EFFECT OF ELEVATED TEMPERATURE ON THE COMPRESSIVE STRENGTH OF MILLET HUSK ASH (MHA) CONCRETE

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ABSTRACT

This work aims to show the effect of elevated temperature on the residual compressive strength of concrete made with available ordinary Portland cement, crushed gravel aggregate, sand and millet husk ash (MHA) added as chemical admixture at a percentage of the cementitious material. Variables of this study are temperatures and MHA contents that ranges between (RT, 200°C, 400°C & 600°C) and (0, 10% & 20%) respectively. The samples were cured in water tanks for 28 days prior to heating. After heating of the samples in the oven to the desired temperatures allowed to cool to the room temperatures (RT) and tested for compressive strength. The average of the three readings obtained is used to represent the condition of the experimental test. The study showed that the compressive strength of MHA concrete and normal concrete decreases when exposed to elevated temperatures, where the MHA concrete improve in strength at elevated temperatures up to 400°C, the normal concrete decrease in strength within the same range. The best potential of the original value at 600°C is at 10% MHA with residual compressive strength of 87% of the pre-heating value.

Keywords *Compressive strength, elevated temperature, millet husk ash*

INTRODUCTION

Concrete under service can be exposed to elevated temperatures during fire or when used in special structures such as furnaces, storage tanks for crude oil, hot waters and reactors. The mechanical properties of concrete, such as strength and elastic modulus decrease remarkably with significant volume deformation upon heating at high temperature resulting in a decrease in the structural quality of concrete, Felicetti & Gambarova (1998). The high temperature behavior of concrete is greatly affected by material properties, such as the properties of the aggregate, the cement paste and the aggregate- cement paste bond, as well as the thermal compatibility between the aggregate and cement paste (Piasta, Sawicz & Rvdzinski, 1984 and Mehta, 1989). When exposed to high temperature, the chemical composition and physical structure of the concrete change considerably. Dehydration, including the release of chemically bound water from calcium silicate hydrate, becomes significant above 110°C. The dehydration of the concrete matrix and the thermal expansion of the aggregate give rise to internal stresses, micro-cracks expanding gradually into the material at temperature around 300°C and a noticeable colour change could be seen (Uzer, Ak¨oz, O¨zt ¨ & UrkDokuzer, 2004; Hertz, 2005 and Ikpo, 2006). Mehta, 1989 and Zega & Di Maio, 2006 reported that Calcium hydroxide ($Ca(OH)_2$), one of the most important compounds in cement paste, dissociates at around 530°C, resulting in the shrinkage of concrete.

One of way of improving the durability properties of concrete is by modifying it constituents by including chemical admixtures in its matrix. Accordingly over the years, research works have been focused on the possibility of knowing the properties of abundantly available local materials; particularly agricultural waste ash, in order to serve as admixture in concrete, to meet both service and engineering requirements (Ademiluyi, 1985

Ashes derived from the incineration of volcanic rocks, agricultural waste or residues notably rice husk, baggash, etc, have been found by various researchers to be pozzolanic materials containing reactive silica or alumina which, when mixed in water possess cementitious properties, Sima (1974). According to Neville, (1992) Pozzolan is used to describe naturally occurring and artificial siliceous or aluminous materials which in themselves possess little or no cementitious values but within finely divided form and in the presence of moisture will chemically react with calcium oxide at ordinary temperature to form compound possessing cementitious properties. Millet Husk ash (MHA) is being strongly suggested as admixture to improve the properties of concrete in general and its durability in particular. It is used as a partial replacement or an addition to cement to modify both the physical structure and the chemical properties of concrete.

Millets are a group of small-seeded species of cereal crops or grains, widely grown around the world for food and fodder. They do not form a taxonomic group, but rather a functional or agronomic one. Their essential similarities are that they are small-seeded grasses grown in difficult production environments such as those at risk of drought (Liu et al., 2009). World millet production stands at around 30 million tons annually and for millions of people in the semi-arid tropics of Asia and Africa, Millets along with sorghum are the most important staple foods. As a result of this abundance of this agriculture produce in Nigeria and Niger state in particular, in which most times the husks are not used for any reasonable purpose rather they are burnt or left to decay, hence the interest on the research of millet husk ash (MHA) as a pozzolan in concrete.

The main objective of this research therefore is to ascertain the effect of elevated temperature on the compressive strength of concrete made with MHA as a partial replacement of Ordinary Portland cement (OPC) and hence establish the probable suitability of it in improving the durability properties of the concrete under service. The chemical analysis of the ash was undertaken to determine the suitability of MHA, through its chemical composition, as a Pozzolana.

MATERIALS AND METHOD

To perform the objectives of this study, concrete was mixed and tested according to ASTM C192 and BS 1881. The specifications of the specimens, concrete proportions and testing conditions are as follows:

Cube specimens with dimensions $100*100*100\ mm^3$.

Cement: Ordinary Portland Cement 275 kg/m^3

Coarse aggregate: crushed stones gravel (20mm)

Fine aggregate: Local sharp sand

Water: 190 Liters (W/C = 0.65)

MHA ratio: 0, 10, 20 %

Temperatures: 200, 400, 600° C.

Curing age: 28 days

The MHA (collected in Minna) used in this study was measured using absolute volume and blended with Dangote brand of OPC and aggregates to ensure a reasonable uniform distribution prior to water addition. For each testing condition, three specimens were used and the averages of the three readings were obtained. The total number of cube specimens was 36. The specimens were cured in water tanks prior to heating, after 28 days of curing, the specimens were taken out of tanks and placed in the electric oven, its temperature capacity is 1200° C. Specimens were left in the oven for 4 hours to achieve a uniform temperature distribution across them. After that, specimens were allowed to cool in the oven for 20 hours, a total of 24 hours of heating and cooling past the curing age. A loading rate of 3 Kn/s was used to get the residual compressive strength of concrete.

RESULTS AND DISCUSSION

The result of the physical properties of millet husk ash (MHA) for this study shows that the specific gravity and moisture content are 2.46, 2.09% respectively. The study also shows that the PH value of the ash is 10.0. This shows that the ash is alkaline in nature. The moisture content of the ash is hydroscopic in nature

Table 1, shows the chemical composition of MHA, the combined SiO_2 + Al_2O_3 + Fe_2O_3 (Silicon dioxide, Aluminium oxide, Ion oxide content) was 76.41% which meets the ASTM c1618 - 78 minimum limit of 70%. The chemical properties of MHA are therefore adequate in Pozzolana. The combined essential oxides of MHA at 76.41% are between that of Rice Husk Ash (RHA) and Pulverized Fuel Ash (PFA) at 73% and 85% respectively as reported by Kamang and Asabo, 2001. The Calcium oxide (Cao) content of the MHA was 10.4% which is higher than that of RHA at 0.16%, Ikpon (1993) and just a sixth of that of Ordinary Portland Cement (OPC) at 63%, Calcium oxide being one of the principal components of OPC, account for its rate of hydration (Neville, 1981). The moisture and carbon contents of MHA expressed as loss on ignition (L.O.I) was 2.1%, L.O.I should not exceed 7%, according to ASTM c1618 (1978).
Figure 1 presents the Mechanical and physical experiments conducted on the samples; the compressive strengths of unheated hardened concrete at 28 days hydrating periods without exposure to high temperature, the residual compressive strengths at elevated temperatures and the relative compressive strength values of the concrete mixtures after exposure to high temperature. Figure 1 also demonstrates that compressive strength decreased with increasing MHA content, and the strength of the sample with 20% replacement was about one third of the 0% replacement. This observation is reasonable considering the reduction of cement content in the mix that occurs with increasing MHA and tendency of slow strength development of pozzolant in concrete, (Mehta, 1981 and Hossain, 2004).

The residual compressive strengths of samples with replacement levels increase relative to the unheated samples with increase in temperature up to 400°C and decrease afterwards with all mixes, the relative highest strength gain was 20% at 200°C with 10% MHA. This phenomenon cannot be unconnected with the evaporation of inner free water of the concrete, Bahar & O˘guzhan (2010). At 600°C, the samples experience significant strength degradation with unblended sample losing about 40% of it strength and 20% MHA recorded a 28% loss of initial strength.

CONCLUSIONS

The following conclusions can be drawn based on the experimental studies presented in this paper:

1. The compressive strength of concrete with or without silica MHA decreases with increasing temperature, the peak value in the ratio of the compressive strength at high temperature to that at ambient temperature is observed around 200°C when MHA is at 10%. This peak value could be attributed to the evaporation of free water inside the concrete.
2. Plain concrete is more sensitive to high temperatures than MHA/OPC concrete, where the poor performance of concrete exposed to elevated temperature, compared to blended cement concrete can be attributed to the effect of vapor pressure built-up inside the concrete causing expansion and cracking because of its denser structure nature.
3. For all mixes containing MHA, the compressive strength was found to increase after four hours of exposure to an elevated temperature up to 400°C. An obvious reduction in the compressive strength was observed after exposure to 400°C, increasing the temperature up to 600°C causes serious deterioration where the decreasing ratio in the compressive strength reached to 40% of the unheated strength. At temperature higher than the scope of this work, a more severe deterioration will occurred for all mixes.
4. The reduction in the compressive strength of concrete was significantly larger for samples exposed to temperatures around 600°C. This result is due to the lost water of crystallization resulting in a reduction of the $Ca(OH)_2$ content, in addition to the changes in the morphology and the formation of micro cracks. It can therefore be said, that MHA is suitable as pozzolan and can improved the durability properties of the concrete under service especially when exposed to higher temperature.

RECOMMENDATION

Based on the conclusions drawn, MHA can be used as chemical admixture to reduce the effect of high temperature on plain concrete among other benefits. It is also recommended research should be carried out at higher temperature to about 900°C and at a higher hydrating periods, to allow for pozzolanic effect of MHA on strength development, in order to be able to draw broader conclusion on the study.

Table 1: Result of Chemical Properties of MHA

S/N	Compounds	% Oxides per sample
1	SiO_2	76.10
2	Al_2O_3	0.00038
3	Fe_2O_3	0.31
4	MgO	0.0023
5	P_2O_5	3.12
6	SO_3	2.01
7	Cl	1.12
8	K_2O	8.54
9	TiO_2	1.15
10	V_2O_5	0.187
11	CaO	10.4
12	ZnO	0.11
13	BiO	0.10
14	Re_2O_7	0.02
15	CuO	0.041
16	BaO	0.13
Total=SiO_2+Al_2O_3+Fe_2O_3		76.41

Source: *A.B.U Center of Energy Research, 2012*

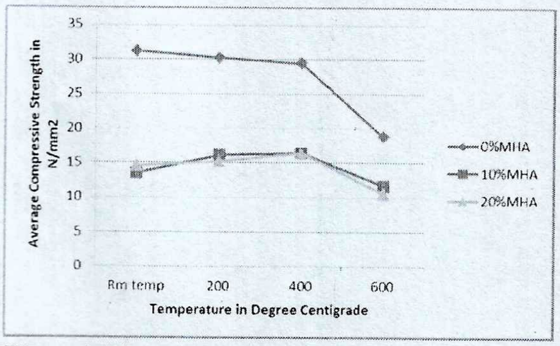

Figure 1: The average compressive strength of the concrete at various elevated temperatures

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