Comparative Study of the Properties of Ordinary Portland Cement Concrete and Binary Concrete Containing Metakaolin Made from Kankara Kaolin in Nigeria

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Abstract

The study explored metakaolin as alternative material to cement. It compares the properties of Ordinary Portland Cement (OPC) concrete and binary concrete containing metakaolin as partial replacement of OPC. Two set of concrete samples; one with 10% Metakaolin (MK) replacing OPC by weight, and the other without MK (100% OPC) as control, were produced. The samples were tested for compressive and tensile strengths at 7, 14, 28 and 90 days. The result revealed that the slump of the binary concrete was 26% lower than the control. However, the compressive and tensile strengths of binary concrete were higher than those of control by 10.8% and 11.9% at 28days, and by 21.6% and 34.5% at 90 days, respectively. Therefore, the MK produced from Kankara Kaolin can be used as Pozzolan to improve the strengths of concrete.

Keywords: Pozzolana, binary concrete, OPC concrete, metakaolin

INTRODUCTION

Environmental concern due to high energy consumption and carbon dioxide (CO_2) emission associated with cement production has brought about pressures to partially substitute Portland cement with pozzolans for concrete production (Aiswarya, Prince & Dilip; 2013, Biljana et al, 2011). Some of the pozzolans are natural and others are by-products (artificial) and both contain silica in amorphous form and that will react with calcium hydroxide (CH) to form more cementitious calcium silicate hydrate (C-S-H) that contribute to the concrete strength (Habeeb & Mahmud, 2009; Najigivi, Abdul Rashid, Aziz, & Salleh,2010; Suryawanshi, Kadam, Ghogare, Ingale, Patil, 2015), .

However, one of the materials that satisfy the requirements of sustainable development and, when added in appropriate proportions, improves the properties of cement, mortars and concrete, is metakaolin (MK), a processed pozzolana (Biljana et al, 2011). MK is produced by heating kaolin at 650-900°C. Kaolin, an alumino-siliceous material, is abundant in Nigeria (Kovo & Edoga 2005; Lori, Lawal, & Ekanem, 2007; Badmus & Olatinsu, 2009). During the heating process, the structure of kaolinite mineral transforms from crystalline to amorphous that makes it a highly reactive pozzolan (Kurtis, 2011).

Recently, a lot of research works have been carried out on the viability of using metakaolin as supplementary cementitious materials in the production of concrete. Such efforts include: Rashad (2015) in Egypt, Aiswarya, Prince, & Dilip (2013), in India, Justice (2005) in Georgia observed that metakaolin increases compressive strength, elastic modulus and resistance to chemical attack of concrete, as compared to conventional concrete, also, the inclusion of metakaolin reduces the workability of the concrete. Ghorpade & Rao (2011), Justice et al, (2005) both observed that chloride ion permeability value decreased considerably with the increase in metakaolin content in concrete, thus indicating improved durability with increasing metakaolin content. According to Kurtins (2011), metakaolin increases compressive strength, impermeability and durability of concrete due to its high surface area and reactivity. Momtazi, Ranjbar, Balalaei & Nemat, (2007), noted that metakaolin can decrease workability, permeability, increase compressive strength and concrete durability.

However, only a few research studies have examined the incorporation of metakaolins for the production of binary or blended concrete in Nigeria on the use of the abundant kaolinitic deposits in the country, resulting in a body of knowledge which is much less complete compared to the literature available for rice husk ash binary blend system. Baba and Usman (2011) investigated the heating parameters for converting Kankara kaolin clay to Metakaolin with a view to ascertaining the possibility of using Nigerian Kaolin Clay as concrete material. It was found out that the optimum thermal condition for the calcination of kankara kaolin was 650^{o}C in 90 minutes, and it can be used for partial replacement of cement. They further concluded that the optimum percentage replacement of cement with kankara metakaolin is 10% which agreed with Suryawanshi et al, (2015) study and The Concrete Countertop Institute (2007) report. Therefore, this research sought to compare the properties of OPC concrete and binary concrete containing the Kankara metakaolin using the optimum percentage replacement (10%).

METHODOLOGY

Research Design: Test of the individual constituents of the concretes (metakaolin, fine and coarse aggregates and cement) was carried out. The tests carried out includes: chemical composition analysis, specific gravity test, moisture content and sieve analysis of aggregates. These tests were performed in accordance with ASTM 618-05, BS 4550 (1978), BS 812 (1984), BS 812 (1985), and BS 882 (1965).

Strategy: The materials used were Ordinary Portland Cement (OPC), fine aggregates, coarse aggregates, metakaolin and water. The OPC used was manufactured by Dangote cement company Plc. The coarse aggregate used was crushed granite while the fine aggregate was fine river sand. They were mixed with tap water fit for drinking.

After testing the individual constituent materials, 100mm×100mm×100mm concrete cubes were cast, using the Building Research Established Method, grade 40 concrete was produced using 0.35 water-cement ratio which served as control. This was followed by producing concrete mix using the supplementary cementing material to replace the Portland cement at the optimum percentage replacement, i.e.10%, and their properties determined. A total of forty eight (48) cubes were produced. At fresh stage the concrete cubes were tested for workability using slump, while at hardened stage, the concrete specimens were tested for compressive and tensile strength at 7, 14, 28 and 90 days curing periods.

Results: The results of the different tests on the concrete constituents and concrete samples described above are as follows:

Table 1: Chemical Composition of Kaolin and Cement.

Oxide	Content %	
	Cement	Kaolin
Al_2O_3	4.9	40.0
SiO_2	20.1	54.9
TiO_2	0.2	0.096
K_2O	0.4	-
CaO	65	0.802
Na_2O	0.2	-
MgO	3.1	0.027
MnO	0.02	-
Fe_2O_3	2.5	0.082
Loss on Ignition	8.8	13

Table 2: Specific Gravity of Metakaolin and Portland Cement

Material	Mass of materials (g)	Volume of materials (ml)	% difference
Metakaolin	138	150	2.56
Portland cement	189	150	2.82

Table 3: Slump Test

Types of concrete	Slump (mm)	% Difference
OPC concrete	31	26
Binary Concrete	23	

Table 4: Average Compressive Strength

Concrete samples	Age(days)			
	7	14	28	90
OPC concrete	12.8	37.4	41.1	41.4
Binary concrete	25.5	35.3	46.1	47

Table 5: Average Tensile Strength

Concrete samples	Age(days)			
	7	14	28	90
OPC concrete	1.35	2.07	3.01	3.84
Binary concrete	1.35	2.07	3.84	5.39

Discussion of results

i. workability

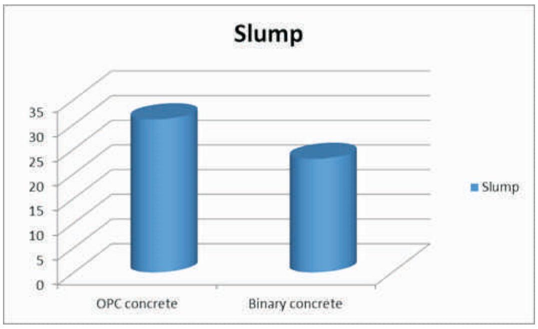

Figure 1: Slump of OPC Concrete and Binary Concrete

Figure 1 shows that the OPC concrete is more workable (31mm) than the binary concrete (23mm) by about 25.8%. This implies that the binary concrete absorbed water more than the conventional concrete which may be due to the high surface area of MK leading to this. The decrease in the workability is in agreement with what Justice (2005) and Momtazi et al (2007) observed.

ii. Compressive Strength

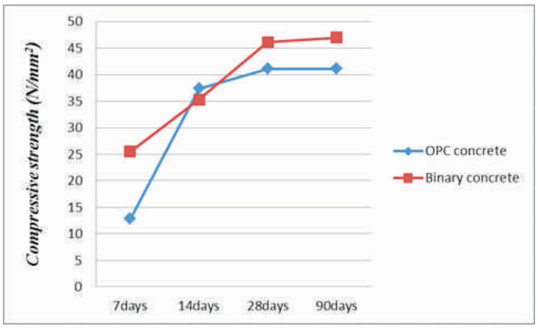

Figure 2: Compressive strength of OPC concrete and Binary concrete

The results of the compressive strength test of OPC concrete and binary concrete are shown in the Figure 2. It can be observed that at the early age, the average compressive strength of the binary concrete is higher by about 49.8% than that of the OPC concrete. At 14 days, the average compressive strength of the OPC concrete is higher than the binary concrete by about 5.6%. The decrease in the strength of the binary might be attributed to error in compaction. Beyond 14 days, the binary showed a steady increase in strength than the OPC concrete by about 10.8% at 28 days and 11.9% at 90 days. The increase in the strength is in agreement with (Kurtins, 2011, Sabu, Rijuldas, & Aiswarya, 2016). Moreover, the strength increase could be due to the micro filling effect of MK on calcium hydroxide which accounts for up to 25% of the hydrated Portland cement (Concrete Countertop Institute2007). The calcium hydroxide does not contribute to the concrete□s strength or durability. Metakaolin combined with the calcium hydroxide to produce additional cementing compounds, (calcium silicate hydrate), that enhances the microstructure and hence the strength of the concrete Rashad (2015), Aiswarya, Prince, & Dilip (2013) Momtazi et al (2007). Less calcium hydroxide and more cementing compounds means stronger concrete.

iii. Tensile Strength

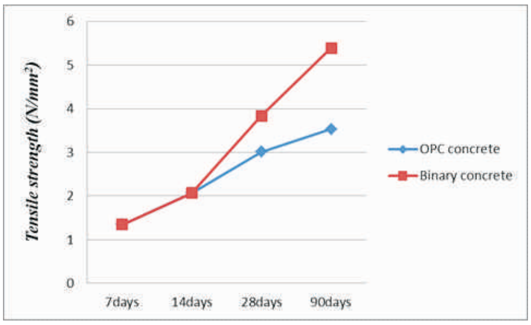

Figure 3: Split Tensile Strength of Binary and OPC Concretes

The results for the tensile strength of OPC concrete and binary concrete are shown in the Figure 3. It can be observed that at the early age upto 14 days, the average tensile strength of the OPC and binary concretes are the same. Beyond 14days, the binary concrete showed higher tensile strength than the OPC concrete (Suryawanshi et al, 2015, Rashad (2015), Aiswarya, Prince, & Dilip (2013), Justice (2005). The increment is by 21.8% at 28 days and 34.5% at 90 days which could be due to micro filler nature of the metakaolin and its effect on calcium hydroxide which lead to greater tensile strength.

Conclusions

Based on the results of the research, the following conclusions were reached:

i. Binary concrete with metakaolin has reduced workability by about 25.8% compared to the OPC.
ii. The inclusion of metakaolin resulted in faster early age strength development of binary concrete than plain OPC concrete.
iii. The binary concrete has improved compressive and tensile strength.
iv. Kankara kaolin can be used for the production of Metakaolin for conctrete production.

References

Aiswarya S., Prince, A. G. and Dilip C. (2013). A Review On Use of Metakaolin in Concrete, IRACST Engineering Science and Technology: An International Journal (ESTIJ), ISSN 2250-3498, *3(3),* 592-597.

Baba S. U. and Usman B. (2011). Thermal Treatment of Kankara Kaolin Clay to Produce Metakaolin as Partial Replacement of Cement in Concrete Production, Unpublished Undergraduate Project, Submitted to the Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria

Badmus B. S. and Olatinsu O. B., (2009), Geophysical evaluation and chemical analysis of kaolin clay deposit of Lakiri village, southwestern Nigeria, International Journal of Physical Sciences Vol. 4 *(10) pp. 592-606, ISSN 1992-1950* www.academicjournals.org/.../pdf/pd*f 009/...*/Badmus%20and20Olatinsu *Accessed 23/09/2011 at 12:14 PM.*

Biljana I. et al (2011). Metakaolin: Kaolin clay Cement production http://www.doiserbia.nb.rs/img/doi/067-598X/2009/0367598X0902107M.pdf, accessed 23/09/2011 at 10:12a

Ghorpade V. G. and Rao H. S. (2011). Chloride Ion Permeability Studies of Metakaolin Base High Performance Concrete, international journal of engineering science and technology (IJEST) ISSN:0975- 5462, PP. 1617 1623., htt://www.ijest.info/docs/TJEST 11-03-0288.pdf, accessed 23/09/2011 by 09:49am.

Habeeb G. A. and Mahmud H. B. (2009). Pozzolans for Sustainable Concrete, International Conference for Technical Postgraduate (TECHPOS), Towards Advancement of Engineering Research Global Challenges, Kuala Lumpur, Malaysia.

Justice M. J. et al (2005). Comparison of two Metakaolins and Silica Fume as Supplementary cementitious materials, Proc. Seventh international symposium on utilization of high- strength/high performance concrete held in Washington D. C., June 20-24, 2005. www.innovateatthiele.com/pdf/Ga_Tech-Kaorock_Reports-cmbin, accessed 23/09/2011 by 09:58 am.

Kovo A. S. and Edoga M. O. (2005), Production and Characterisation of Zeolite from Ahako Clay in Kogi State, Nigeria, Leonardo Electronic Journal of

Practices and Technologies, P.31-40, ISSN 1583-1078. www.lejpt.academicdirect.org/A07/31_40pdf accessed 23/09/2011 at 11:02 am.

Kurtins, K. E. (2011), Benefits of Metakaolin in HPC, HPC Bridge Views, ISSUE www.hpcbridgeviews.com/i67/Article3.asp, accessed 23/09/2011 by 10:08am.

Lori, J. A., Lawal, A. O. & Ekanem E. (2007). Characterisation and Optimisation of Deferration of Kankara Clay, ARPN Journal of Engineering and Applied Sciences, Asian Research Publishing Network (ARPN), Vol. 2, No. 5, October 2007, pp. 60-74. ISSN1819-66, www.arpnjournals.org/jeas/research_papers/rp_2007/jeas_1007_68.pdf, accessed23/09/2011 at 12:20 PM.

Momtazi, A. S., Ranjbar, M. M., Balalaei, F. and Nemati, R.,(2007), The effect of Iran's metakaolin in enhancing the concrete Compressive strength, Department of civil engineering, University of guilan, www.claisse.info/special%/20papers/sdrmomtazi_full_text.pdf, accessed 23/09/2011by 10:32 am.

Najigivi, A., Abdul Rashid S., Aziz, F. N. A. and Salleh M.A.M.(2010), Contribution of Rice Husk Ash to the Properties of Motar and Concrete, Journal of American Science, USA,http://.www.Americascience.Org, accessed23/09/2011 at 12:20 PM.

Rashad, A. M. (2015). Metakaolin: Fresh Properties And Optimum Content For Mechanical Strength In Traditional Cementitious Materials-A Comprehensive Overview, Metakaolin: Fresh Properties And Option, Metakaolin, accessed 01/09/2016 by 10:32 pm.

Sabu, S. C., Rijuldas, V., Aiswarya S. (2016). Effect of Metakaolin on Various Properties of Concrete - An Overview, International Journal Of Advanced Technology In Engineering and Science, Vol. 4, Issue No. 01, ISSN 2348-7550, www.ijates.com, accessed 18/08/2016 at 06:10Pm

Shiathas, C. et al (2004). A Comparative Study of the Properties and Durability of Binary and Ternary Cementitious Systems,University of Surrey, UK.

Suryawanshi, Y. R., Kadam, A. G., Ghogare, S. S., Ingale, R. G., Patil, P. A. (2015), Experimental Study on Compressive Strength of Concrete by Using Metakaolin, International Research Journal of Engineering and Technology (IRJET), www.irjet.net accessed 14/11/2015 at 07:16 am.

The Concrete Countertop Institute, Using Metakaolin As A Cement Replacement In Concrete www.ConcreteCountertopInstitute.com, accessed 23/09/2011 by 10:06am