EFFECTS OF COMBINING METAKAOLIN AND CEMENT KILN DUST AS CEMENT REPLACEMENT MATERIAL IN CONCRETE.

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Abstract
Results of Compressive strength test and slump test of concrete containing Metakaolin and CKD at varying replacement levels are discussed and are compared with those obtained with the control (pure Portland cement concrete). The total partial replacement was considered in the range of 0% (i.e. control) to 50% by weight in steps of 10%. The combination for each replacement level apart from 0% are as follows: 10% (8%CKD and 2%MK), 20% (l6%CKD and 4%MK), 30% (24%CKD & 6%MK), 40% (32%CKD & 8%MK) and 50% (40% CKD and 10% MK). Cubes were cast with three mixes with varying water cement ratio; 0.55/1:1.5:3, 0.6/1:1.5/3 and 0.65/1:/1.5/3 with the aim of achieving medium strength structural grade concrete. Cubes were cured in water and tested at 7, 14 and 28 days respectively, to appreciate the strength development at each replacement value. It was observed that workability decreased with increase in replacement and that strength also decreased with increase in replacement, the best result for replacement was obtained at 10% replacement with at least 95% of the control strength. It was also observed that more than 90% of the compression strength at 28days had been attained at 14days.

Keywords: *Cement kiln dust, Metakaolin, compressive strength, workability, replacement, Boque's equation.*

1.0 INTRODUCTION

Increasing focus on the beneficial usage of industrial and agricultural waste in order to ensure environmental protection, energy conservation with minimal impact on economy have been motivating researchers to source for other alternatives for cement in the concrete industry. Such materials provide environmentally safe, stable, more durable and low cost civil engineering construction. For, it is well known that the production of cement (key building component of concrete) is costly, consumes high energy, depletes natural resources and emits large amount of greenhouse gases (mostly CO_2).

Industrial and agricultural by-products and wastes are often economic and environmental burdens to the society, hence recycling of such waste as a suitable construction material appears to be a viable solution not only for the pollution problem but also economic purpose.

Waste materials from mineral and industrial sources are generated daily and the safe disposal of these wastes is increasingly becoming a major concern around the world. Some of these by-products include but are not limited to, Blast Furnace Slag (BFS), Pulverised Fly Ash (PFA), Cement Dust, Stone Crusher Dust, Marble Dust, Bricks Dust, Sewer Sludge, Glass, Metakaolin, etc (Moses and Afolayan, 2013; Yusuf, 2001; Okpala, *et al.*, 1998;) Millions tonnes of these waste materials whose disposal often constitutes a challenge are abundantly available and discarded every year in the world.

The present work focuses on investigating the optimal replacement of cement in Concrete with a combination of Metakaolin (MK) and Cement Kiln Dust (CKD) using the Boque's equation approach. Previously, researchers have shown a lot of interest in these two industrial wastes individually and they have been found to possess both pozzolanic and micro filler characteristics (Dvorkin *et al.*, 2012, Marku *et al.*, 2012; Poon *et al.*, 2001).

Metakaolin is normally produced by calcining pure clays at appropriate and controlled temperatures. It is also known that metakaolin can be obtained by the calcinations of indigenous laterite soils. On calcinations of laterite in the range 750-800°C, kaolinite and gibbsite are transformed into transition phases of metakaolin and amorphous alumina both of which possess pozzolanic properties. Pera and Ambroise (1985) showed that blended cements containing 30% calcined laterite produced strengths (between 7 and 28 days) higher than that of plain concrete pastes. At 180 days the strength of paste containing 50% calcined laterite was 87% of that developed by plain Portland cement. Metakaolin is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicate hydrates. This is in line with the observation of Caldron and Burge (1994) who stated that metakoalin is a material with high pozzolanic activity comparable to or exceeding the activity of silica fume. Thus the addition of metakaolin has been shown to improve or enhance the strength and other qualities of concrete such as shrinkage, alkali silicate reaction, durability of concrete including resistance against chloride attack, etc (Ding *et al.*, 1997; Tazawa and Miyazawa, 1995; Liu and Wen, 1995; Coleman and Page, 1997; Zhang *et al.,* 1995 and Majudar Singh, 1992). Also, reported by Justice and Kurtis (2007) was an increase in compressive strengths with increase proportion of metakaolin; they reported that compressive strength increases in the range of 15-50% depending on the metakaolin type, water/cement ratio and age when compared with concrete without cement replacement. However, various researchers have reported that workability of concrete decreases with increase in proportion of cement replacement Justice and Kurtis (2007); Dubey and Banthia (1998); Quian and Li, (2001); and Wong and Rasak, (2005).

Also, the use of CKD as cement replacement or addictive with or without other pozollanas in the production of concrete has been investigated by a number of researchers sometimes with varying results (Abo-El-Enein *et al.*, (1994); Ali-Harthy *et al.*, (2003); Adaska and Taubert (2008); Abdulabbas, (2013); Chaunsali and Peethamparan, (2013); Mahure and Mohitkar, (2013); Mehetre *et al.*, (2014); and El-Mohsen *et al.*, (2015); Al-Harty *et al.,* (2003) reported that up to 5% CKD replacement has no negative effect on strength properties. However, Mahure & Mohitkar, (2013) reported that up to 20% CKD replacement has no significant effect on the compressive, flexural and tensile strengths of the concrete. Furthermore, Abdulabbass, (2013) reported that using CKD as an additive at up to 20% resulted in increase in compressive strength while using CKD as cement replacement resulted in decrease in strength up to the 20% replacement level that was investigated. Abdulabbass, (2013) reported like previous researchers that inclusion of CKD resulted in decrease in workability but that the use of super plasticisers resulted in increase in workability and corresponding increase in strength of the concrete.

Thus, previous works have shown that metakaolin and CKD can be beneficial as cement replacement material, individually or when used with other pozollanas. However, these other works have concentrated on replacing cement in the mix in step replacement of 10 to 100% without any consideration on the change in composition of the resulting cementing materials. Furthermore, it is of note that most of these researches were based on metakaolin produced under controlled conditions or from highly efficient industrial processes; therefore their qualities will be very high. In Nigeria, most clay brick industries are not run as efficiently as in developed or advanced developing countries, so some of the results observed may not be replicable in Nigeria. The present study aims at using metakaolin which is waste from local brick industries.

Furthermore, hitherto, replacement or combination of pozollanas has not been based on any particular rational method. Though Adepegba, (1990) suggested a method of producing cement by combining at least three pozzolanas at appropriate proportion for effective result. This approach was not proven because there is no report that such cement was produced or tested for performance. Furthermore, their method is not for cement replacement but the production of an alternative to OPC by combining pozzolanas other than cement. The rational approach adopted in this study is based on the Boque's (Rosemount, 1995) equation which works out the proportion of the products of cement hydration based on the proportion of oxides of the cement. The MK and CKD were blended with cement in such a way as to produce quantities of hydration that were close to or similar to those that would have been produced with normal cement.

2.0 MATERIALS AND METHODS

2.1 Materials

Table 1: Major Oxide Composition of Cement Kiln Dust, Metakaolin and Cement

OXIDE	CKD	METAKAOLIN	CEMENT
SiO_2	9.36	57.32	22.0
Al_2O_3	5.9	23.7	6.0
CaO	40.77	0.376	63.0
Fe_2O_3	2.53	14.03	3.0

a) Cement Kiln Dust: The CKD used was obtained from freshly deposited heaps of the waste at the Sokoto Cement production plant, located in Nafada LGA in Sokoto State, Nigeria. The CKD was sieved through BS No 200 and was stored in an air tight container before usage. The major oxide composition of cement kiln dust is given in Table 1. Chemical analysis of CKD was carried out at the Chemical Laboratory of National Geology Research Laboratories Centre, Kaduna. The X-ray Analyzer together with the atomic absorption spectrophotometer (AAS) was employed for the analysis.

b) Metakaolin: The reddish brown metakaolin (MK) used was obtained from freshly deposited heaps of the waste at a brick block production plant located in Chukun Local Government Area of Kaduna State, Nigeria. The reddish tint is assumed to come from high content of Iron oxides. The MK has a specific gravity of 2.5. It was ground and passed through BS No. 200 sieve (75 µm aperture) and stored in air-tight containers before usage. The portion passing the sieve was compared to the required degree of fineness, that is 63 microns and below while the MK retained on the sieve was reground and sieved again. Chemical analysis of MK was carried out using an X-ray analyzer together with an atomic absorption spectrophotometer (AAS). The major oxide composition of the MK is also presented in Table 1.

c) Cement: Cement used was Dangote Grade 42.5R brand of Ordinary Portland Cement bought from a local dealer in Mando area of Kaduna. The major oxide composition of the cements is as presented in Table 1.

d) Water: In this study, normal tap water from the laboratory was used. Water is needed for the hydration of cement and to provide workability during mixing and for placement.

e) Aggregates: The fine aggregate used is a well graded sharp river sand, while the coarse aggregate was machine crushed granite chippings of 20mm nominal size obtained from a depot around the NAF Base, Mando Roundabout, Kaduna.

2.2 Methods

a. **Blending of Cement:** Cement was replaced in the mixes from 10% to 50% at 10% intervals. The proportion of OPC, CKD and MK in each blend or each level of replacement is as shown in Table 2. The proportioning was obtained from the estimated amount of hydration products using the Boque's equation as a basis. The optimum blend proportion at each level of replacement was obtained by targeting simultaneously the highest total amount of products of hydration and highest amount of C_3S and C_2S estimated to be produced; the process was aided by an EXCEL spreadsheet programme). Boques (Davies and Barry, 1994) indicated that the proportions of the product of hydration of cement are dependent on the proportion of the major chemical oxides of the cement and is given as follows:

i. $C_3S = 4.07CaO - 7.60Si0_2 - 6.72Al_20_3 - 1.43Fe_20_3 - 2.85S0_3$
ii. $C_2S = 2.87Si0_2 - 0.754(3\ CaO.Si0_2)$
iii. $C_3A = 2.65A1_20_3 - 1.69Fe_20_3$
iv. $C_4AF = 3.04Fe_20_3$

Table 2: Blending of Binders and Expected Amount of Product of Hydration

BLEND ID/ REPLACEMENT VALUE	OPC .(%)	CKD (%)	MK (%)	BOGUES (%)				Total	C_3S+ C_2S
				C_3S	C_2S	C_3A	C_4AF		
A: 0%	100	0	0	54.0	16.7	11.0	9.2	**90.9**	**70.7**
B: 10%	90	8	2	40.4	26.6	11.6	9.7	**88.3**	**67.1**
C : 20%	80	16	4	26.9	36.6	-12.2	10.2	**73.7**	**63.4**
D : 30%	70	24	6	13.3	46.5	12.8	10.8	**83.4**	**59.8**
E: 40%	60	32	8	-0.03	56.3	13.3	11.0	**80.6**	**56.3**
F : 50%	50	40	10	-13.7	66.3	14.1	11.9	**92.3**	**66.3**

Note: Negative values ignored in addition

b. Mix design: Prescribed mix approach was adopted with a view to targeting structural grade concrete of 25-30N/mm^2 measured on 100mm cubes. The following prescribed mixes were adopted after a set of preliminary trial mixes; 0.55/1:1.5:3, 0.6/1:1.5:3 and 0.65/1:1.5:3.

c. Mixing Procedure: The mixing procedure was divided into three stages. In the first stage, all the binders (cement, metakaolin and cement kiln dust) were weighed accordingly and mixed by hand until all the constituents mixed uniformly to produce a homogenous mix. The second stage involves mixing the binders with the aggregates for about 5 minutes. At the final stage, measured water was added into the concrete mix and mixing continued manually until a consistent mix was obtained.

d. Preparing Test Cubes: Nine (9) 100mm cubes were cast per mix and per replacement level. Each result is an average of results of three cubes. Preparation was according to the procedure of BS EN 12390-2:2000 and BS EN 12390-3:2003 using tamping rod for compaction. The cubes were demoulded after 24hrs and cured in water at ambient temperature (about 24°C) until the day of testing.

e. **Testing:** After mixing and before casting of cubes, the slump test was used to determine the workability of each mix. This test was carried out according to the procedure in BS EN 12390-2:2000 and BS EN 12390-3:2003

At ages 7, 14 and 28days, the compressive strength of the cubes were determined at the Concrete Laboratory of the Civil Engineering Department, Nigerian Defence Academy with the Automatic 3000kN ELE Compression Testing machine according to the procedures in BS EN 12390-3:2003

3.0 DISCUSSION RESULTS

3.1 Workability

The results of the Slump test which was conducted to determine the workability of the mixes are presented in Table 3. As would be expected, the workability increased with increase in water/cement ratio for every binder combination. Furthermore, the workability decreased with increase in cement replacement indicating increasing water demand of the both CKD and MK. This latter observation is similar to that in many previous works (Okpalla, 1987; Zhang and Malhotra, 1996; Alabadan et al. 2005, Oriola and Moses, 2014) involving cement replacement with pozollanas.

Table 3: Workability of Concrete Mixes

BINDER COMBINATION	WORKABILITY (SLUMP)		
	w/c = 0.55	w/c = 0.6	w/c = 0.65
A	Shear slump/ 115mm	Shear almost collapse slump/ 128mm	Collapse slump/ 145mm
B	True slump/ 49mm	Shear slump/65mm	Collapse slump/ 115mm
C	True slump/40mm	Shear slump/52mm	Shear slump/92mm
D	True slump/ 30mm	True slump/43mm	Shear slump/ 75mm
E	True slump/ 20mm	True slump/30mm	Shear slump/62mm
F	True slump /25mm	True slump/35mm	True slump/43mm

3.2 Strength Development

Fig. 1, 2 and 3 shows the result of the compressive strength test at 7, 14 and 28 days for 0.55/1:1.5:3, 0.6/1:1.5:3 and 0.65/1:1.5:3 mixes respectively. Generally, increased compressive strength was observed as curing period increases. However, the increase in strength between 14days and 28days was not appreciable. This observation seems to contradict the observation of FAO, (1986) that the strength of concretes made with pozollanas normally improve with age, since pozzolanas react more slowly than cement due to different composition and at one year or about the same strength is attained. In this study it appears that the strength gain has virtually been completed at 14days. Therefore, it is essential that curing at early age up to 14 days should be very strict, if the targeted strength is to be achieved with this combination or blending method.

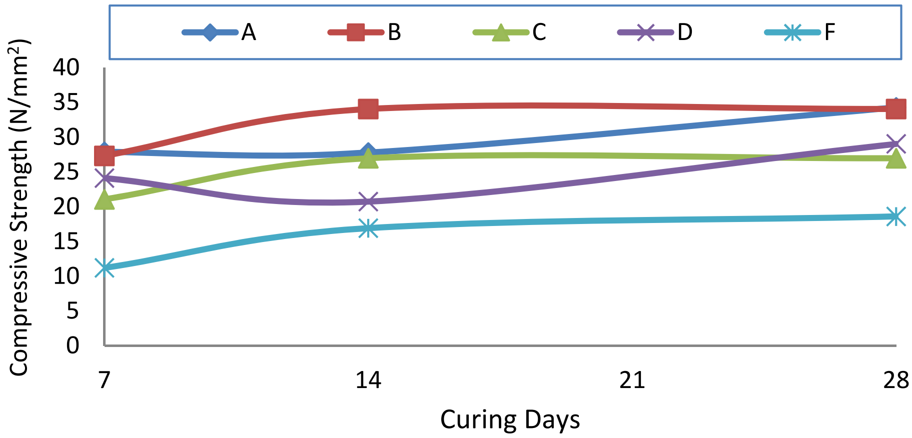

Fig.1: Curing days/Compressive Strength for various replacement of OPC (0.55 w/c ratio)

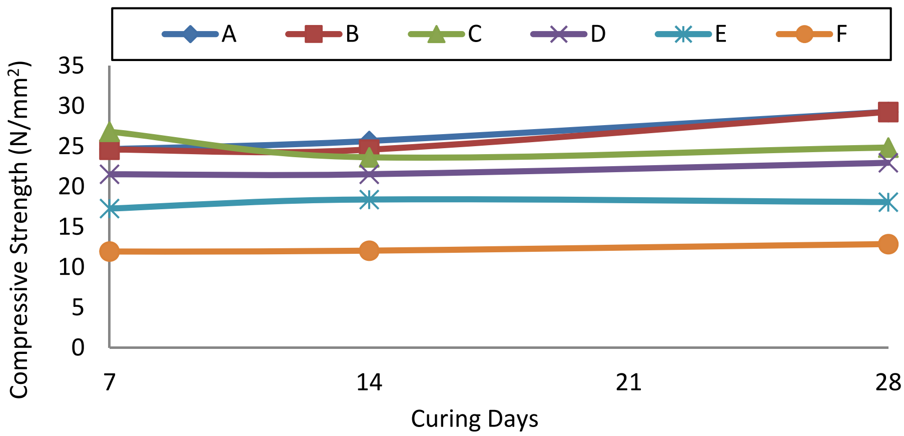

Fig.2: Curing days/Compressive Strength for various replacement of OPC (0.60 w/c ratio)

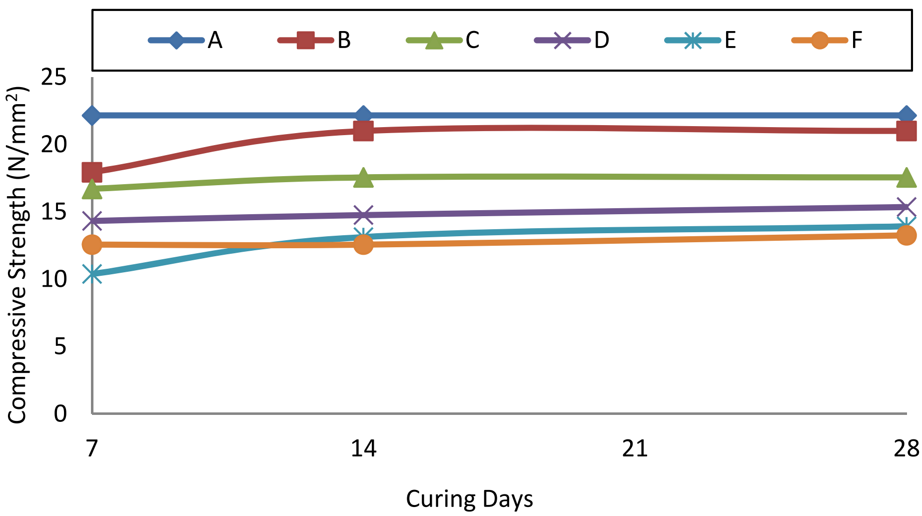

Fig.3: Curing days/Compressive Strength for various replacement of OPC (0.65 w/c ratio)

3.3 28day Compressive Strength

a) Variation with water/cement ratio: The compressive strength of all the mixes decreased with increasing water/cement ratio. The trend is similar at all levels of cement replacement; this is presented in Fig. 4 Therefore, increase in workability arising from more water did not result in increase in compressive strength for this mix. It would appear that there is more than enough water for hydration at every water cement ratio. Therefore, indirectly, compaction was not the problem even for mixes with low slump values.

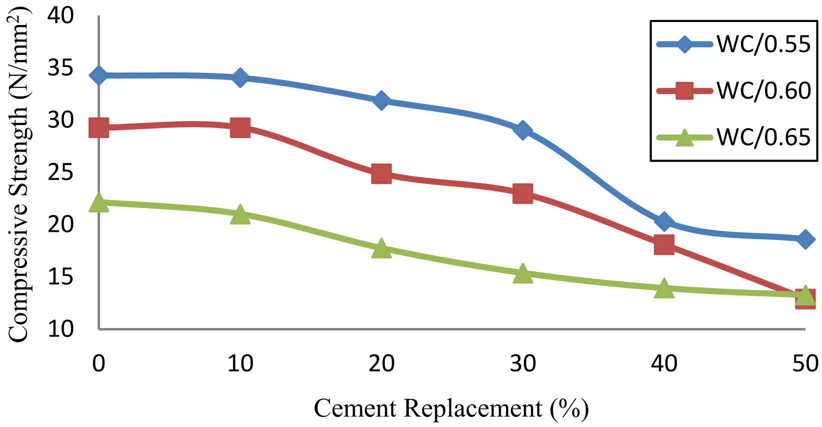

Fig. 4: Variation of Grade of Concrete with Variation in Cement Replacement and Water/Cement Ratio

b) Variation with Percentage of Cement Replacement: Fig. 4 also shows the variation of the compressive strength at 28 days (grade) with respect to percentage of cement replacement for the three concrete mixes. For concrete with 0% replacement the observed compressive strength values were 34, 29 and 22N/mm^2 for 0.55, 0.6 and 0.65 w/c ratio respectively. Therefore, for this mix proportion only mixes of 0.55 and 0.6 w/c ratios produced structural grade concrete, though the 0.65 w/c ratiomix can be used for mass concrete works.

In general and for each w/c ratio the compressive strength decreased with increasing level of cement replacement; the decrease was gentle up to 30% replacement level but was followed by a sharp drop. More details of this variation are presented in Table 4. It indicates that for w/c ratio of 0.55, the percentages of compressive strength as compared to the control are 100%, 94%, 85.3%, 60% and 56.3% for 10%, 20%, 30% 40% and 50% replacement level respectively. At w/c ratio of 0.6, these values are 100%, 86.2%, 79.3%, 62.1 and 54% respectively. Furthermore, at w/c ratio of 0.65, the percentages of compressive strength as compared to the control are 95.5%, 80%, 69.5%, 63.3% and 60.5% for 10%, 20%, 30%, 40% and 50% replacement level respectively. The results indicate that the level of strength loss increases with increase in water/cement ratio and increase in workability should not be achieved with increasing water/cement ratio.

Furthermore, if an acceptance level of about 15% of the control strength is adopted, then for workable mixes, up to 30% replacement can be adopted for low water/cement ratio, 20% replacement could be adopted for medium/moderate water/cement ration and only 10% replacement will satisfy this bond for high water/cement ratio. FAO, (1986) reported that cement blended with pozzolanas would produce 65 to 95 % strength of OPC concrete in 28 days In this study, the lower limit of 65% compressive strength was achieved for all the mixes with 30% or lower replacement of cement, while the 95% upper limit was achieved only at about 20% for the mix with w/c ratio of 0.5 and at 10% for mixes with w/c ratio of 0.6 and 0.65. However, to achieve this level of confidence, the curing regime must be very strict. These results are similar to those obtained by Oriola and Moses, (2013). on the effect of replacing cement with CKD in concrete. This is not unexpected because the Boque's equation adopted tends to favour CKD over MK in the proportioning of the blending because of the high CaO content.

Table 4: Level of Compressive Strength at Various Cement Replacement Level Compared with the Control

BINDER COMBINATION ID	COMPOSITION			Compressive Strength with respect to Control(%)		
	OPC%	CKD%	MK%	0.55/1:1.5:3	0.6/1:1.5:3	0.65/1:1.5:3
A	100	0	0	100.0	100.0	100.0
B	90	8	2	100.0	100.0	95.5
C	80	16	4	94.0	86.2	80.0
D	70	24	6	85.3	79.3	69.5
E	60	32	8	60.0	62.1	63.3
F	50	40	10	56.0	54.0	60.5

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Laboratory tests and analysis were undertaken to investigate the possibility of combining CKD and MK obtained as waste from burnt clay industries as a replacement material for OPC in concrete based on the Boque's equation. The result suggests that the cement replacement may be achieved at ratio of 80%:20% for CKD and MK at every level of replacement. With this approach, the compressive strength is not significantly different from the control at up to 20% replacement at low w/c ratio and workable mix. For moderate to high w/c ratio, the compressive strength is not significant at 10% level of replacement. In general however, up to 30% level of replacement may be adopted but a plasticiser is recommended for low w/c ratio. It also shows that much of the strength development has taken place in the first 14 days of curing and that much further strength growth cannot be guaranteed.

4.2 Recommendations

a) Metakaolin obtained from burnt clay Brick Industry may be combined with CKD to achieve concrete of similar strength to normal concrete up to a replacement level of 20%, when the CKD and metakaolin is combined at the ratio of 4:1.

b) Up to 30% replacement may also be adopted at low water/cement ratio and with the use of water reducing agent to aid workability.

c) Concrete must be properly cured with the first 14days to ensure that the target strength is achieved.

REFERENCES

American Society for Testing and Materials Standards (1992), *ASTM C618 Standard Specification for Fly Ash and Raw or Calcium Natural Pozzolanas for Use as a Mineral Admixture in Portland Cement Concrete*, West Conshohocken, Pennsylvania, USA, , Volume 04.

Abo El-Enein, S. A.; Hekal, E. E.; Gabir, N. A. and El-Bambary, M. I. (1994), "Blended Cements Containing Cement Kiln Dust, " Silicates Industrials, 59: 9-10.

Abdulabbas, Z.H. (2013). “Utilization of Cement Kiln Dust in Concrete Manufacturing”. Jordan Journal of Civil Engineering, 7(1): 111-125

Adaska, W. S. and Taubert, D. H. (2008). “Beneficial Uses of Cement Kiln Dust”, IEEE/PCA 50th Cement Industry Technical Conference, Miamu, Florisa May 2008.

Adepegba D. (1990), “Nigeria: Pozzolana – The cheap alternative to Portland Cement”, *Seminar Paper, Seminar on Local Building Materials for Housing, 3rd Int. Seminar of the African Network of Scientific and Technological Institutions (ANSTI),* Mauritius, Reduit, March 1990.

Ali-Harthy, A.S., Taha, R. and Al-Maamary, F. (2003). “Effect of Cement Kiln Dust) on Mortar and Concrete Mixtures”. Construction and Building Materials, 17: 353-360.

British Standards Institution (1985), *BS 8110 Part 2: Structural use of concrete. Code of practice for design and construction*, London, 1985, p. 7/1

Chaunsali, P. and Peethamparan, S. (2013). “Influence of the Composition of Cement Kiln Dust on its Interraction with Fly Ash and Slag”. Cement and Concrete Research, 54: 106-113

Dubey and Banthia, (1998), Background Report on Fertilizer Use, Contaminants and Regulations, National Program Chemicals Division, Office of Pollution Prevention and Toxics, United States Environmental Protection Agency, Washington, DC, USA, EPA
747-R-003, January 1998.

El-Mohsen, M.; Anwar, A.M. and Adam, I.A. (2015). “Mechanical Properties of self-consolidating concrete incorporating Cement Kiln Dust”. Housing and Building Research Center Journal, 11:1-6

FAO, (1986) *Farm Structures in Tropical Climates: A Textbook for Structural Engineering and Design*. FAO/SIDA Cooperative Programme. Edited by L.P. Bengtsson and J.H. Whitker. 1986 pp 394.

Justice and Kurtis (2007) " Effect of Mechanochemical Activation on Reactivity of Cement Kiln Dust-Fly Ash System" ACI Materials Journal, 100(1):55-62

Lee (1970), Use of Cement Kiln Dust in Stabilizing Clay Soils, Portland Cement Association, Skokie, Illinois, USA,1970.

Mahure, S.H. and Mohitkar, V.M. (2013). “Effect of Mineral Admixture on Fresh and Hardened Properties of Self Compacting Concrete”. International Journal of Innovative Research in Science, Engineering and Technology, 2(10), Oct 2013.

Malhotra and Baguant K, (1991) "Soil Stabilization Using Cement Kiln Dust," Proceedings of the 7th International Conference on Expansive Soils, Dallas, Texas, USA, August 1991.

Malhotra, (1999) "Soil Stabilization Using Cement Kiln Dust," Proceedings of the 7th International Conference on Expansive Soils, Dallas, Texas, USA, August 1991

Mehetre, C.U.; Urade, P.P.; Mahure, S.H. and Ravi, K. (2014) "Comparative study of properties of self compacting concrete with Metakaolin and Cement Kiln Dust as Mineral Admixtures". International Journal of Research in Engineering & Technology, 2(4):37-52

Okpalla, D.C. (1987), "Rice Husk Ash as a Partial Replacement for Cement in Concrete", *Proceedings of the Annual Conference of the Nigerian Society of Engineers*, Port Harcourt, Nigeria, pp. 1-12.

Oriola and Moses, (2014). "Partial Replacement of Sand with Foundry Sand in Bagasse Ash Concrete" Academy Journal of Science and Engineering. Nigerian Defence Academy, 7(1): 1-9

Pas and Ambroise (1985) "What is Dust? Characterization and Classification of Kiln Dust", 24th Technical Meeting, Holder bank Management and Consulting, Ltd. Technical Center, Material Division, Aargau, Switzerland, Report No. MA 77/2505/E, 1985.

Quian and Li, (2001) "Potential of Cement Kiln Dust for the Stabilization of Dune Sand in Highway Construction, " Journal of Building and Environment, 25(4):285-289.

Ravindrarajah, R. S., "Usage of Cement Kiln Dust in Concrete, " International Journal of Cement Composites and Lightweight Concrete, Harlow, UK, Vol. 4, No.2, May 1982.

Rosemount (1995) Method and Mixture for Solidifying and Immobilizing Various Hazardous Waste Contaminants in an Organic Matrix, Patent and Trademark Office, United States Department of Commerce, Washington, DC, USA, Patent No.: 4,909,849, 1995.

Spence R (1992), alternative cementing evaluation of experience. In; hill, N; homes, S and matter D (Ed) lime and other alternative cement, intermediate technology publication. London (1992) pp 3-17.

Soroushian and Hassan, (2012) "Comparison of Sewage Ash, Crushed Limestone and Cement Kiln Dust As Ameliorants for Acid Soils," Australian Journal of Experimental Agriculture, Commonwealth Scientific and Industrial Research Organization, East Me/bourne, Australia, 29(4).

Wong and Rakas, (2005) "Effects of Cement Kiln Dust (CKD) Chemistry and Content of Properties of Controlled Low-Strength Materials (CLSM)," PCA R&D Serial No. 2816, Portland cement Association, Skokie, illinois, USA, 2005.

Zhang, M. and V. M. Malhotra. 1996. High-Performance Concrete Incorporating Rice Husk Ash as a supplementary Cementing material. *Materials Journal*. 93(6): 629-636