EFFECT OF METAKAOLIN ON CONCRETE PRODUCED WITH A POZZOLAN

ELVIS .M. MBADIKE
E-mail: elvis_mbadike@yahoo.com
Phone No: 08138804020

ABSTRACT

The physical and mechanical properties of Portland Cement containing metakaolin or combination of metakaolin and pozzolan ((Palm Bunch Ash (PBA)) and the compatibility between such materials were investigated in this study. A mix proportion of 1:2:6:4.1 with water/cement ratio of 0.4 were used. The percentage replacement of ordinary Portland Cement (OPC) with a pozzolan (Palm Bunch Ash) (PBA) and Pozzolan/metakaolin used were 0%, 5%, 10%, 20%, 30% and 40%. Concrete cubes were cast and cured at different days. Similarly, the setting time was also determined. At the end of each hydration period, the concrete cubes were crushed and their compressive strength determined. Similarly the setting time of Ordinary Portland Pozzolan and Ordinary Portland Cement/Pozzolan and Metakaolin was also determined. The result of the compressive strength of 5-40% replacement cement with the Pozzolan (PBA) ranges from 5.87 – 35.50 N/mm^2 as against 14.10 – 36.22N/mm^2 for the control test. Similarly, the result of the compressive strength of 5-40% replacement of cement with pozzolan and metakaolin ranges from 6.40 – 35.90N/mm^2 as against 14.10 – 36.22N/mm^2 for the control test. The setting time of cement with 5-40% replacement of cement with pozzolan (PBA) ranges from 57 – 109 mins for the initial setting time and 608 – 731mins for the final setting time as against 50 mins and 585 mins respectively for the initial and final setting time of the control test. Similarly, the setting time of cement with 5-40% replacement of cement with the pozzolan (PBA) and metakaolin ranges from 54-98 mins for the initial setting time and 590 – 692 mins for the final setting time as against 50mins and 585 mins respectively for the initial and final setting time of the control tests.

KEYWORDS: Metakaolin, Pozzolan, Compressive strength, Workability, Palm Bunch Ash.

INTRODUCTION

Metakaolin is a thermally activated alumino-silicate material with high pozzolanic activity comparable to or exceeded the activity of fume silica (Caldaron and Burge, 1994). Metakaolin is quite useful in improving concrete quality such as enhancing strength, shortening setting time (Ding et al, 1997), decreasing autogenous shrinkage (Tazawa and Miyazawa, 1995), controlling alkali aggregate reaction (Liu and Wen, 1995), reducing risk of chloride, induced corrosion of embedded steel (Colemen and Page, 1997), controlling hydrate transformation of high-alumina cement (Majundar and Singh, 1992), and improving the durability of concrete (Zhang et al, 1995). Therefore, metakaolin is a promising material for manufacturing High Performance Concrete (HPC).

In previous research, (Mbadike, 2008) the use of pozzolan (Palm Bunch Ash) as a supplementary cementitious material (SCM) was studied, with SCM levels ranging from 0 to 40%. The pozzolan used had a strength activity index of 64.7% and a total silicon dioxide, aluminium oxide and iron oxide content of 72.73% for the pozzolan and 98% for the metakaolin which are greater than 70% minimum content required by ASTM C618 for natural pozzolans. In this regard, the pozzolan (Palm Bunch Ash) acted as a supplementary cementitious material and thus contributed to the properties of the hardened concrete through pozzolanic activity. In the research, presented here, a second material, metakaolin was used together with the pozzolan in the same percentage replacement level. To use supplementary cementitious materials (SCM_s) optimally, it is important to thoroughly document and understand their characteristics and behaviour (Elinwa et al, 2005).

METHODOLOGY

Concrete mixtures with six levels of pozzolan and pozzolan/metakaolin replacement ranging from 5 to 40% and control mixtures with no pozzolan (PBA)) were investigated to determine their effect on compressive strength of concrete. The mixtures were labeled M0, M5, M10, M20, M30 and M40 with the different pozzolan and pozzolan/metakaolin replacement percentages represented by the figures in the label. The mixtures were proportioned for a target cube strength of 35N/mm^2, a fine aggregate content of 766.35kg/m^3, a coarse aggregate content of 1198.65kg/m^3 and a water-cementitious material ratio of 0.4.

The pozzolan (PBA) was obtained from palm bunch. The palm bunch was burned in a kiln from where the ash was obtained after sieving it with 150µm sieve size.

The Kaolin used for the production of the metakaolin was obtained from a ceramic factory, ground in a bond test mill and thermally activated at the temperature of 800°C. The heated metakaolin was then sieved through a 15µm sieve. Table 1 gives the physical and chemical characteristics of the pozzolan (PBA) and metakaolin.

The total content of silicon dioxide (SiO_2), aluminmium oxide (Al_2O_3) and iron oxide (Fe_2O_3) was 72.73% for the pozzolan and 92.3% for the metakaolin. Both values are greater than the minimum of 70% specified in ASTM C618 and suggests that the metakaolin was more reactive than the pozzolan (PBA). As shown in table 1, the main oxide phases of the pozzolan (PBA) in decreasing order of amount were SiO_2, Al_2O_3 and CaO while those of the metakaolin were SiO_2, Al_2O_3 and Fe_2O_3. The strength activity indices of the pozzolan (PBA) and metakaolin were 64.7% and 84% respectively, confirming that the metakaolin was more reactive.

The fine aggregate used was clean river sand, free from deleterious substances with a specific gravity of 2.62 and a bulk density of 1533kg/m^3. The coarse aggregate was obtained from a local supplier with a maximum size of 20mm, specific gravity of 2.63 and bulk density of 1364kg/m^3. Both the fine and coarse aggregate conforms to BS 3797 (1964) and BS 877 (1967) specification. The cement used was Ordinary Portland Cement (Eagle) which conforms to BS 12.

Tests to determine slump, density and compressive strength were carried out in this study. For slump, density and compressive strength tests, pozzolan and pozzolan/metakaolin were used to replace 0 to 40% of cement by weight. For the compressive strength tests, 150 mm (6in) cube specimens were used. A total of 180 specimens were cast and cured in water at room temperature in the laboratory for 3, 7, 28 60 and 90 days. At the end of each hydration period, three specimens for each mixture were tested for compressive strength and the average was recorded.

RESULT AND DISCUSSION

Workability of the concrete decreased as the percentage of pozzolan (PBA) and pozzolan/metakaolin replacement increases. The decrease in slump ranges from 4-9mm for pozzolan and 5-10mm for the pozzolan/metakaolin respectively. The density of the concrete mixture decreased as the percentage of the pozzolan and pozzolan/metakaolin replacement increased. At 0% pozzolan (PBA) replacement, the density was 3320kg/m^3. The density decreased to 2560kg/m^3 at 40% replacement representing a decrease of about 23%.

Optimum compressive strength was obtained with a pozzolain and pozzolan/metakaolin content of about 5%. The result of the compressive strength of 5-40% replacement of cement with the pozzolan (PBA) ranges from 5.87-35.50N/mm^2 as against 14.10-36.22N/mm^2 for the control test. Similarly, the result of the compressive strength of 5-40% replacement of cement with pozzolan and metakaolin ranges from 6.40-35.90N/mm^2 as against 14.10-36.22N/mm^2 for the control test. The setting time of cement with 5-40% replacement of cement with pozzolan (PBA) ranges from 57-109mins for the initial setting time and 608-731mins for the final setting time as against 50mins and 585mins respectively for the initial and final setting time of the control test. Similarly, the setting time of cement with 5-40% replacement of cement with the pozzolan (PBA) and metakaolin ranges from 54-98mins for the initial setting time and 590-692mins for the final setting time as against 50mins and 585mins respectively for the initial and final setting time of the control test. Thus, this study showed that metakaolin increased the early strength of the pozzolan (PBA) concrete (5-40% replacement) and that the early age loss of strength due to slow process of hydration when pozzolan alone was incorporated has been compensated for by replacing half of pozzolan with metakaolin. Khan et al (2003) made the same observation when working with pulverized fuel ash and silica fume, where silica was the reactive component. This research showed that Palm Bunch Ash decreased the early strength gain of concrete because it reacted slower than Portland Cement.

TABLE 1: Physical and Chemical Properties of Pozzolan (PBA) and Metakaolin

PROPERTY	PBA	METAKAOLIN
Moisture content (%)	0.32	0.40
Specific gravity	3.26	3.51
Bulk density (kg/m^3)	780	830
pH	9.50	7.86
SiO_2 (%)	58.60	49.55
Al_2O_3 (%)	13.87	40.25
Fe_2O_3 (%)	0.26	2.71
CaO (%)	18.20	2.50
MgO (%)	0.78	1.02
Na_2O (%)	0.34	0.11
K_2O (%)	Nil	0.24
SO_3 (%)	Nil	0.99
P_2O_5 (%)	Nil	Nil
MnO (%)	0.56	0.37
Loss in ignition	7.39	2.04
TiO_2	Nil	0.22

TABLE 2: Result of Compressive Strength Test for The Pozzolan Replacement (N/mm^2)

Mix label	%(PBA) Content	3days	7days	28days	6odays	90days
M0	0	14.10	21.96	25.83	31.90	36.22
M5	5	11.72	14.93	23.42	29.51	35.50
M10	10	8.89	11.69	21.76	24.77	33.86
M20	20	8.66	11.53	20.58	23.38	29.61
M30	30	7.69	9.24	18.44	20.43	23.83
M40	40	5.87	8.75	15.40	17.10	20.94

TABLE 3: Result of Compressive Strength Test for Pozzolan/Metakaolin Replacement (N/mm^2)

Mix label	% (PBA)/metakaolin Content	3days	7days	28days	6odays	90days
M0	0	14.10	21.96	25.83	31.90	36.22
M5	5	12.81	15.87	23.94	31.10	35.95
M10	10	9.39	11.88	23.20	25.62	33.36
M20	20	9.10	12.07	20.96	23.63	29.70
M30	30	8.68	9.76	18.70	21.35	28.30
M40	40	6.40	8.93	16.10	18.80	22.67

TABLE 4: Initial and Final Setting Time of OPC/Pozzolan Paste

%Cement Replacement	Initial Setting Time(Mins)	Final Setting Time (Mins)
0	50	585
5	57	608
10	65	624
20	80	655
30	92	686
40	109	731

TABLE 5: Initial and Final Setting Time of OPC/Pozzolan/Metakaolin Paste

%Cement Replacement	Initial Setting Time (Mins)	Final Setting Time (Mins)
0	50	585
5	54	590
10	60	605
20	71	620
30	84	640
40	98	682

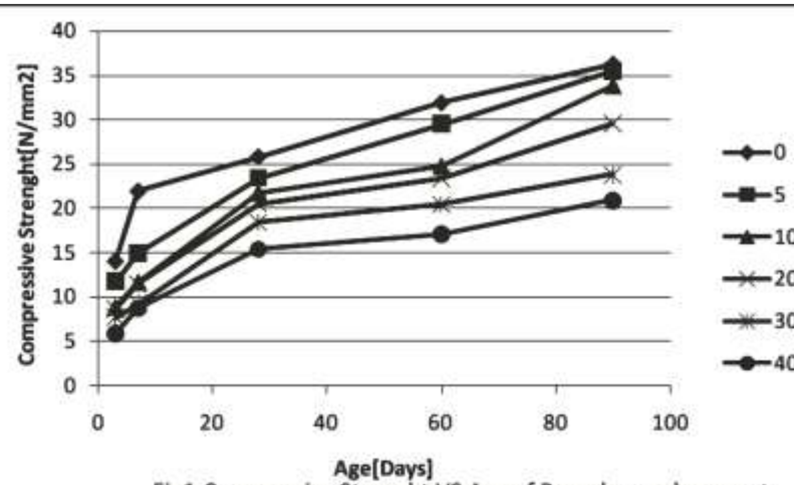

Fig1:Compressive Strenght VS Age of Pozzolan replacement

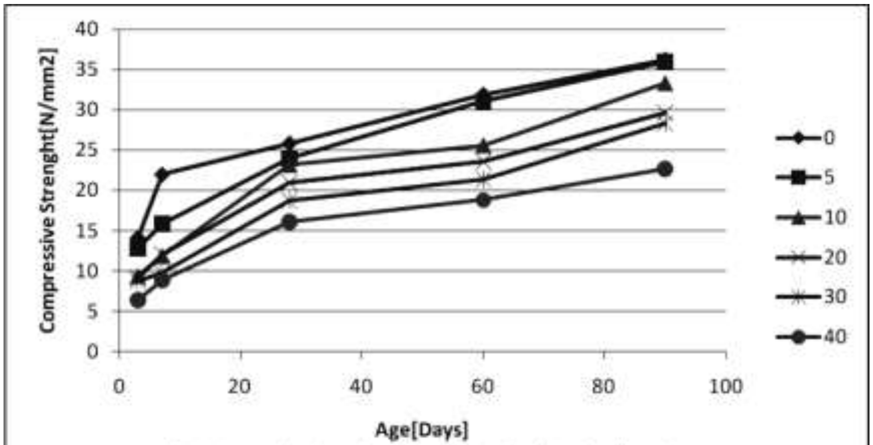

Fig2:Compressive Strenght VS Age ofPozzolan/Metakaolin replacement

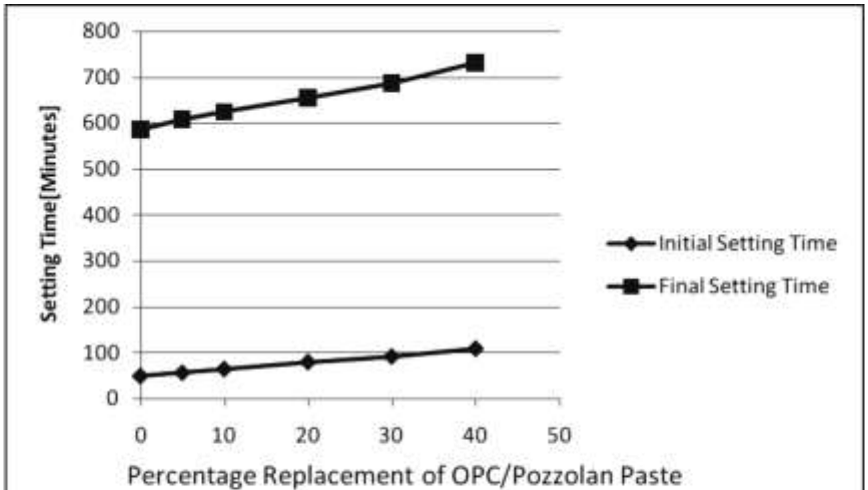

Fig3:Setting Time VS Percentage Rep.of OPC/pozzolan Paste

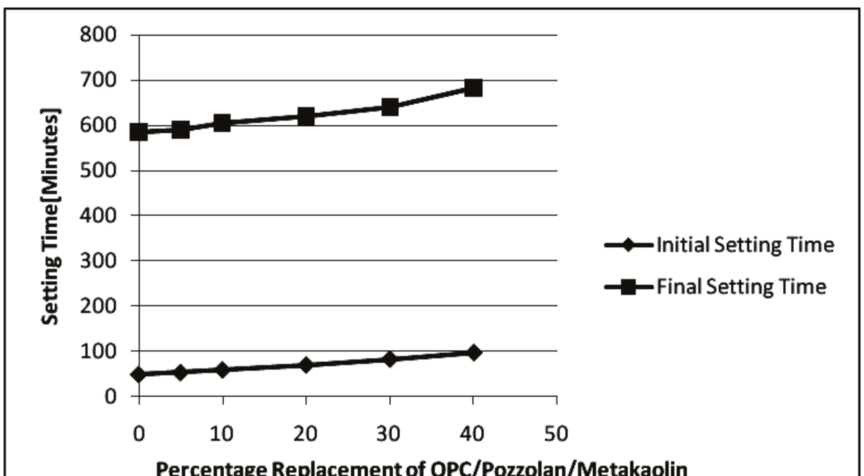

Fig4:Setting time VS Percentage Rep.of OPC/Pozzolan/Metakaolin Paste.

CONCLUSION

The conclusion of this study can be summarized as follows:

(a) Due to high specific surface area and amorphous characteristics, both pozzolan and metakaolin have remarkable pozzolanic activity and can be used as supplementary cementing materials.

(b) With the incorporation of metakaolin into pozzolan residue, the setting time of the OPC/Pozzolan paste is shortened. This behaviour may be due to the early formation of a large amount of C-S-H gel from hydration of C_3S and from the reaction of metakaolin residues and $Ca(OH)_2$.

(c) The addition of metakaolin residue can increase the compressive strength of OPC/Pozzolan significantly as can be seen in the test result.

(d) The increased compressive strength may be due to the fact that $Ca(OH)_2$ diminished or, wholly disappeared and C-S-H increased with the incorporation of the metakaolin residues.

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