The Effect of Metakaolin on Compressive Strength of Rice Husk Ash Concrete at Varying Temperatures

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Abstract
In the case where the concrete is exposed to high temperatures such as fire which undergo severe loss of compressive strength due to permeability interconnected durability. The use of metakaolin as a recent material in the construction industry, proves to be very useful to modify the properties of concrete. The study investigates the effect of Metakaolin on compressive strength of rice husk ash (RHA) concrete at varying temperatures. The plain and binary blended with 10%MK cement replacement and ternary MK-RHA blended concrete cube specimens were produced by incorporating 5%, 10%, 15%, 20%, 25% and 30%RHA as cement replacement levels while 10%MK addition was fixed. All the concrete specimens were cured for 28days inside water tank at room temperature, air dried for 24hours, thermally treated at 200°c, 400°c, 600°c, and 800°c for one hour and then allowed to cooled. Three specimens for each temperature including control sample of the same mix were tested for compressive strength at room temperature. The compressive strength were assessed before and after fired. The results show that the inclusion of 10% MK has improved the fire resistance beyond the maximum temperature of plain concrete. The 10%RHA replacement gives better fire resistance than other replacement levels with 22% relative residual strength gain up to 600°c.
Keywords: Concrete, Metakaolin (MK), Rice husk ash (RHA), Compressive strength, Temperature.

Introduction

The extensive used of concrete as a structural material has lead to the demand to fully understand the resistance of concrete at high temperatures. Concrete is known to have an enhanced behavior in fire when comparing with bare steel, there are some chemical and physical transformations in function of temperature that may compromise this performance (Cristina et'al, 2012). As concrete is exposed to elevated temperatures in an accidental building fire, an operating furnace, or a nuclear reactor, its mechanical properties such as strength and modulus of elasticity may be decreased remarkably and results in undesirable fractures and spalling. Exposed to elevated temperatures cause physical changes including large volume changes due to thermal dilatations, thermal shrinkage and creep related to water loss. The volume changes can result in large internal stresses and lead to micro cracking and fracture. Elevated temperature also cause chemical and micro-structural changes, such as water migration, increased dehydration, interfacial thermal incompatibility and the chemical decomposition of hardened cement paste and aggregate. In general, all theses changes decrease the stiffness of concrete and increase irrecoverable deformation (srinivasa et'al, 2004). One of the changes which occur as the temperature rises to about 400°c is the decomposition of calcium hydroxide so that lime is left behind in consequence of drying. If, however after cooling, water ingresses into concrete, the rehydration of lime can be disruptive, thus the damage manifests itself subsequently to the fire. From this standpoint, inclusion of pozzolanas in the mix, which remove calcium hydroxide, is beneficial (Neville, 1997). Pozzolanic materials including silica fumes, fly ash, slag, rice husk ash (RHA) and Metakaolin (MK) have been used in recent years as cement replacement material for developing HSC with improved workability, strength and durability with reduced permeability. Metakaolin (MK), which is relatively new material in the concrete industry, is effective in increasing strength, reducing sulphate attack and improving air-void network. Pozzolnic reactions change the micro structure of concrete and chemistry of hydration products by consuming the released calcium hydroxide(CH) and production of additional calcium silicate hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability (sanjay et'al, 2013). Rice husk ash (RHA) is a highly reactive pozzolanic material that is produced by incineration of rice husk (RH) which contains a very high percentage of either amorphous or crystalline silica. If RH is burnt under controlled temperature, time and rate of burning, amorphous silica is produced which is highly reactive in nature. When over burning occurs (above 700°C), the amorphous SiO_2 will be changed to cristoballite, quartz and tridymite, and when it is burnt at low temperatures (below 500°C), much carbon will exists in the product; in either case the pozzolanic activity of RHA will be decreased greatly (Chandrasekhar et al, 2003). Under normal environmental conditions, kaolin is quite stable. However, when heated to temperatures of 650-900 C, kaolin loses 14% of its mass in bound hydroxyl ions. This heat treatment, or calcinations, breaks down the structure of kaolin such that the alumina and silica layers become puckered and lose their long-range order. Resulting from this dehydroxylation and disorder is MK, a highly reactive transition phase. MK is an amorphous pozzolan, with some latent hydraulic properties, that is well-suited for use as an SCM [Bensted, 2002]. In general, SCMs with higher alumina contents such as MK, tend to have higher pozzolanic capacities because formation of C-A-H has a high CH demand. This is critical, as CH does not make a significant contribution to concrete strength and can be detrimental to durability. Its elimination or reduction by secondary reaction with MK can greatly enhance concrete performance (Mindess,2003;Poon,2002). When used as a replacement for cement, concrete mixtures will experience some effect of the removal of cement from the reacting system. As such, unless the SCM begins reacting immediately, there will generally be a reduction in the rate of heat evolution and strength gain in proportion to the amount of cement being replaced. Fly ash, especially, and even silica fume to a lesser extent, do not show beneficial effects until later in the hydration process (Curcio, 1998; Poon, 2001). Popular blending components used for partially replacing the cement are pozzolanic mineral admixtures such as fly ash, slag, metakaolin, rice husk ash and silica fume. Combine use of such mineral admixture can lead to economic advantages and to technological improvements (Fokkema, 2002). One of the advantages offer by high strength concrete with Metakaolin as admixtures is the ability to significantly increase the residual strength of refractory concrete after firing, typically lose 50% of its strength after heating to 800°c (Sanjay, et'al 2013). (Patnaikuni, et al, 2013) has reported the x-ray diffraction studies on RHA concrete samples, and concluded that at 300^0c the inner surface of the specimen shows an extra compound, Copper Iron Lead Telluride $CuFePbTe_4$ along with $Si0_2$, $Al_5Fe_2Zn0_4$ was present on the surface which also and might be responsible for imparting additional strength to 7.5% RHA concrete at 300^0c whereas at 1000^0c the additional chemical compounds formed at lower temperatures were not found at 1000^0c in both outer and inner surfaces of the samples indicating its possible reason for exhibiting poor strengths for all specimens. (Morsy, 2008; Ilugbuhi, 2004) have reported that 10%MK OPC replacement gives better fire resistance than other replacement levels. Research studies on the blending of MK with other mineral admixtures such as fly ash, silica fume e.t.c subjected to elevated temperatures are abundant. However, Research in the field of MK-RHA concrete which are used as potential mineral admixture in concrete exposed to high temperature is scanty. therefore, in this present study, the effect of MK on compressive strength of RHA concrete at varying temperature were proposed for investigation.

Materials, Mixtures Proportions and Concrete Production, Exposure to Temperature, and Test Method.

The research study was carried out in structures and materials laboratory of Abubakar Tafawa Balewa university Bauchi, Bauchi state of Nigeria.

Materials

Summarized information about materials used in the present study and their characteristics are presented herein. The chemical properties of the MK and RHA are shown in table 1. The cement used was Ashaka brand of ordinary Portland cement(OPC), manufactured by Ashaka cement plc in Gombe state , Nigeria. The test result are 28.63% normal consistency, 87 minutes initial setting time, 153 minutes final setting time and 2.1mm soundness, which are in conformity to OPC as specified in BS12:1978. The fine aggregate used was sharp sand obtained from river source along Dass road in Bauchi state with 2.46 S.G, 2.36mm size and the coarse aggregate used was purchased from renowned dealers located within Bauchi metropolis, the test results are 20mm size, 2.62 S.G, 15.34%ACV and the test results are in conformity to BS 812: part 2:1975 and BS 812: part 110: 1990. The kaolin used for the production of the MK was obtained from Alkalari in Bauchi state. Samples collected were grounded into powder and burnt up to 700^oc using a kerosene vaporization burner kiln at the Industrial Design Programme of the Abubakar Tafawa Balewa University, Bauchi. The temperature was monitored by a pyrometer until a required level was attained. The ash was allowed to cool and then allowed to pass through 212 microns sieve. The MK conformed to ASTM C 618 -12a:1978, Type N pozzolanas specification. The rice husk used for the production of RHA was obtained from Yelwa Tudun rice mill in Bauchi. The RH were burnt up to 700^oc and the RHA was obtained in a similar way as MK. The RHA conformed to ASTM C 618-12a:1978, Type N pozzolana specification. The water was obtained from locally available portable water source.

Table 1. chemical properties of MK and RHA.

OXIDE	MK(%)	RHA(%)
AL_2O_3	39.20	0.91
Fe_2O_3	4.35	0.68
SiO_2	54.03	89.09
CaO	1.70	0.11
MgO	Trace	1.65
Na_2O	0.85	0.65
K_2O	0.17	0.85
LOI	0.08	6.06

Mixture Proportions and Concrete Production

Seventy two (72) trial mix with the weight method of mix design in ratio of 1:2:4 was first carried out at varying percentages of replacement level of 0, 5, 10, 15, 20, 25 and 30% of OPC for RHA at different w/c ratio of 0.5, 0.6 and 0.7 in order to assess the suitability of MK-RHA as partial replacement of OPC in concrete production. They were immersed in ordinary water for 28days and crushed to determine their compressive strength. 0.6 w/c ratio was adopted for the production of the final specimens. The mix proportion is as shown in table 2. One hundred and twenty (120) concrete specimens were produced with fifteen specimens in each percentage replacement levels. The materials were poured into an oiled steel mould of size 150mmx150mmx150mm and compacted in three layers of 50mm each by ramming using steel bar with square end. After 24 hours the specimens were demoulded and placed in a curing tank filled with water for 28days at room temperature. Test cubes were made from fresh concrete in compliance with BS 1881-108:1983.

Table 2. Mix Proportion for Concrete Production

Percentage replacement (%)	Water (kg)	OPC (kg)	RHA (kg)	MK (kg)	Sharp Sand (kg)	Crushed Stones (kg)
0MK:0RHA	10.62	17.70	________	______	35.40	70.80
10MK	10.62	15.93	________	1.77	35.40	70.80
5RHA	10.62	15.14	0.88	1.68	35.40	70.80
10RHA	10.62	14.34	1.77	1.59	35.40	70.80
15RHA	10.62	13.55	2.65	1.50	35.40	70.80
20RHA	10.62	12.75	3.54	1.41	35.40	70.80
25RHA	10.62	11.96	4.42	1.32	35.40	70.80
30RHA	10.62	11.15	5.31	1.24	35.40	70.80

Exposure to Temperature and Testing

The concrete cubes were fed into the kiln and heated to a varied temperatures of 200, 400, 600 and 800^{o}c, each temperature was maintained for one hour to achieve the thermal steady state. The concrete cubes were allowed to cooled after which their compressive strength were determined. All cubes were tested according to BS1881.

Result and Discussion

The % residual compressive strength of concrete is expressed as % of their respective 28-days compressive strength of control specimens. Table 3 show the variation of compressive strength gain and loss with the temperature for all cement replacement levels of 0,5,10,15,20,25, and 30%RHA, and 10%MK respectively.

Discussions

Figure 1 & 2 illustrate the typical % residual compressive strength gain and loss. When exposed to temperatures in the range of 20^{o}c - 200^{o}c, both the plain and modified concrete showed a gradual increase in compressive strength of all the replacement levels except 5%RHA. The 10%MK cement replacement increased the compressive strength by 9% due to pozolanic activity as shown in fig. 1. The decrease in compressive strength of 5%RHA may be attributed to the absence of some extra compounds and low cement replacement level, (Patnaikuni, et al, 2013). The increase in compressive strength in the plain specimen up to 200^{o}c may be due to the formation of micro-crystalline material, with low surface area, from the hydration of the inner un-hydrated core of the cement grains as a result of internal vapour pressure built up effect, (Neville, 1997). Between 200^{o}c - 400^{o}c, there is a gradual decrease in compressive strength of 10%MK; 0, 20, 25, and 30%RHA, and gradual increase in compressive strength of 5,10, and 15%RHA. Dehydration of C-S-H may be responsible for the decrease in compressive strength of the plain concrete specimen; and low additional C-S-H and C-A-H formation from secondary pozzolanic reaction may be responsible for the decrease in compressive strength of 10%MK; 20, 25 and 30%RHA. Beyond 400^{o}c, the compressive strength was observed to have decreased up to a temperature of 600^{o}c of 10%MK; 0, 15 and 30%RHA; and increase in compressive strength was observed of 5,10,20 and 25%RHA replacement levels. Dryness of the concrete and decomposition of CH may be attributed to the decrease in compressive strength of the plain specimen (Neville,1997); and the increase in compressive strength may be due to the dense concrete which restrict moisture migration in 5, 10, 20 and 30%RHA. Rapid decrease in compressive strength was observed in the temperature range of 600^{0}c-800^{o}c of all the samples. This may be attributed to the decomposition of C-S-H or weakening of the microstructure or interfacial transitional zone between the aggregate and the cementitious paste. Structurally, at 20^{o}c, micro structural deformation occurs of 5%RHA. At 200^{o}c, 10%MK; 0, 20, 25 and 30%RHA showed deformation. At 400^{o}c, 15%RHA showed deformation. And at 600^{o}c, 10%RHA showed micro structural deformation.

Conclusion

In conclusion, the inclusion of 10%MK and cement replacement of 10%RHA result in a micro structural refinement with dense and less permeable concrete that give better fire resistance than other replacement levels with 22% relative strength gain up to 600^{o}c. Also, these materials used in this study did not only improved the concrete property but promote environmental protection and economic sense in concrete production by reducing RH & RHA disposal problem and less quantity of cement to be used in concrete production.

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Table 3: Result of Compressive Strength of Plain and Modified Concrete Before and After Fire.

PARTIAL REPLACEMENT BY WEIGHT	TEMPERATURE (^{O}C)	AVERAGE FORCE (KN)	COMPRESSIVE STRENGTH (N/MM^2)	RESIDUAL COMPRESSIVE STRENGTH (%)
OMK:ORHA	20	436	19.37	100
	200	538	23.91	123
	400	457	20.31	105
	600	413	18.35	94
	800	188	8.35	43
10MK	20	419	18.62	100
	200	553	24.57	132
	400	464	20.62	110
	600	417	18.53	99
	800	198	8.80	47
5RHA	20	371	16.48	100
	200	331	14.71	89
	400	360	16.00	97
	600	373	16.57	101
	800	171	7.60	46
10RHA	20	277	12.31	100
	200	308	13.70	111
	400	315	14.00	113
	600	338	15.02	122
	800	138	6.13	49
15RHA	20	273	12.13	100
	200	291	12.93	106
	400	325	14.44	119
	600	300	13.33	110
	800	136	6.04	49
20RHA	20	210	9.33	100
	200	289	12.84	137
	400	269	11.95	128
	600	354	15.73	168
	800	145	6.44	69
25RHA	20	149	6.62	100
	200	275	12.22	184
	400	240	10.66	161
	600	302	13.42	202
	800	99	4.40	66
30RHA	20	134	5.95	100
	200	253	11.24	188
	400	222	9.86	165
	600	200	8.88	149
	800	88	3.91	65

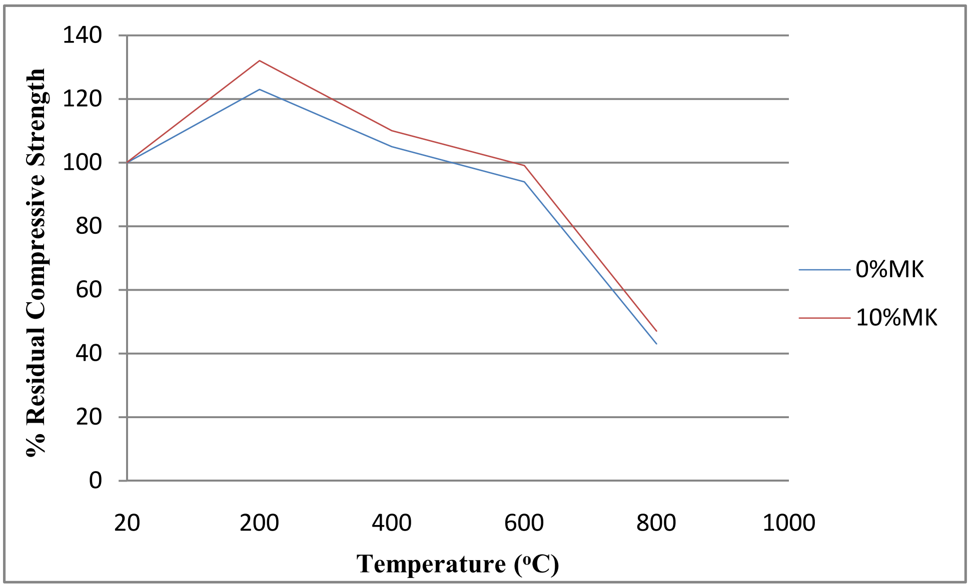

Fig 1. % Residual Compressive strength for Plain and 10%MK

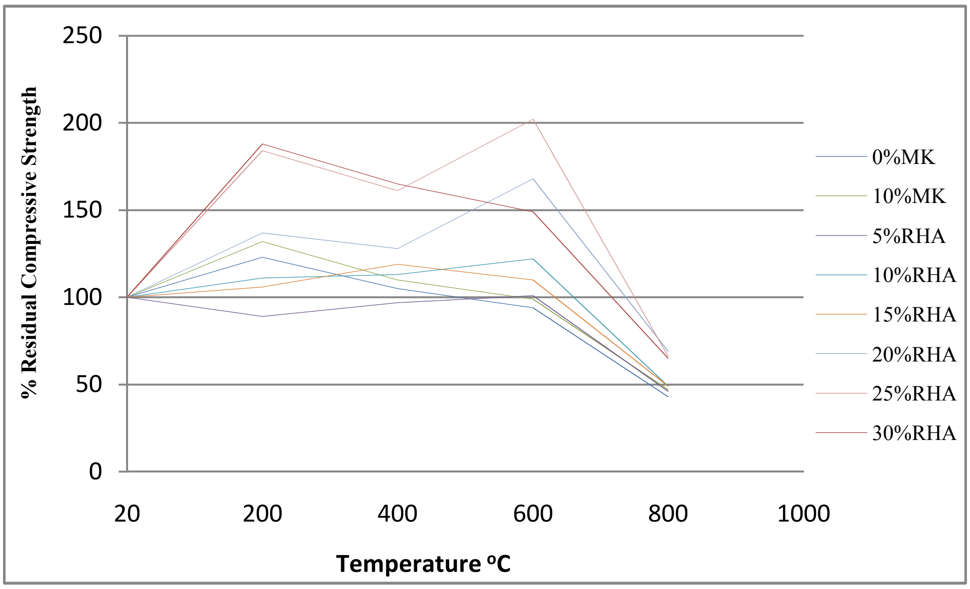

Fig 2. % Residual Strength for different mix at varying Temperatures