



COMPRESSIVE STRENGTH ASSESSMENT OF METAKAOLIN HOLLOW SANDCRETE BLOCKS

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ABSTRACT

This study examines the effect of partially substituting metakaolin (MK) for cement on the hollow sandcrete block's compressive strength. Sandcrete hollow blocks measuring 225 x 225 x 450 mm were made using a 1:6 mix ratio, which is one part cement to six parts fine aggregate (sand). The study was carried out by partially replacing metakaolin with cement at 0% to 35% at 5% intervals to assess the impact on the hollow sandcrete block's strength. The blocks were cured using the sprinkling method, and compressive strength tests were conducted on the hollow sandcrete block samples at 1, 3, 7, 14, 21, and 28 days. The compressive strength of hollow sandcrete blocks samples ranges from 3.65 N/mm² to 0.86 N/mm². The compressive strength results showed that the optimum percentage of metakaolin (MK) replacement by weight of cement was 10% having a strength of 3.65 N/mm² after 28 days of curing. These value meets the stipulated requirement specified by Nigeria Industrial Standard NIS 87 (2000), BS 6073, and National Building Code (2006) and are adequate for usage as non-bearing and load-bearing structures in areas where moisture infiltration may occur. The research was aimed at using metakaolin (MK) as a partial replacement of cement in the production hollow sandcrete blocks to curtail the reduction of cement components by block producers to produce low-quality sandcrete block for structural purposes and improve the strength properties of blocks in terms of its production.

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1.0 Introduction

Sandcrete blocks can be defined as composite construction materials made from combining cement, fine aggregate (sand), and water and molded into various sizes (Barry, 1999., and Anthony, et al., 2015). 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. Sandcrete blocks are perhaps the most widely used building material in Nigeria, having been employed in the construction of over 90% of the country's physical infrastructure. In Nigeria and other African nations, it is extensively utilized as non-load-bearing and load-bearing walling components, and they have many advantages because of some of their unique properties like strength, density, water absorption, shrinkage, durability, costs, and dimensional accuracy. Many factors, including the materials used in the manufacturing process, the length of time the blocks are left to cure, and the shape and size of the blocks, affect the quality of sandcrete blocks (Esegbuyota et al., 2019). Cement, the primary binder used to make concrete, mortar, sandcrete blocks, and other cement products, is very costly, especially in developing nations. Due to the recent expansion of infrastructure development, there is an increasing global consumption of cement used in the production of concrete (Zareei, 2017; Thomas, 2018; Attah et al., 2020). Reducing the cost of producing cement and the amount of carbon dioxide (CO₂) emission into the atmosphere (Mehta, 2001 Khan et al., 2012; Johnson et al., 2013;), decreasing housing costs, and meeting the increasing need to protect the environment, has intensified the efforts of researchers at seeking and developing affordable and accessible alternative local materials that could be employed for environmentally friendly building (Awodiji et al., 2018; Onwuka et al., 2013, Nwa-David et al., 2023a). All the challenges have

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resulted in increasing the cost of construction of houses and cement-based physical infrastructure, Hence the need to search for alternative binding materials as a whole or partly as a substitute for cement. Thus, Part of the solution to reducing the increasing cost of cement in the production of concrete in recent times is the use of supplementary cementitious materials (SCMs) including periwinkle shell ash, corncob ash, rice husk ash, cassava peel ash, oyster shell ash, sawdust ash and metakaolin for developing high-strength concrete with enhanced workability, strength and durability and reduced permeability (Olutoge *et al.*, 2012; Kamau *et al.*, 2016; Ogbonna *et al.*, 2020).

Kaolin clay is refined and then calcined under specific conditions (temperature and time) to produce metakaolin, a pozzolanic material. By increasing strength and decreasing setting time, metakaolin is a very useful material for improving the quality of concrete and may be a potential material for the production of high-performance concrete (Li and Ding, 2003). Metakaolin is produced for a specific purpose under controlled conditions, making it different from other supplementary cementitious materials like fly ash, slag, or silica fume. It is manufactured by heating kaolin to temperatures between 650-900°C for periods ranging from 1 hour to 12 hours. The kaolin's structure is broken down by this heat treatment. When metakaolin is added during the hydration process, it reacts with free lime to form additional CSH material, thereby enhancing the strength and durability of the concrete (Goud *et al.*, 2017; Saand *et al.*, 2017). However, for some time now, the majority of hollow sandcrete blocks used in developing nations, particularly in sub-Saharan Africa are substandard. (Anosike and Oyebade 2011). Previous studies conducted in Nigeria have also demonstrated how poorly these sandcrete blocks perform, with their strength and durability falling well short of the required standards. According to Odeyemi *et al.* (2018), stated that many of the hollow sandcrete blocks produced by commercial block producers do not meet the Nigeria Industrial Standard's recommended maximum water absorption of 12% and the minimum standard requirement for compressive strength values of 2.5 N/mm² and 3.45 N/mm² for non-load bearing walls and load bearing walls, respectively. some of these blocks even fail while being transported because of their weight, leading to or contributing to the collapse of buildings, especially the failure of load-bearing walls constructed with these blocks. This problem has been attributed to poor quality control and substandard constituent materials. (Olusola and Akintayo 2009).

Due to their porous nature, sandcrete blocks generally take in fluid when exposed to moist conditions. According to studies by Siddique and Klaus (2009), Cassagnabère *et al.* (2010) and Marchand *et al.* (1996), the addition of mineral admixtures to concrete and mortar improved the porous structure's resistance to bending, compression, and efflorescence, thereby increasing the material's strength and durability. Due to the pozzolanic and filling actions of certain mineral admixtures, they are capable of improving durability through pore refinement, and the reduction in the calcium hydroxide of the cement paste, these cement composites improve the mechanical properties and life of the structure. The physical action of the pozzolanas provides a uniform, more homogeneous, and denser paste (Chindaprasirt *et al.*, 2004).

Much attention has been paid to the utilization of metakaolin in mortar and concrete as a partial substitute for cement. Metakaolin is used as a supplementary cementitious material in concrete to improve durability, decrease permeability, enhance strength and the rate of strength gain, and reduce cement consumption (Asbridge *et al.*, 2001; Aquino *et al.*, 2001; Boddy *et al.*, 2001; Justice *et al.*, 2005 and Khatib and Wild, 1998). Metakaolin can also be used as a sandcrete block constituent, substituting part of the cement content since it has pozzolanic properties. This paper investigates experimentally the effect of partially replacing cement with metakaolin on the compressive strengths of hollow sandcrete blocks.

2. Materials and Methods

2.1 Materials

The constituent materials used for the production of Metakaolin hollow sandcrete block were portable water, fine aggregate (sand), cement, kaolin, and metakaolin only.

2.1.2 Fine Aggregate (Sand)

The fine aggregate (sand) used in this study was sourced locally in Zaria, Kaduna State, Nigeria, and was devoid of any organic or chemical debris, clay, loam, or dirt. It was fine aggregate sand passing through a sieve of size 4.76 mm to remove some of the contained coarse aggregates. The sand had a specific gravity of 2.61 and an average moisture content of 9.08%.

2.1.3 Cement

Dangote Portland limestone cement (3X brand) was used for this study. It was obtained from a dealer in Zaria, Kaduna State, Nigeria, and its properties met NIS 444-1:200 and BS EN 197-1 (2011) requirement.

2.1.4 Water

Water from the Civil Engineering Department, Ahmadu Bello University, Zaria, was used for both the specimen preparations and curing of sandcrete blocks throughout the investigation and it conformed with the recommendations of BS 3148:1980.

2.1.5 Kaolin

The kaolin used in the study was a product of the 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 study (Elimbi et al., 2011).

2.1.6 Metakaolin

The incineration of kaolin to obtain metakaolin for the study was carried out under controlled temperature conditions. Ahmadu Bello University Zaria's School of Physical Science Multipurpose Laboratory was used to assess the oxide composition by mass of a metakaolin sample. To ascertain the percentage oxide composition and categorize the metakaolin as pozzolanic material, the X-ray fluorescence (XRF) method was utilized to analyze the oxide composition of the material. The test was carried out in compliance with the guidelines provided in BS EN 197-1: 2011 and BS EN 196-2: 2000. The Specific gravity test was carried out on the metakaolin in accordance with BS 1377-2: (1990)



Figure 1: Kaolin before calcination



Figure 2: Kaolin after calcination

2.2 Methods

2.2.1 Hollow Sandcrete Blocks Production

The hollow sandcrete blocks were produced using standard metal molds in accordance with NIS 87: 2000 (2000). A mix proportion of 1:6 (which is one part cement to six parts fine aggregate (sand)) was used in the production of hollow sandcrete blocks measuring 450 mm x 225 mm x 225 mm as specified by (NIS 87:2000, 2000), for the production of sandcrete blocks in Nigeria. The cement was replaced partially with metakaolin at 0% to 35% levels at 5% intervals. The quantities of the materials were batched by weight. In the production of these blocks, hand mixing was used and the materials were thoroughly mixed until an even color and consistency were achieved. The mixture was poured and compacted into a metal mold measuring 450 x 225 x 225 mm. After that, the excess material was removed, leaving the surface smooth. Following these method, Corresponding author's email address: musa.ibrahim@bazeuniversity.edu.ng

168 hollow sandcrete blocks measuring $450 \times 225 \times 225$ mm were produced. The blocks were removed from the molds and placed on the pallets with a space between two hollow sandcrete blocks for the period of curing.

2.2.2 Curing

The hollow sandcrete blocks were cured in compliance with (NIS 87:2000, 2000). Throughout the curing process, the hollow sandcrete blocks were left on wooden pallets and kept wet. The curing was done by sprinkling water twice (Morning and Evening) a day for 1, 3, 7, 14, 21, and 28, days. For the curing of sandcrete blocks produced, clean water devoid of salt and other harmful substances was used at a temperature of 23 ± 2 °C.



Figure 3: Metakaolin sandcrete blocks produced at various replacement levels

2.2.3 Compressive Strength Test

A compressive testing machine was used to carry out the compressive strength of the blocks in the Material Testing Laboratory at Ahmadu Bello University Zaria, Kaduna State, Nigeria, after the necessary curing days of 1, 3, 7, 14, 21, and 28 days. The compressive strength test was carried out on the hardened hollow sandcrete blocks at 1, 3, 7, 14, 21, and 28 days of age to determine the load-bearing capacity of the hollow sandcrete block samples, which was carried out as stipulated in BS 6073 Part 1, (1981). For each mix, 3 blocks were crushed to obtain the average strength using the following Equation

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Crushing load}}{\text{Net area of block}} \quad (1)$$



Figure 4: Crushing Strength of MKSB by Universal Compression Machine

3. Results and Discussion

3.1 Specific Gravity/Bulk Density

The specific gravity of Metakaolin was found to be 2.57 as shown in Table I. The specific gravity value is a little lower than the 2.62 reported by Poon *et al.*, (2001) but greater than 2.5 obtained by Al-Akhras *et al.* (2006) and Tfraoui *et al.* (2005). Also, the bulk density of Metakaolin is 1865 Kg/m³. Table I compares the specific gravity and bulk density of Ordinary Portland Cement with Metakaolin, demonstrating that OPC values are higher in both cases.

Table I: Comparison between Physical Properties of OPC and Metakaolin

Item	Ordinary Portland Cement (OPC)	Metakaolin
Bulk Density	1320 Kg/m ³	1865 Kg/m ³
Specific Gravity	3.15	2.57

3.2 Chemical Analysis of Metakaolin

The result of the oxide composition of metakaolin as shown in Table 2 shows that Metakaolin contains Silicon oxide (SiO₂ = 56.48%), Aluminum oxide (Al₂O₃ = 36.09%), and Iron oxide (Fe₂O₃ = 0.59%). The total percentage composition of SiO₂, Al₂O₃, and Fe₂O₃, is 93.16% which is in line with ASTM C 618-78 (American Society for Testing and Materials, 1978) minimum requirement of 70% for pozzolanas. Therefore, the Kankara metakaolin meets the stipulated requirement for pozzolanas and is classified as class F. The presence of siliceous and aluminous material in the Metakaolin in its fine form suggests that it can react with calcium hydroxide to produce calcium silicate hydrate (CSH), a cement-forming substance that increases strength (ASTM C618).

Table 2: Chemical Composition of Metakaolin

Elemental Oxide	Percentage (%) of Metakaolin
SiO ₂	56.48
Al ₂ O ₃	36.09
Fe ₂ O ₃	0.59
CaO	0.28
MgO	0.67
Na ₂ O	0.02
K ₂ O	0.06
TiO ₂	5.15
SO ₃	0.33

With its low combined alkali concentration of 5.21% (Na₂O + K₂O), Metakaolin decreases the likelihood of the destructive aggregate alkali reaction that causes the disintegration of concrete. It is also observed that the SO₃ and MgO values are 0.33% and 0.67% which are less than the maximum of 2.5% and 4% specified in BS 3892: 1990 parts 1 and 2 respectively. This suggests that adding metakaolin to concrete mixes could improve their durability and reduce unsoundness when utilized in the production of Metakaolin hollow sandcrete blocks.

3.3 Compressive Strength of Metakaolin Sandcrete Blocks

The result of the average compressive strength of the tested metakaolin sandcrete blocks with a mix ratio of 1:6 (which is one part cement to six parts fine aggregate (sand) at 1, 3, 7, 14, 21, and 28 days of curing is shown in Table 3, whereas the plots in Figure 5 illustrates the increase of the compressive strength of hollow sandcrete blocks with the age of curing for different levels of replacement of cement with Metakaolin.

Table 3: Compressive Strength of Hollow Sandcrete Blocks

Age of Curing (Days)	Compressive Strength (N/mm ²) at Various Levels of Replacement of Cement with Metakaolin							
	Control Mix	5%	10%	15%	20%	25%	30%	35%
1	0.52	0.86	1.10	0.83	0.80	0.49	0.41	0.31
3	1.33	1.51	2.04	1.47	1.32	0.70	0.66	0.56
7	1.90	2.31	2.53	2.30	1.89	1.30	0.99	0.70
14	2.61	2.73	2.87	2.24	1.79	1.67	0.85	0.81
21	2.81	3.04	3.19	2.53	2.12	1.51	0.83	0.70
28	3.51	3.36	3.65	2.61	2.21	1.58	1.10	0.86

The compressive test results obtained for sandcrete blocks produced at different replacement level of cement with metakaolin indicates that the compressive strength of sandcrete blocks increases with an increase in the Metakaolin content from 5% to 20% and decreases with an increase in metakaolin content from 25% to 35% replacement of cement with metakaolin. After 28 days of curing, the compressive strength at 5% replacement of cement with metakaolin is lower compared to that of the control mix. This can be seen when 5% cement is replaced with metakaolin achieving a compressive strength of 3.36 N/mm² compared to 3.51 N/mm² respectively. It is evident that the 5% replacement level of metakaolinite is insufficient to produce additional

C-S-H, and hence does not increase the compressive strength over the control at all ages. The metakaolinite available only reacts with a portion of calcium hydroxide released from the byproduct of hydration of cement which limits the strength development at the later ages (Siddique *et al.*, 2009).

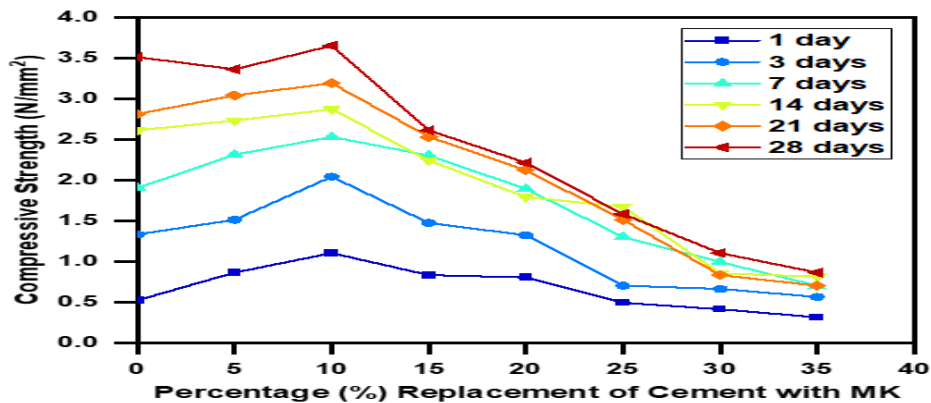


Figure 5: Compressive Strength of Metakaolin Sandcrete Blocks with varying curing days.

Metakaolin sandcrete blocks with 10% metakaolin replacement level exhibit the best strength development revealing that 10% metakaolin replacement is the optimum as seen in Figure 2. The average compressive strength of 3.65 N/mm² after 28 days of curing was attained at a 10% cement replacement level with metakaolin. The mean compressive strength of 3.65 N/mm² at 28 days of curing was achieved at a 10% replacement level of cement with metakaolin. This satisfied the Nigeria Industrial Standard NIS 87 (2000)'s compressive strength requirements of 2.5 N/mm² for non-load-bearing walls and 3.45 N/mm² for load-bearing walls. This also satisfies BS 6073 which recommends 2.80 N/mm² for the mean strength, and 2.59 N/mm² for the lowest individual strength. The compressive strength at 5%, 15%, and 20% replacement levels with metakaolin are 3.36 N/mm², 2.61 N/mm², and 2.21 N/mm² respectively at 28 days of curing which satisfies the requirement given in the Nigeria Federal Ministry of Works, and Housing (1979) specification, National Building Code (2006) specification, NIS 87: 2000 for hand compacted blocks. Although, compressive strength at 25%, 30%, and 35% replacement at 28 days of curing exhibit significant strength of 1.58 N/mm², 1.10 N/mm², and 0.86N/mm² respectively. This strength is higher than commercially produced blocks in some regions of Nigeria according to Ewa and Ukpata (2013) and Tsado *et al.*, (2014) which ranges from 0.23 N/mm² and 0.58 N/mm².

4. Conclusion

The Metakaolin obtained by the incineration (under controlled conditions) of the kaolin, a product of the Kankara kaolin clay deposit from Kankara Local Government Area of Katsina state, Nigeria met all the requirements of oxide composition and has a SiO₂, Al₂O₃, and Fe₂O₃ combination of 93.16% which is higher than the 70% minimum recommended limit as stipulated by ASTM C 618-05. This suggests that the metakaolin utilized in this study, which was derived from kaolin, is a high-quality reactive pozzolana.

The compressive strength of hollow sandcrete blocks increases with an increase in the Metakaolin content from 5% to 20% but reduces with an increase in metakaolin content from 25% to 35% in the mix. The compressive strength results indicate that the optimum percentage of Metakaolin replacement by weight of cement was 10% having a strength of 3.65 N/mm² at 28 days of curing and also which meets Nigeria Industrial Standard NIS 87 (2000), BS 6073, and National Building Code (2006) stipulated requirement.

It is recommended that Metakaolin sandcrete blocks produced at 10% cement replacement with metakaolin are adequate for use as load-bearing and non-load-bearing structure in areas where they may be subjected to moisture ingress. Sensitization is needed in the production of commercial hollow sandcrete blocks to block producers of low-quality blocks and how Metakaolin can be utilized as a partial substitute for cement to achieve the required profit margin with standard for structural purpose.

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