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EFFECT OF PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN ON THE DURABILITY OF HOLLOW SANDCRETE BLOCKS

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ABSTRACT

This paper investigates effects of a partial replacement of cement with metakaolin (MK) on the durability of hollow sandcrete blocks. Sandcrete hollow blocks of size 225 mm x 225 mm x 450 mm were produced from a mix of ratio 1:6 (binder : sand), and cured in water for 28 days. The cement was replaced with metakaolin at 0% to 35% levels at 5% intervals. Effect of replacing cement with MK in the sandcrete blocks on their dry density, total water absorption and porosity, wet and dry compressive strength were investigated. The average dry density of metakaolin hollow sandcrete blocks produced at various replacement levels after 28 days is 1892 Kg/m^3, which falls within the minimum specification of 1500 Kg/m^3 recommended for first grade (type "A" - load bearing block) sandcrete blocks by Nigeria Industrial Standard NIS 87: 2000. The inclusion of MK must have transformed the weaker and more porous metakaolin sandcrete blocks fabric into a far denser, more homogeneous and more impermeable component. Sandcrete hollow blocks samples made with 10% metakaolin had lowest water absorption of 6.25% which produces blocks with dense and compacted unit; this is as result of metakaolin ability to fill the void within the block fabrics attributed to metakaolin fineness. There was a sudden increase in water absorption from 15% to 35% replacement level caused by increase in metakaolin content in the mix. This might be due to the formation of a denser hydration phase. The porosity values of all metakaolin replacement with cement sandcrete blocks was less than 30% and are considered to be of low porosity. The ratio of dry and wet compressive ranges between 1.3 and 2.0 with the control block having 1.7. The findings shows that the higher and broader the ratio between mean dry compressive strength and wet compressive strength, the lower can the degree of inter granular bonding are expected to be. The results obtained indicated that replacement with 10% metakaolin satisfies Nigeria Industrial Standard requirements and British Standard Specification (6.25%) for water absorption. Metakaolin sandcrete blocks produced at 10% cement replacement with metakaolin is adequate for use as load bearing and non-load bearing structures in areas where they may be subjected to moisture ingress.

Keywords: *Metakaolin, block water absorbtion, porosity value, mean compressive strength, cement partial replacement.*

INTRODUCTION

Performance of sandcrete block depends on its mechanical and durability properties. A Sandcrete block, which comprises of sand, water, cement and in some cases admixture are widely used in Nigeria as walling units either as load bearing or non-load bearing wall. Observation has shown that many ancient buildings in Nigeria are made of clay works, presently still in existence and usable. Despite the introduction of new materials such as life bricks, modified clay blocks, sandcrete blocks seem to be an improvement over these materials which has gained wide usage in construction industries for use as load bearing and non-load bearing structure which has tremendous advantages due to some of its characteristic properties such as strength, density, water absorption, shrinkage, durability, costs and dimensional accuracy. The quality of sandcrete blocks are influenced by so many factors such as the constituent materials, the process adopted in manufacture, duration of curing, form and size of blocks. However, for some time now, most sandcrete blocks used in developing countries, especially in sub-Saharan Africa, have been found to be substandard (Anosike and Oyebade 2011). Earlier investigations in Nigeria have also revealed the very poor performance of these sandcrete blocks as they exhibit strength and durability far below the standard requirements (NIS: 1975). Some of these blocks even fail while being transported due to self-weight, which results or contribute to collapse of buildings especially failures of load bearing walls made from these blocks. This problem has been attributed to poor quality control and use of substandard constituent materials (Olusola and Akintayo 2009). As cited by several authors including Illston *et al*. (1979) and Nwokoye (1999), were of the view that structural failure is a direct function of constituent material failures and the material-to-material interactions within the structural unit. For this reason, if constituent materials of any structural unit are improved, it will ultimately improve the structural value of the whole unit.

Due to their porous nature, sandcrete blocks generally take in fluid when exposed to moist conditions. Studies by (Marchand *et al*., 1996, Siddique and Klaus, 2009, Cassagnabère *et al*., 2010) have showed that the use of mineral admixtures in mortar and concrete afforded porous structure refinement, increasing resistance to compression and bending and its potential for efflorescence, increasing, thereby, the durability. By addition of some pozzolanic materials, the various properties of concrete such as workability, durability, strength, resistance to cracks and permeability can be improved (Mental, 1994; Falade, 1997; Oyekan, 2001). Due to pozzolanic and filling effects of these certain mineral admixtures, They are capable of enhancing the durability through the pore refinement and the reduction in the calcium hydroxide of the cement paste, this cement composites improves mechanical properties and life of the structure. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste.

Metakaolin is a pozzolanic material which is manufactured from kaolin clay, after refinement and calcination under specific conditions (temperature and time). It is quite useful for improving concrete quality, by enhancing strength and reducing setting time, and may thus prove to be a promising material for manufacturing high performance concrete (Li and Ding 2003). It differs from other supplementary cementitious materials like fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under controlled conditions. It is produced by heating kaolin to temperatures of 650-900°C for periods ranging from 1 hour to 12 hours. This heat treatment serves to break down the structure of kaolin. When Metakaolin is added in the hydration process, it reacts with the free lime to form additional CSH material, thereby making the concrete stronger and more durable.

The use of metakaolin as a partial cement replacement material in mortar and concrete has received considerable attention. Metakaolin is used as a supplementary cementitious material in concrete to reduce cement consumption, to increase strength and the rate of strength gain, to decrease permeability and to improve durability (Khatib and Wild, 1998; Aquino *et al.,* 2001; Asbridge *et al.,* 2001; Boddy *et al.,* 2001; Justice, *et al.,* 2005). Metakaolin can also be used as a sandcrete block constituent, replacing part of the cement content since it has pozzolanic properties. This paper investigates experimentally the effect of partially replacing cement with metakaolin on some durability properties (Block Dry Density, Total Water Absorption, Total Volume Porosity and Wet and Dry Compressive Strength) of the sandcrete blocks.

MATERIALS AND METHODS

The materials used for the production of hollow sandcrete block samples tested in the laboratory are water, fine aggregate (sand), cement, and metakaolin only.

Fine Aggregate (Sand)

The fine aggregate (sand) used was clean, river sand, which was free of clay, loam, dirt and any organic or chemical matter and was locally sourced in Zaria. It was sand passing through sieve of size 4.76 mm. The sand had a specific gravity of 2.61 and an average moisture content of 9.08%

Cement

Dangote Portland limestone cement (3X brand) was used for this study. It was obtained from a dealer in Zaria, Kaduna State, Nigeria with properties conforming to BS EN 197-1 (2011).

Water

Potable water which was used for both specimen preparations and curing of sandcrete blocks throughout the investigation.

Kaolin

Kaolin used in the study was a product of Kankara kaolin clay deposit from Kankara Local Government Area of Katsina state, Nigeria precisely around longitude 7°26E and 7°28E and latitude 11°53N. The kaolin was subjected to close burning at 700°C to obtain the metakaolin that was used for this research.

Production of Sandcrete Blocks

The blocks (all hollow) were produced using standard metal molds in accordance to NIS 87: 2000. A mix proportion of 1:6 (binder: sand) was used in the production of 450 mm x 225 mm x 225 mm sandcrete block. Cement was replaced partially with metakaolin at replacement levels of 0, 5, 10, 15, 20, 25, 30, and 35% by weight are used. In the production of these blocks, hand mixing was employed and the materials were thoroughly mixed until an even color and consistency was attained. The mixture was poured into the mold and rammed and compacted. The excess material was stripped leaving the surface flat. The sandcrete blocks were removed from the mold, the blocks were left on pallets with a space between two blocks for the period of curing. They are kept wet during this period by watering daily. The curing was done by sprinkling water twice in a day as shown in Plate I. Testing for durability was carried out after 28 days curing.

Plate 1: Metakaolin sandcrete blocks produced at various replacement levels

Durability Test Evaluation on Metakaolin Sandcrete Block (MKSB)

The bulk properties identified as likely to have direct bearing with the investigation of the durability of metakaolin sandcrete blocks (MKSB) produced include the following

Block Dry Density

The density of a block is a valuable indicator of its quality. The determination of the dry density was done carefully in accordance to (BS 6073: Part 2, 1981) by weighing the block samples after they were oven-dried at 105 ± 5°C for 24 hours as shown in plate 2 and the dimensions of the block samples were taken with an accurate steel tape. The dry density was then calculated using the formulae in Equation (1).

$$\ell d = \frac{m}{v} \text{ kg /m}^3 \quad (1)$$

where, ℓd = Dry density

m = Mass of dry block sample

v = Volume of block sample.

The density obtained in each case was expressed to the nearest kg/m³ .

Plate 2: Block samples oven dry in oven for 24 hours

Total Water Absorption (TWA)

Cold immersion method was used in determining the total water absorption of the block samples, which was carried out in accordance to BS 3921, 1985. This involves oven-drying the block samples for 48 hours followed by cold-immersion in water as shown in Plate 3. The block samples were dried in oven to constant weight, thereafter they were immersed in water for 24 hours. The weights of the wetted blocks were then measured. The percentage water absorption was calculated from the formula in Equation 2.

$$TWA = \frac{Mw - Md}{Md} \% \quad (2)$$

where,

TWA = percentage moisture absorption (%),

Mw = mass of wetted sample (g),

M_d = mass of dry sample (g).

The mean values obtained from the calculations were taken as the Total Water Absorption (TWA) of the sample. The result was expressed as a percentage of the original dry mass of the specimen to the nearest 0.01% the dry mass.

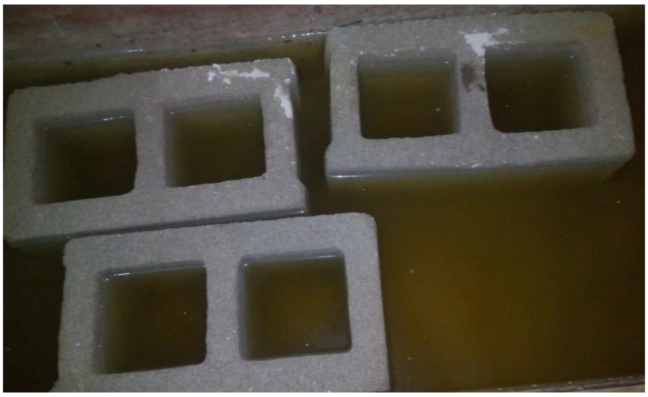

Plate 3: Blocks samples immersed in water for 24 hours

Total Volume Fraction Porosity (TVP)

The term porosity refers to the total amount of voids and pore structure within a block sample. The total volume fraction porosity of the sandcrete blocks was determined by direct measurement of the weight gain on saturation with water of an initially dry block after evacuation to remove air from the pore network (Jackson and Dhir, 1996). The water absorption is expressed as before in weight percent. The value of the water absorption may be converted to volume basis porosity by using the following relationship (Jackson and Dhir, 1996):

$$n = \frac{TWA \times \varrho d}{100 \times \varrho w} \quad (3)$$

where,

n = volume fraction porosity,

ϱd = dry block density (kg/m^3)

ϱw = density of water (kg/m^3),

TWA = Total water absorption

Wet and Dry Compressive Strength

The wet and dry compressive strength test was carried out to determine the load bearing capacity of the hollow sandcrete block samples, which was carried out in accordance to BS 6073 Part 1, (1981). Compressive strength was obtained for each sample using the formula in Equation (4).

$$Compressive\ strength\ (N/mm^2) = \frac{\text{Crushing load}}{\text{Net area of block}} \quad (4)$$

For the wet compressive strength test, block samples were pre-soaked for 24 hours while for the dry compressive strength block samples were oven dried to constant mass.

RESULTS AND DISCUSSION

Dry Density of the Block Samples

Table 1 shows the result of the block dry density of metakaolin hollow sandcrete blocks produced at various replacement levels at 28 days curing. Hollow sandcrete blocks with 10% replacement of cement with metakaolin had highest average density of 1982 Kg/m^3, this was as a result of inclusion of metakaolin which filled the void within the block fabric. At this percentage replacement, the hollow sandcrete block is more compact.

Table 1: Block dry density, total water absorption and total volume porosity

Item	0	5	10	15	20	25	30	35
Block Dry Density (Kg)	1959	1843	1982	1835	1820	1812	1920	1967
TWA $= \frac{Ww-Wd}{Wd}$ (%)	7.09	7.06	6.25	9.35	9.96	10.12	10.32	10.71
TWA $= \frac{Ww-Wd}{vd}$Kg/m^3	139.4	139.4	123.9	178.1	193.6	193.6	201.3	209.1
TVP $= \frac{TWA*\varrho d}{100x\varrho w}$ (%)	14.15	13.26	12.63	17.49	18.48	18.70	20.19	21.48

The values of metakaolin sandcrete block at various replacement level falls within the stipulated values of density for type "A" blocks according to BS 2028 (1970), and also falls within the minimum specification of 1500 Kg/m^3 recommended for first grade (type "A"- load bearing block) sandcrete blocks by Nigeria Industrial Standard NIS 87: 2000.

Total Water Absorption (TWA)

Table1 shows the results obtained from the test of block dry density, total water absorption and total volume porosity conducted on sandcrete block at various replacement level of cement with metakaolin. It can be noted that the metakaolin hollow sandcrete block with 10% replacement has the least water absorption of about 6.25%. It is observed that the presence of the metakaolin makes the average absorption rate to drop. This signifies more compact blocks. 5% replacement attained 7.06%, a little below the control sample with 7.09%. There was a sudden increase in water absorption from 15% to 35% replacement level caused by increase in metakaolin content in the mix. This might be due to the formation of a denser hydration phase. The water absorption value of blocks produced with 0%, 5%, 15%, 20%, 25% 30%, and 35% replacement level were higher than the maximum water absorption value of 7% specified for blocks by BS 2028 (1970). Blocks produced with 10% replacement have water absorption value of 6.25% satisfied the maximum water absorption value of 7% given in BS 2028 (1970).

According to NIS 87: 2004, the average water absorption should be maximum of 12%. All values obtained fell below the maximum NIS recommendation. However, 35% metakaolin content retains water more than both Control and other metakaolin sandcrete blocks samples. Also, American society for testing and materials (ASTM C140: 2001) specifies that the average water absorption should be less than 240 kg/m^3. The values obtained were in the range of 123.9 to 209.1 kg/m^3.

According to BS 2028 Part 1, total water absorption values below 7% are regarded as being low, while those above 12% as high. The values for metakaolin sandcrete blocks at 15%, 20%, 25% 30%, and 35% replacement level were below 12% and as such can be regarded as moderate while for the 5%, 10% and control blocks, the values are lower than and within 7 hence can be regarded as low. Thus, the metakaolin hollow sandcrete blocks produced by hand compacted passed the water absorption test.

The result of water absorption test conducted in this research is in line with what was reported by Razak *et al.* (2004) who studied the effect of metakaolin on the water absorption and sorptivity of concrete and concluded that the inclusion of metakaolin reduces the water absorption and sorptivity of concrete, when compared with concrete made with ordinary Portland cement.

Total Volume Porosity (TVP)

The result of total volume porosity is shown in Table 1; the total volume fraction porosity values are lower at 10% than that of the control sample and other replacement levels. The values for the hollow sandcrete blocks at various replacement levels compared well with those of like materials; Clay bricks 0 - 30%; Concrete blocks 4 - 25%; calcium silicate bricks 6 -16% (Jackson and Dhir, 1996). Materials with Total Volume Porosity above 30% are considered to be of high porosity (Keralli, 2001). All the hollow sandcrete blocks evaluated during this research can therefore be considered to be of low porosity since the value obtained is below 30% that is, it ranges between 12.63% and 21.48%.

Dry and Wet Compressive Strength

The values of the average 28-day curing of the wet and dry compressive strength for both the control hollow sandcrete block and metakaolin sandcrete block (hollow sandcrete block at various replacement level) is given in Table 2. The ratio of the mean dry and wet compressive strength for the control sandcrete block and metakaolin sandcrete blocks are also given in Table 2.

Table 2: Wet compressive strength (WCS) and dry compressive strength (DCS)

Item	225 mm blocks at various replacement level							
	0	5	10	15	20	25	30	35
WCS (N/mm^2)	2.13	1.71	2.37	1.58	1.51	1.20	0.82	0.64
DCS (N/mm^2)	3.55	3.38	3.70	2.58	2.26	1.50	1.17	0.99
Ratio	1.7	2.0	1.6	1.6	1.5	1.3	1.4	1.5

The values of the average 28-day curing for wet and dry compressive strength for the control block is 2.13 N/mm^2 and 3.55 N/mm^2 and that of metakaolin sandcrete blocks ranges between 0.64 N/mm^2 and 2.37 N/mm^2, .099 N/mm^2 and 3.70 N/mm^2 at 35% and 10% replacement level respectively, this implies that, at 10% replacement level having perform the best in terms of density and compressive strength have higher wet and dry compressive strength than both the control block and metakaolin sandcrete blocks produced at various replacement level. The lower values obtained is as a result of excess metakaolin in the mix which has no calcium hydroxide to consumed, hence resulting in lower compressive strength.

Ratio of Dry and Wet Compressive Strength

The ratio of dry and wet compressive ranges between 1.3 and 2.0 with the control block having 1.7 and blocks with 5% replacement level having higher value of 2.0 as shown in table 5. The findings show that the higher and broader the ratio between mean dry compressive strength and wet compressive strength, the lower can the degree of inter granular bonding be expected to be. It can be concluded that the reduction in ratio for metakaolin sandcrete blocks is directly attributed to the inclusion of metakaolin. This must have transformed the weaker and more porous metakaolin sandcrete blocks fabric into a far denser, more homogeneous and more impermeable matrix. The values obtained fall within the range of recommended values in literature that the ratio of the mean dry and wet compressive strength sandcrete hollow blocks should not be greater than 2, Keralli (2001). Therefore, the experimental results obtained for both control blocks and metakaolin blocks fall well within this limit

CONCLUSIONS

i. From the result of research work carried out, it can be concluded that the block dry density values of metakaolin sandcrete blocks falls within the stipulated values for type A blocks according to BS 2028 (1970).

ii. Total water absorption result show that the best replacement level of cement with metakaolin to produce sandcrete blocks are obtained at the optimum metakaolin content of 10%. At this optimum value the sandcrete block obtained is very compact.

iii. The results of the total water absorption values compare well with current recommended maximum values for sandcrete blocks. The recommended maximum is 12% (NIS 87: 2004).

iv. The total volume porosity values for all the metakaolin replacement with cement sandcrete blocks is less than 30% and can therefore be considered to be of low porosity.

v. The value of the ratio of the mean dry and wet compressive of all samples are below the stipulated value of 2.0 recommended by keralli (2000).

It is recommended that Metakaolin sandcrete blocks produced at 10% cement replacement with metakaolin is adequate for use as load bearing and non-load bearing structures in areas where they may be subjected to moisture ingress.

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