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INFLUENCE OF METAKAOLIN ON THE RESISTANCE OF CEMENT MORTAR TO ELEVATED TEMPERATURES

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ABSTRACT

Ordinary Portland cement mortar exposed to elevated temperature experiences physico-chemical changes that can lead to the deterioration of its strength and durability performance. However, the inclusion ofpovgplanic material in cement mortar modifies the response of mortar to elevated temperatures. This paper examined the effect of metakaolin (MK) on the resistance of cement mortar to elevated temperatures. Two sets of cement mortar specimens, one with 20% MK replacing cement (MK-specimen) and the other without MK (control) were produced. Constant aggregate to cement ratio of 2.75 and water to binder ratio of 0.35 were used to produce the mortar specimens. After 28 days of curing in water and pre-heating at 105°C for 24 hours, the two sets of specimens were heated to different temperatures of 200, 400, 600 and 800°C at a constant heating rate of 2.5"C/min. After achieving the targeted temperatures, the specimens were maintained for 2 hours before cooling to ambient temperature in the furnace. The compressive strengths and ultrasonic pulse velocities of the heated specimens were tested The results showed that the retained compressive strengths of the MK-specimens at 200, 400, 600 and 800"C were 104%, 74%, 68% and 42%, respectively while, the corresponding values for the control specimens were 101%, 67%, 55% and 45%. Moreover, the retained pulse velocities values for the MK-specimens were 95%, 74%, 44% and 36%, while those for the control specimens were 91%, 70%, 41% and 33% at the same temperatures. Impliedly, MK improved the retained compressive strength and pulse velocity of cement mortar at elevated temperatures. Therefore, cement mortar blended with MK may be used as afire resisting construction material.

KEY WORDS: *Cement; Compressive strength; Elevated Temperature, Metakaolin; Mortar*

INTRODUCTION

Concrete as the most recognized construction material for building and civil engineering structures may be vulnerable to high temperatures and pressure during fire outbreak. High temperature changes the physico–chemical characteristics of concrete constituents that may lead to the reduction of concrete properties such as compressive strength, modulus of elasticity and durability (Mehta & Monteiro, 2006) . However, the extent of damage largely depends on the compositions of concrete such as aggregate and cement type.

Ordinary Portland cement as the most common binder for concrete has calcium hydroxide, $Ca(OH)_2$, and calcium silicate hydrate (CSH) as the major hydration products. These products influence concrete strength and durability (Nevillie, 2002). At temperatures of about 500°C, $Ca(OH)_2$ decomposes to calcium oxide and water vapor (Peng & Huang, 2008). The decomposition causes thermal cracks that ultimately impair strength and durability of concrete. However, the addition of pozzolans such as silica fume and metakaolin (MK) reduces the amount of $Ca(OH)_2$ in concrete through pozzolanic reaction. Pozzolans are siliceous or siliceous and aluminous materials that react with $Ca(OH)_2$ to form cementitious compounds that enhance concrete properties.

MK is an aluminosilicate material produced by thermal treatment of kaolinitic clay at 500-800°C (Kadri, Kenai, Ezziane, Siddique, & De Schutter, 2011). Kaolinitic clay is abundant in Nigeria (Jibril, Yusuf, Abdulmumin & Ahmad, 2016). Improvements in the mechanical properties and resistance to chemical attack of concrete were achieved with the use of up to 20% MK replacing Portland cement (Rashad, 2013). However, study on the effect of MK on the resistance of cement mortar exposed to elevated temperatures is very scarce. Therefore, the effect of elevated temperatures on the compressive strength and pulse velocity of cement mortar containing 20% MK was assessed in this study.

MATERIALS AND METHODS

Materials

Ordinary Portland cement (OPC) and Metakaolin (MK) were used as binders in this study. The MK was produced by heating kaolin at 650°C for 1 hour. The heating was necessary to activate the pozzolanic activity of MK. The physical and chemical compositions of the binders are shown in Table 1. River sand of 1.18mm maximum size and fineness modulus of 2.57 was used as fine aggregate. Also, water fit for drinking was used for mixing and curing.

Specimen production

Two sets of mortar specimens of constant cement aggregate ratio of 2.75 and constant water to binder ratio of 0.35 were prepared in accordance with the ASTM C 109 (ASTMC109C109M, 2013). One set of the specimens labeled as OPC constitutes cement as the only binder while, the other set (20MK) contains 20% MK partially substituting cement as binder. After thorough mixing, the fresh mortar specimens were cast in cube moulds of 50 mm x 50 mm x 50 mm size and vibrated for 60 seconds to achieve adequate consolidation. The hardened mortar specimens were demoulded and immersed in water for curing after 24 hours of casting. The curing lasted for 28 days.

Table 1: Chemical compositions and physical properties of OPC and MK

Chemical composition (%)	OPC	MK
Silicon dioxide (SiO_2)	19.78	54.70
Aluminum oxide (Al_2O_3)	3.90	39.90
Iron oxide (Fe_2O_3)	3.00	1.43
Calcium oxide (CaO)	63.38	-
Magnesium oxide (MgO)	2.00	0.34
Sulfur trioxide (SO_3)	2.85	-
Sodium oxide (Na_2O)	0.75	-
Phosphorus pentoxide (P_2O_5)	0.12	-
Chloride (Cl)	0.01	-
Potassium oxide (K_2O)	0.18	2.58
Titanium oxide (TiO_2)	-	0.70
Loss on Ignition (LOI)	1.90	1.50
$SiO_2 + Fe_2O_3 + Al_2O_3$	-	96.03
Physical properties		
Specific gravity	3.15	2.19
Strength activity index (%)	-	111
Retained on 45um sieve (%)	-	2

Heat-Treatment and Testing of Specimens

After curing and pre-heating at 105°C for 24 hours to minimise spalling effect, the two sets of specimens were heated to different temperatures of 200, 400, 600 and 800°C at a constant heating rate of 2.5°C/min in an electric furnace. At each targeted temperature, the specimens were maintained for 2 hours to achieve a thermal steady state before cooling to ambient temperature in the furnace. The cooled specimens were then subjected to compressive strength and ultrasonic pulse velocity tests in accordance with the ASTM C109 (ASTMC109C109M, 2013) and ASTM C 597 (ASTMC597, 2009), respectively. Three specimens were used for each test.

RESULTS AND DISCUSSION

Retained Compressive Strength

Table 2 shows the relative retained compressive strength of plain OPC and MK blended cement mortar specimens heated to different temperatures. The relative compressive strength of the specimens at each temperature, expressed in percentage was

Table 2: Retained compressive strength of specimens at different temperatures

Temperature (°C)	Specimen Type			
	OPC (Plain OPC)		20MK (MK blended)	
	Compressive strength (MPa)	Relative compressive strength (%)	Compressive strength (MPa)	Relative compressive strength (%)
27 (ambient)	70.81	100	70.97	100
200	71.83	101	74.07	104
400	47.3	67	52.34	74
600	39.24	55	48.06	68
800	31.9	45	29.69	42

Table 3: Retained Ultrasonic Pulse Velocity of specimen at different temperatures

Temperature (°C)	Specimen Type			
	OPC		20MK	
	Pulse velocity (UPV) mm/s	Relative UPV (%)	Pulse velocity (UPV) mm/s	Relative UPV (%)
27 (ambient)	4887	100	4978	100
200	4447	91	4739	95
400	3421	70	3678	74
600	2004	41	2190	44
800	1613	33	1792	36

calculated as the quotient of the compressive strength values of specimen after and before heating. It can be seen that, at the temperatures beyond 200°C, both plain OPC (control) and MK blended specimens experienced reduction in compressive strength. But generally, MK blended specimens retained higher compressive strength than those of plain OPC. Impliedly, MK improves strength retention capacity of plain OPC mortar. Similar improvement was also observed when concrete containing silica fume as pozzolan was exposed to elevated temperatures (Morsy, Alsayed, & Aqel, 2010). At 200, 400, 600 and 800°C, the relative retained compressive strength of MK blended specimens were 104%, 74%, 68% and 42%, respectively. While, the corresponding values for the plain OPC (control) specimens were 101%, 67%, 55% and 45 %. The improvement exhibited by MK blended specimen can be related to the reduction of $Ca(OH)_2$ by MK through pozzolanic reaction. $Ca(OH)_2$ expands and decomposes at about 500°C and when cooled, it contracts and tends to recrystallise (Peng and Huang, 2008). The transformation of $Ca(OH)_2$ to phases leads to the distortion of microstructure that ultimately impairs the strength capacity of cement mortar.

Retained Ultrasonic Pulse Velocity of specimen at different temperatures

The pulse velocities of plain OPC and MK blended mortar specimens before and after heating at up to 800°C are shown in Table 3. In a similar pattern to the compressive strength results, the MK blended specimens showed higher retained pulse velocity values than the plain OPC specimens at all temperatures. The relative retained pulse velocity values for the MK-specimens were 95%, 74%, 44% and 36%, while those for the control specimens were 91%, 70%, 41% and 33% at 200, 400, 600 and 800°C, respectively. The same reasons stated in the case of the compressive strength may be behind the higher performance of MK blended specimen than the OPC specimen (control).

Relationships between Compressive Strength and Pulse Velocity

The relationships between pulse velocity and compressive strength of plain OPC and MK blended mortar specimens heated at different temperatures are shown in Figure 1. A strong linear relationship with a coefficient of correlation (R^2) of 0.9 for both plain OPC and MK blended specimens can be observed. However, the rate of change of compressive strength and pulse velocity of plain OPC specimen (1.1167) exposed to elevated temperatures is greater than that of MK blended specimen (1.0803) as shown in the linear equation in Figure 1. This may be attributed to the refinement of microstructure of mortar caused by MK. The linear relationship indicated that UPV as a non-destructive method can be used to assess the compressive strength of MK mortar exposed to elevated temperature.

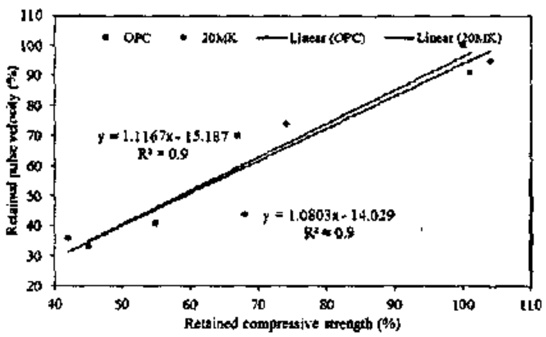

Figure 1: Relationships between Retained Pulse Velocity and Retained Compressive Strength of Mortars Exposed to Elevated Temperatures

CONCLUSION

Addition of 20% MK improved compressive strength and pulse velocity of cement mortar exposed to elevated temperature up to 800°C. The relationship between the compressive strength and pulse velocity of MK blended mortar exposed to elevated temperatures was linear.

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