructure construction (Elinwa *et al.*, 2005; Wazumtu and Ogork, 2015).

The use of additives or admixtures in concrete is necessary in situations where there is a need to enhance the properties of either fresh or hardened concrete or both for a particular purpose. In most situations the realization of such improvement can only be achieved effectively and more rapidly when appropriate additives or admixtures are used. According to Neville, (2003), chemical admixtures are added to concrete in small doses, often not more than 1 % by weight of cement, while mineral admixtures are introduced in larger doses, up to 5 % by weight of cement.

Researches on use of local materials such as agricultural waste and by-products from industrial processes as admixtures are still evolving. Many research works on use of local waste materials as admixtures in concrete have been conducted from universities and other tertiary institutions in Nigeria and most developing countries. However, the research findings have remained unexplored for these admixtures to be used in construction works. This may be due to the weak link between academic research and the industry for large scale production, amongst other reasons.

A few of the researches on local waste materials as admixtures and their effects on the durability of concrete include dye residue ash of up to 5.0 % by weight of cement reported to slightly improve concrete workability, and enhances strength and durability (Ogork and Koko, 2010). According to Aboshio *et al.* (2009) and Ogork *et al.* (2010), rice husk ash when used as additive at doses up to optimum of 5.0 % by weight of cement improved workability and compressive strength of concrete, but the durability of the concrete was impaired. Researches by Audu and Mamman (2013) and Ogork and Audu (2015) indicated that cocoa pod husk ash at doses up to optimum of 0.6 % by weight of cement acted as a retarder, improved workability, enhanced compressive strength and durability of concrete. In another research, sawdust ash in additions up to optimum of 2.0 % by weight of cement increased setting time, enhanced compressive strength and durability of concrete (Ogork and Ayuba, 2014). Groundnut shell ash in additions up to optimum of 4.0 % by weight of cement was also reported to have increased setting time, compressive strength and resistance to sulphuric acid (Wazumtu and Ogork, 2015).

The durability of concrete is an important property which significantly determines the service life of concrete structures (Turkel *et al.*, 2007). It is a measure of the ability of concrete structures to withstand the environmental conditions to which it is exposed. According to Yuksel *et al.* (2007), durability of concrete is its ability to resist chemical and physical attacks that lead to deterioration of concrete during its service life. These attacks include leaching, acid attack, carbonation, alkali-aggregate reaction, freezing-thawing and abrasion.

Acidic attack usually originates from industrial processes, but it can even be due to urban activity. The acidic attack is brought about by the processes of decomposition and leaching of the constituent of cement matrix (Gutt and Harrison, 1997). Acids react with alkaline components of the binder (calcium hydroxide, calcium silicate hydrates and calcium aluminate hydrates) lowering the degree of alkalinity. The degradation of concrete due to acids occur gradually and leads to loss of alkalinity, loss of mass, loss of strength and rigidity (Turkel *et al.*, 2007).

Calcium carbide waste (CCW) is a by-product obtained from the acetylene gas (C_2H_2) production process as shown in Equation (1) (Makaratat *et al.*, 2011):

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

Acetylene gas is widely used for ripening fruits in agriculture and for welding in industry (Sun *et al.*, 2015). In Nigeria and most developing countries, the acetylene gas is used for welding in local panel beating workshops across the cities. The by-product (CCW) is often discarded as waste and dumped in landfills and this poses a threat to the environment. The CCW is mainly composed of calcium hydroxide and is mainly alkaline, with pH greater than 12 (Sun *et al.*, 2015). In order to reduce environmental pollution, attempts have been made to use CCW in more useful ways, especially in the building industry. Research findings such as that by Wang *et al.* (2013) have indicated that CCW, when combined with certain pozzolanas containing high silicon dioxide and aluminium oxide could due to pozzolanic reactions yield final products that are similar to those obtained from cement hydration process. Ogork and Ibrahim (2017) also reported on the use of CCW as an additive in cement paste and concrete. They indicated that CCW can be used as an accelerator and up to optimum of 0.5 % CCW by weight of cement increased the compressive strength of concrete. More researches still need to be conducted on the use of CCW in construction, especially on the durability of concrete. It is against this background that this research aimed to investigate the resistance of CCW concrete exposed to acidic environment.

2. MATERIALS AND METHODS

2.1 Materials

Sand was obtained from River Watari in Kano, Nigeria. The particle size distribution curve of the sand is shown in Figure 1. The coarse aggregate is crushed granite of nominal size of 20 mm. The particle size distribution curve is also shown in Figure 1. The physical properties of the materials are shown in Table 1. Ordinary Portland cement (Ashaka brand) was used. The oxide composition of the cement is shown in Table 2. Calcium carbide waste (CCW) was sourced from a local panel beating workshop in Kano, Nigeria. The CCW was sundried and sieved through a 75 µm sieve. Chemical composition analysis of the CCW was conducted using X-Ray Fluorescence (XRF) analytical method and the results are shown in Table 2.

2.2 Methods

2.2.1 Concrete mix Proportion: Concrete mix of 1:2:4 and water-cement ratio 0.5 was used to assess the effect of CCW as additive in concrete. Five mixes were used; M-00 is the control mix and M-01, M-02, M-03 and M-04 representing mixes with addition of CCW of 0.25, 0.5, 0.75 and 1.0 %, respectively.

2.2.2 Compressive strength test on CCW-Concrete: The compressive strength of concrete with CCW additive was carried out in accordance with BS EN 12390-3 (2009) for the prescribed concrete mix of 1:2:4 and water-cement ratio of 0.5. A total of sixty (60) number 150 mm cube specimens were cast and cured in water for 3, 7, 28 and 56 days. At the end of every curing period, compressive strength was determined in accordance with BS EN 12390-3 (2009).

2.2.3 Water Absorption test of CCW-Concrete: This test was done in accordance with BS EN 12326-2 (2002) using CCW-concrete cubes of the five mixes of concrete. A total of fifteen (15) samples of concrete were cast and after 28 days curing in clean water, water

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absorption capacity was determined in accordance with BS EN 12326-2 (2002).

2.2.4 Test of CCW-Concrete in Acidic Environment: The five mixes of CCW-Concrete were used to determine the effect of acidic media on concrete. A total of thirty (30) number cubes of 150 mm x 150 mm x 150 mm of concrete were cast and cured in clean water for 28 days. At the end of every curing regime, three samples were air dried, then weighed before immersing in 10 % concentration of sulphuric acid and hydrochloric acid. The concrete cubes were weighed after immersion in the acidic media for 28 days and tested in compression to determine the compressive strength of the samples.

2.2.5 Statistical Modeling of CCW-Concrete Resistance in Acidic Environment: Statistical models were developed from experimental data using MINITAB 11 software to predict resistance behavior of CCW-Concrete. The models were also used to analyze the sensitivities of CCW in the resistance to acid attack. In developing the resistance prediction models of the concrete, two effects were considered; influence of CCW content and influence of duration of exposure on compressive strength of concrete sample retained. The software generates model equations and graphs that would best fit the experimental data. A comparison is then made between the experimental data and data generated by the models and the error difference evaluated.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Physical properties of concrete constituent materials: The physical properties of the constituent materials are shown in Table 1, while the particle size distribution curves are shown in Figure 1. The grain size curve indicates that the sand used is classified as zone 2 based on BS 882-2 (1992) classification.

Table 1: Physical properties of constituent materials

Property	Cement	Sand	Crushed granite	CCW
Specific gravity	3.14	2.55	2.65	2.04
Bulk density (kg/m^3)	-	1630.0	1562.0	-
Moisture content (%)	-	-	-	1.82

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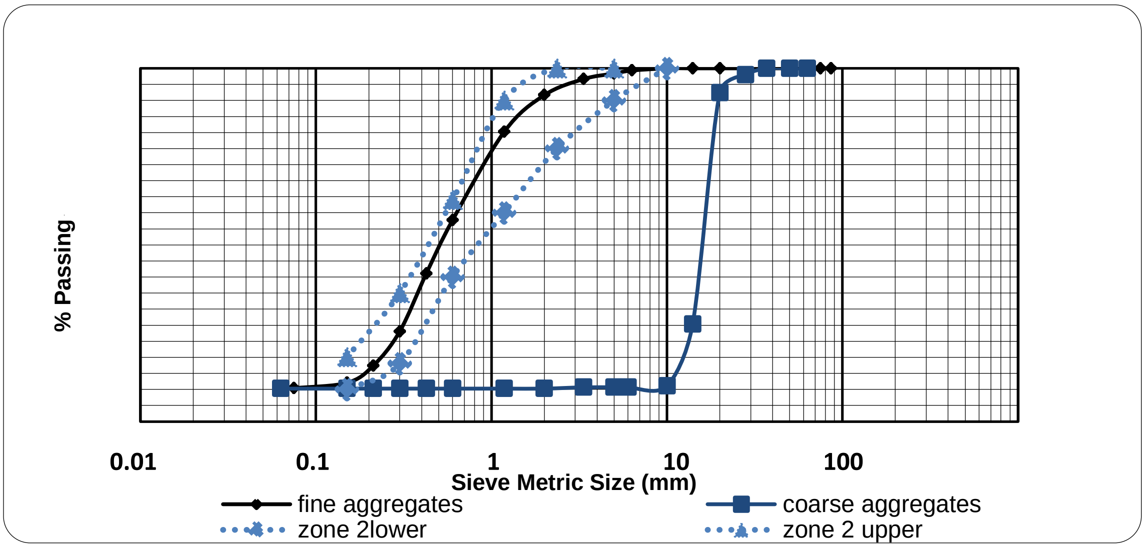

Figure 1: Particle size distribution of River sand and coarse aggregate

3.1.2 Cement and Calcium carbide waste: The oxide composition of cement and calcium carbide waste (CCW) is presented in Table 2.

3.1.3 Compressive Strength of CCW-concrete: The compressive strength behaviour of CCW-concrete is shown in Figure 2.

Table 2: Oxide composition of OPC (Ashaka brand) and CCW

Oxide (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	BaO	L.o.I
OPC	18.0	3.10	4.80	67.34	1.48	0.35	0.32	1.82	0.35	0.16	1.30
CCW	2.1	0.50	0.54	95.69	-	0.47	-	0.31	-	0.09	

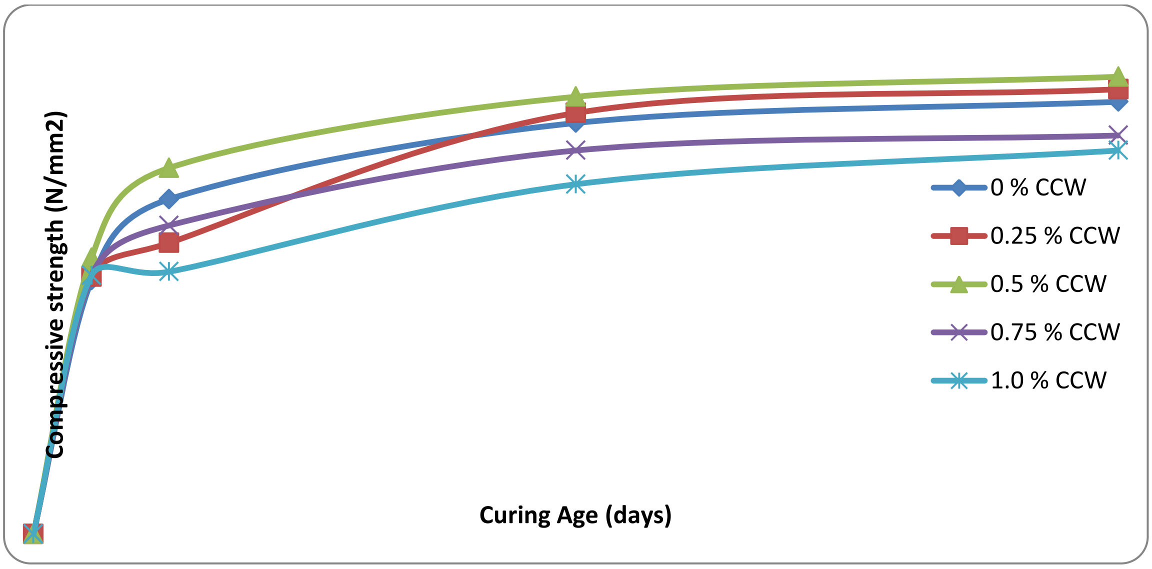

Figure 2: Compressive Strength Development of CCW-Concrete

3.1.4 Water Absorption of CCW-Concrete: The water absorption characteristics of CCW-Concrete is presented in Figure 3.

3.1.5 Resistance of CCW-Concrete in Acidic Environment: The effect of acid attack on CCW-concrete is shown in terms of compressive strength in Figure 4, and compressive strength loss in Figure 5.

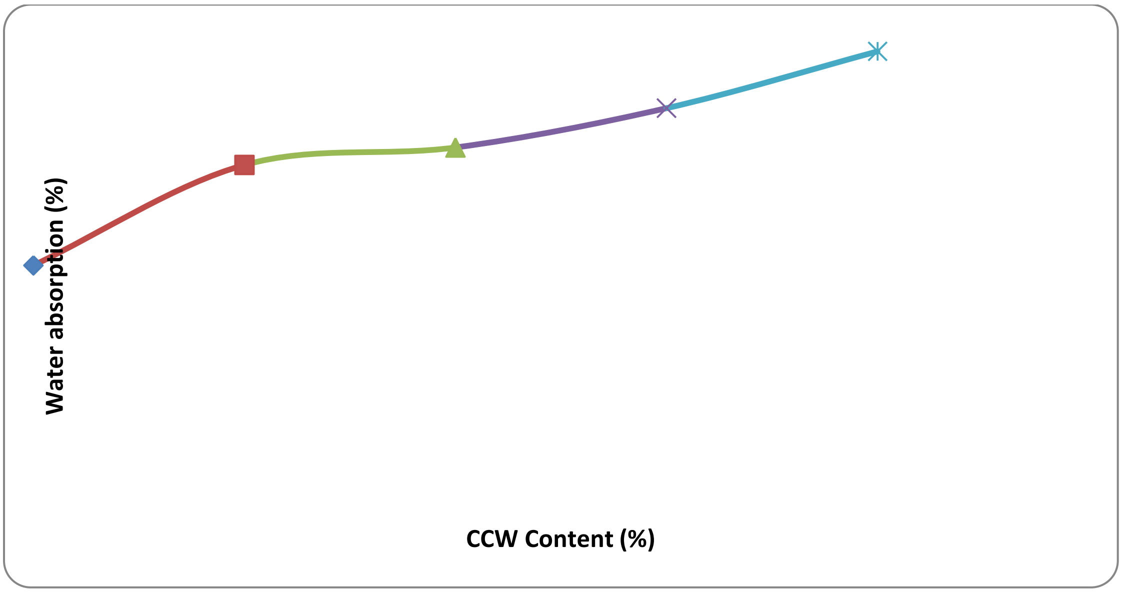

Figure 3: Water Absorption of CCW-Concrete

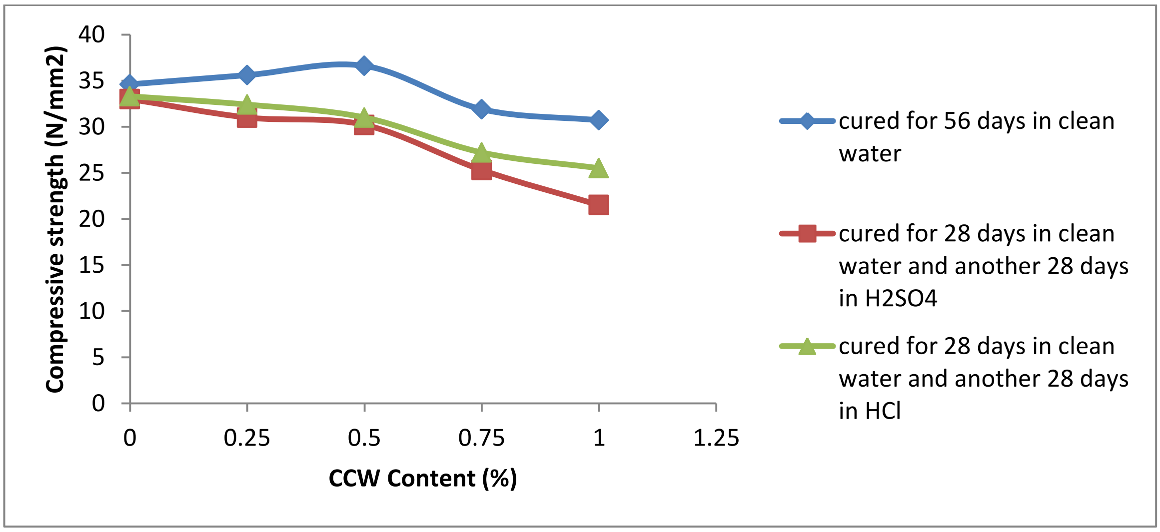

Figure 4: Comparison of Compressive Strength of CCW-Concrete Exposed to Acidic Media and clean water

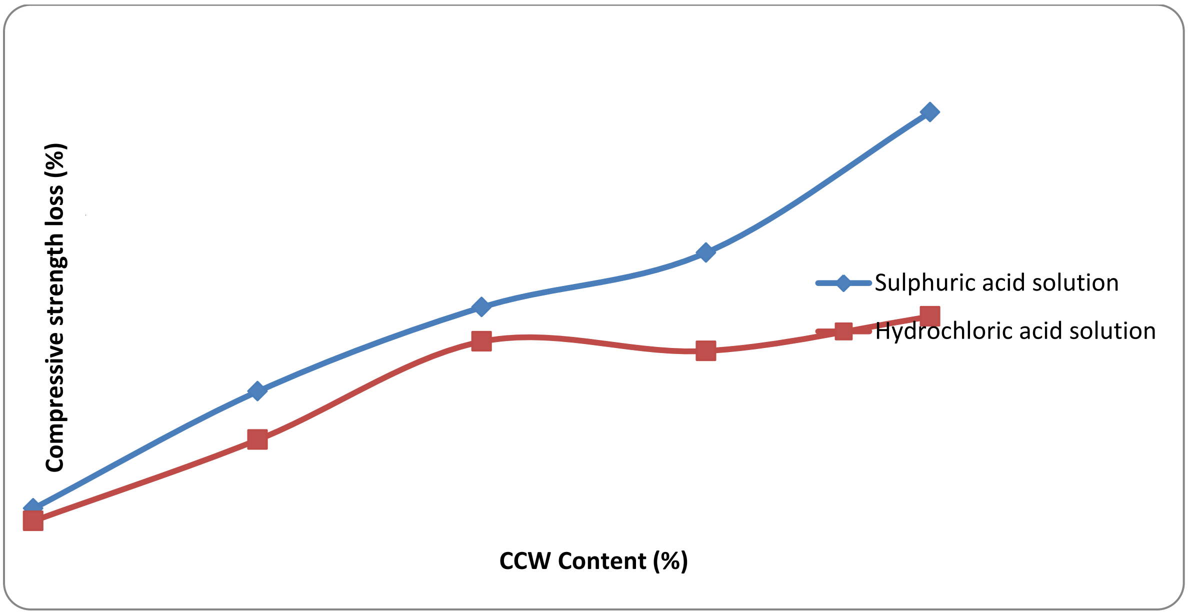

Figure 5: Compressive Strength Loss of CCW-Concrete Exposed to Acidic Media

3.1.6 Compressive Strength Models for CCW-Concrete in Acidic Environment: The model equations for CCW-concrete compressive strength retained in H_2SO_4 and HCl environments are given in Equations (2) and (3), respectively.

$$f_{H2SO4} = 126.0 - 2.93\ CCW - 17.1\ E \qquad (2)$$

$$f_{HCl} = 117.0 - 1.62\ CCW - 11.8\ E \qquad (3)$$

Where; $f_{H2SO4,}$ $f_{HCl,}$ is concrete compressive strength retained in H_2SO_4 and HCl medium, respectively. CCW and E are CCW content at 0, 0.25, 0.5, 0.75, 1.0 % addition and exposure duration of 0-28 days of samples, respectively.

3.2 Discussion of Results

3.2.1 Cement and Calcium carbide waste: The oxide composition of calcium carbide waste (CCW), Table 2 indicates that it is predominantly CaO (95.69 %) and low combined SiO_2, Al_2O_3 and Fe_2O_3 content of 3.14 %. This shows that CCW is cementitious and may combine with certain pozzolanas containing high silicon dioxide and aluminium oxide in a hydrated mix, and due to pozzolanic reactions yield final products that are similar to those obtained from cement hydration process, consistent with Wang *et al.* (2013). The chemical composition of the cement is satisfactory and has met the BS EN 197-1 (2000) standard.

3.2.2 Compressive Strength of CCW-concrete: The compressive strength of CCW-concrete (Figure 2) shows that compressive strength increased with curing age and also increased with addition of up to optimum of 0.5 % of CCW. Further increase in addition of CCW showed a decrease in compressive strength of the concrete as shown in Figure 2. The 28 days compressive strength of concrete with 0.5 % CCW content was 6.4 % more than that of control, while that of concrete with 1.0 % CCW content was 14.9 % less than that of control. The increase in compression strength with curing age is due to hydration of cement and CCW, while increase in compressive strength with addition of CCW up to 0.5% may be due to formation of additional calcium silicate hydrates from the hydration of CCW. The reduction in compressive strength with addition of CCW of 0.75 % and above may be due to saturation of the cement mix with oxides of CaO from CCW which may inhibit the formation of strength giving calcium silicate hydrates from cement hydration; this is consistent with Elinwa and Abdulkadir (2011) report on sawdust ash in concrete.

3.2.3 Water Absorption of CCW-Concrete: The water absorption of CCW-Concrete shown in Figure 3, increased with increase in CCW addition, with highest value of 1.16 % at 1.0 % CCW content. The water absorption was however below 10 %, which is still within the range experienced in most good concrete (Neville, 2003). The increase in water absorption may be due to the reaction between sulphate ions present in the calcium carbide waste and the $Ca(OH)_2$ of cement which cause increment in the pore sizes of the concrete thereby causing more water absorption. This is in agreement with works of Limaye *et al.* (1992).

3.2.4 Resistance of CCW-Concrete in Acidic Environment: The effect of acid attack on CCW-concrete shown in terms of compressive strength in Figure 4, and compressive strength loss in Figure 5 shows that CCW-concrete offered less resistance to sulphuric acid and hydrochloric acid aggression than ordinary Portland cement concrete. There was a reduction in the compressive strength with increase in CCW content of the concrete samples exposed to the acidic media. This may be attributed to the attack on $Ca(OH)_2$ from CCW, and $Ca(OH)_2$ and C-S-H formed during cement hydration. The extent of acid attack is dependent on the type of acid and solubility of the calcium salt formed (Goyal and Kumar, 2009). The compressive strength loss of CCW-concrete due to sulphuric acid attack ranged from 4.6-30 % for concrete with 0 – 1.0 % CCW content, while that in hydrochloric acid experienced a compressive strength loss of 3.8-16.9 % for concrete with 0–1.0 % CCW content. The results showed that sulphuric acid was more aggressive than hydrochloric acid to CCW-concrete.

3.2.5 Compressive Strength Models for CCW-Concrete in Acidic Environment: For the model equations for CCW-concrete compressive strength retained in H_2SO_4 and HCl environments as given in Equations (2) and (3), respectively, at 0.05 level of significance, from the regression analysis, P-value = 0.000 for both CCW content and exposure duration in H_2SO_4 solution, and shows that both variables are significant ($P < 0.05$) signifying that the variation in the concrete compressive strength retained in H_2SO_4 medium is caused by CCW content and exposure duration. In the case of CCW concrete exposed in HCl medium, at 0.05 level of significance, P-value = 0.001 and 0.000 for CCW content and exposure duration, respectively. This also shows that both variables are significant ($P < 0.05$) signifying that the variation in the concrete compressive strength retained in HCl medium is caused by CCW content and exposure duration.

The coefficient of determination, (R^2) of the models is 81.6 % and 80.7 %, for compressive strength retained in H_2SO_4 and HCl medium, respectively. This indicates that the variation of concrete compressive strength retained is significantly dependent on the variations of CCW content and exposure duration in H_2SO_4 and HCl solution. The residual and normality plots (Figure 6 and 7; 8 and 9) were drawn for the CCW-concrete compressive strength retained in H_2SO_4 and HCl medium, respectively to further examine how well the models fit the data used. It was observed that there were few large residuals (16.67-22.22 % of residuals in plots), similar to works of

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Field (2002), and Elinwa and Abdulkadir (2011); and limited apparent outlier, consistent with observations of Razak and Wong (2004). This confirms that the models are adequate for prediction of the sensitivities of CCW activity in concrete in acidic environment.

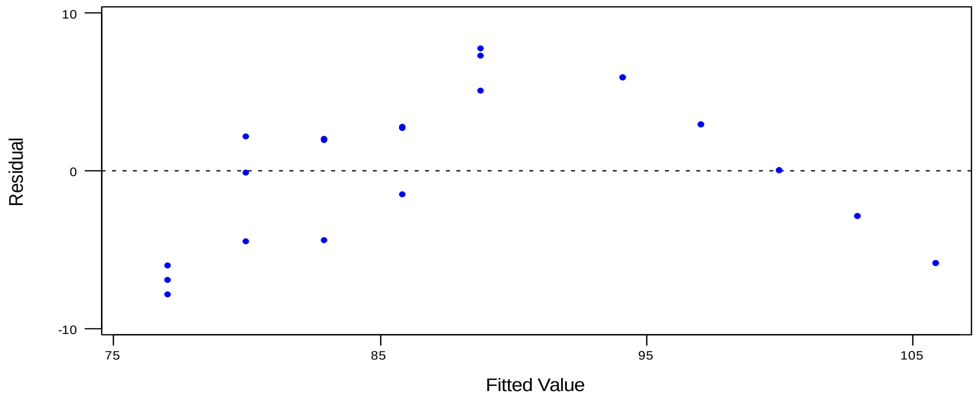

Figure 6: Residual versus fitted values for compressive strength retained of CCW-concrete in H_2SO_4 solution

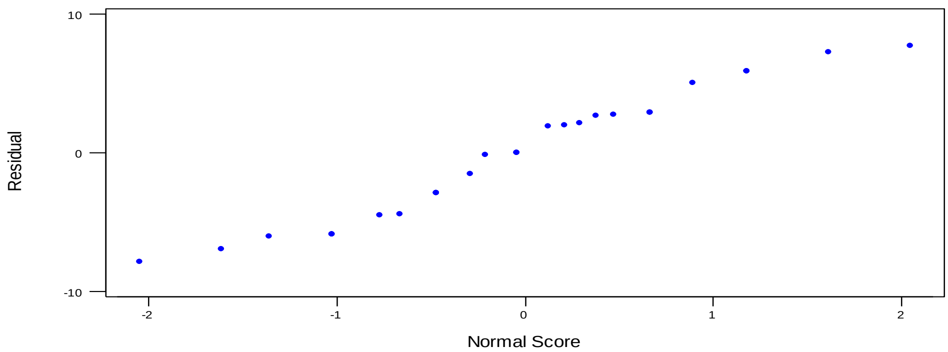

Figure 7: Normal probability of residuals for compressive strength retained of CCW-concrete in H_2SO_4 solution

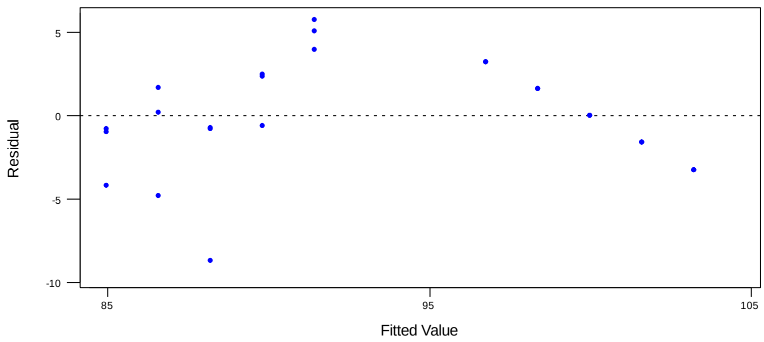

Figure 8: Residual versus fitted values for compressive strength retained of CCW-concrete in HCl solution

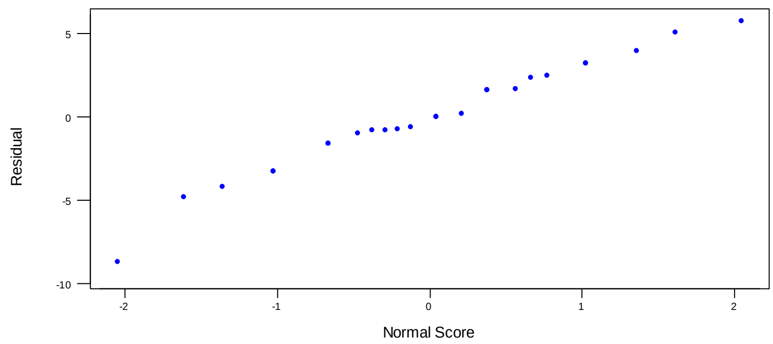

Figure 9: Normal probability of residuals for compressive strength retained of CCW-concrete in HCl solution

4. CONCLUSIONS

Calcium carbide waste (CCW) is predominantly of CaO (95.69 %). The addition of up to optimum of 0.5 % CCW increased the compressive strength of concrete. The addition of CCW slightly increased water absorption of concrete

The addition of CCW decreased the resistance of concrete exposed to acidic environment and therefore not suitable for use in acidic environment. The models of compressive strength for CCW-concrete in acidic environment given in Equations (2) and (3) with R^2 values of 0.816 and 0.807 could be used to predict the concrete compressive strength exposed to acidic environment.

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