



Comparative Analysis of the Compressive Strength of Metakaolin Sandcrete Blocks and Sandcrete Blocks Incorporating Selected Supplementary Cementitious Materials

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ABSTRACT

This paper examines the effect of partially substituting metakaolin (MK) and some selected supplementary cementitious materials (such as Olive Seed Ash, Maize Cob Ash, Millet Husk Ash, and Guinea Corn Husk Ash) for cement on the hollow Sandcrete blocks 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 comparing the compressive strength of Sandcrete blocks produced at 10% and 20% replacement of Metakaolin and other selected supplementary cementitious materials to assess the impact on the hollow Sandcrete block's strength. The result of compressive strength of metakaolin and some selected SCMs was analyzed and compared after 28 days of curing. The compressive strength of all the SCM-based hollow Sandcrete block samples for this study ranges from 2.16 N/mm² and 4.50 N/mm² at 0% (control), 1.73 N/mm² and 4.05 N/mm² at 10%, and 1.50 N/mm² and 3.15 N/mm² at 20% replacement of cement with SCM. Sandcrete blocks made with Millet Husk Ash had the highest compressive strength, followed by those made with Maize Cob Ash, Olive Seed Ash, Metakaolin and Guinea Corn Hush Ash with 4.50, 4.30, 3.82, 3.51 and 2.16 N/mm² respectively which meet the requirement specified by Nigeria Industrial Standard NIS 87 (2000), BS 6073, and National Building Code (2006) except Guinea Corn Hush Ash and are adequate for usage as non-bearing and load-bearing structures in areas where moisture infiltration may occur. Sandcrete blocks produced at 20% replacement of cement with SCM can all be used as non-bearing walls except Guinea Corn Hush Ash, which does not meet the minimum requirement specified by various codes. It can be concluded that 10% and 20% replacement of cement with other SCM can be effectively substituted with 10% and 20% as cement in structural Sandcrete blocks, and the quality of materials will not be compromised.

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INTRODUCTION

Sandcrete block is a composite construction material primarily made up of cement, sand, and water, which are moulded into a variety of sizes (Odeyemi et al., 2018). Despite the introduction of new materials like life bricks

and modified clay blocks, Sandcrete blocks appear to be an improvement over the currently available materials. The construction industry is a vital economic sector in developing countries like Nigeria. Sandcrete blocks are widely used in Nigeria and virtually all African countries for the

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construction of over 90% of the country's physical infrastructure (Baiden and Tuuli 2004) and used for both load-bearing and non-load-bearing walling components. Some of the Sandcrete blocks, including strength, density, water absorption, shrinkage, durability, cost, and dimensional accuracy, provide them with numerous advantages. Many factors affect the quality of Sandcrete blocks, such as the materials used in the production process, the amount of time the blocks are allowed to cure, and the size and form of the blocks.

Concrete, mortar, Sandcrete blocks, and other cement products are made mostly of cement, which is quite expensive, particularly in developing nations. The rapid growth of infrastructure development has led to a rising global demand for cement, utilized in the production of concrete. (Zareei, 2017; Thomas, 2018; Attah *et al.*, 2020). Reducing the cost associated with the production of cement and the amount of carbon dioxide (CO₂) emitted 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, have driven 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)

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.

However, the majority of hollow Sandcrete blocks used in developing countries, especially in sub-Saharan Africa, have been considered substandard (Anosike and Oyeade 2011). Previous research carried out in Nigeria also demonstrated how inadequately these Sandcrete blocks perform, with their strength and durability falling well short of the minimum standard requirement. According to Ibrahim *et al.* (2025), stated that 60% of the hollow Sandcrete blocks produced by commercial block producers in Kaura district, Abuja, Nigeria, do not meet the Nigerian Industrial Standard's minimum standard requirement for compressive strength values of 3.45 N/mm² for load-bearing walls. Some of these blocks may crack during transportation due to their weight, which causes or contributes 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 the use of substandard constituent materials. (Olusola and Akintayo, 2009).

When exposed to moist conditions, Sandcrete blocks generally absorb fluids because of their porous structure. According to studies by Siddique and Klaus (2009), Cassagnabère *et al.* (2010), and Marchand *et al.* (1996), the incorporation of mineral admixtures to concrete and mortar enhances the porous structure's resistance to bending, compression, and efflorescence, thereby increasing the material's strength and durability. These cement composites enhance the mechanical properties and lifespan of the structure by reducing the calcium hydroxide in the cement paste and improving durability through pore refinement, which is made possible by the pozzolanic and filling actions of certain mineral admixtures. The physical action of the pozzolanas provides a uniform, more homogeneous, and denser paste.

Metakaolin's use as a partial cement replacement in mortar and concrete has received a lot of attention. Metakaolin is used as a supplementary cementitious material in concrete to improve durability, decrease permeability, enhance strength and the rate of strength gain,

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and reduce cement consumption (Justice *et al.*, 2005; Khatib and Ibrahim, 2025). Metakaolin can also be used as a Sandcrete block constituent, substituting part of the cement content since it has pozzolanic properties. This paper compares experimentally the effect of partially replacing cement with metakaolin to produce Sandcrete blocks on some selected supplementary cementitious materials based Sandcrete blocks based on their compressive strengths.

MATERIALS AND METHODS

Materials

The materials used for the production of Metakaolin hollow Sandcrete block were Ordinary Portland Cement (OPC), portable water, fine aggregate (sand), kaolin, and metakaolin only.

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%

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 are following NIS 444-1:200 and BS EN 197-1 (2011) specifications.

Water

Water use for this study is obtained from the Civil Engineering Department, Ahmadu Bello University, Zaria, which is used for both the specimen preparations and curing of Sandcrete blocks throughout the investigation, and it conforms with the recommendations of BS 3148:1980.

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 a temperature of 700°C to obtain the metakaolin that was used for this study (Elimbi *et al.*, 2011).

Metakaolin

For this study, kaolin was burned to produce metakaolin at a defined temperature. Ahmadu Bello University Zaria's School of Physical Science Multipurpose Laboratory was used to analyse the oxide composition by mass of a metakaolin sample. To obtain 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 following the specification provided in BS EN 197-1: 2011 and BS EN 196-2: 2000. The Specific gravity test was carried out on the metakaolin specified in BS 1377-2: (1990)

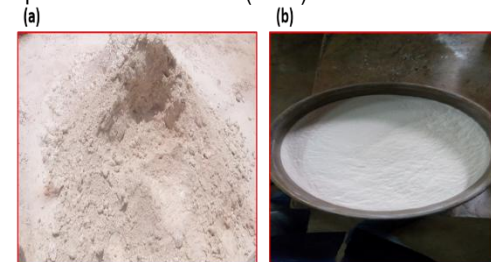


Figure 1: Kaolin (a) Before calcination, (b) After calcination

Methods

Hollow Sandcrete Blocks Production

Standard metal molds were used for producing the hollow Sandcrete blocks following NIS 87: 2000 (2000). According to NIS 87:2000, hollow Sandcrete blocks with dimensions of 450 x 225 x 225 mm were produced using a mix ratio of 1:6 (one part cement to six parts fine aggregate (sand)). 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 employed, 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 × 225 × 225 mm. After that, the

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excess material was removed, leaving the surface smooth. Following this method, 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.

Curing

The hollow Sandcrete blocks were cured following (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 $23 \pm 2^\circ\text{C}$.



Figure 2: Metakaolin Sandcrete blocks produced at various replacement levels

Compressive Strength Test

After the required curing days of 1, 3, 7, 14, 21, and 28 days, the blocks' compressive strength was measured using a compressive testing machine at Ahmadu Bello University, Zaria, Kaduna State, Nigeria. 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 specified in BS 6073 Part 1 requirement (1981). For each mix, 3 blocks were crushed to obtain the average strength using the following Equation

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

RESULTS AND DISCUSSION

Specific Gravity

The specific gravity of cement, metakaolin, and some selected supplementary cementitious materials (Olive Seed Ash, Maize Cob Ash, Millet Husk Ash, and Guinea Corn Hush Ash) was found to be 3.15, 2.57, 2.75, 2.38, 2.61, and 2.23, respectively, as shown in Table 1.

Table 1: Comparison between the specific gravity of OPC, Metakaolin, and some selected SCM

S/No	Supplementary Cementitious Materials SCM	Specific Gravity
1	Metakaolin (MK)	2.57
2	Olive Seed Ash (OSA)	2.75
3	Maize Cob Ash (MCA)	2.38
4	Millet Husk Ash (MHA)	2.61
5	Guinea Corn Hush Ash (GCHA)	2.23
5	Cement	3.15

The specific gravity value for metakaolin is a little lower than the 2.62 reported by Poon et al., (2001) but higher than 2.5 obtained by Al-Akhras et al. (2006) and Tafroui et al. (2005). When the specific gravity of metakaolin is compared with some selected supplementary cementitious materials, the value is close to 2.61

and 2.75 obtained by Solomon & Jonas (2017) and Anowai et al (2023) for Millet husk ash (MHA) and Olive Seed Ash but its higher than the 2.38 obtained by Anowai et al (2020) for Maize cob ash (MCA) and, 2.23 obtained by Tahomah et al (2017) for Guinea corn hush ash (GCHA). The specific gravity of all the supplementary

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cementitious materials was compared against that of OPC, as shown in Table 1, and it shows that the value of OPC is higher than all the supplementary cementitious materials that are used for analysis in this study.

Chemical Composition of Metakaolin and Other Supplementary Cementitious Materials

The result of chemical analysis of Metakaolin (MK), Olive Seed Ash (OSA), Maize Cob Ash (MCA), Millet Husk Ash (MHA), and Guinea Corn Husk Ash (GCHA) is presented in Table 2. The result showed that the sum of the percentages of Silicon Oxide, Aluminum Oxide and Iron Oxide ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) for of Metakaolin (MK), Olive Seed Ash (OSA), Maize Cob Ash (MCA), Millet Husk Ash (MHA), and Guinea Corn Husk Ash (GCHA) is 93.16%, 70.92%, 88.48%, 70.10% and 59.43%

respectively. The result indicates that Metakaolin (MK), Olive Seed Ash (OSA), Maize Cob Ash (MCA), and Millet Husk Ash (MHA) are in line with ASTM C 618-78 (American Society for Testing and Materials, 1978) minimum requirement of 70% for pozzolanas.

According to ASTM C618, the presence of siliceous and aluminous material in the fine form of all supplementary cementitious materials except Guinea corn husk ash indicates that it can react with calcium hydroxide to generate calcium silicate hydrate (CSH), a cement-forming substance that increases strength. The Guinea Corn Husk Ash (GCHA) result is less than 70% as the minimum required for pozzolanas according to ASTM C618 (2001). This reduces the pozzolanicity of the GCHA. All the ash tested for loss on ignition satisfies the NIS 87 (2004) requirement, which specifies a maximum of 12.

Table 2: Chemical Composition of MK, MCA, MHA, and GCHA

Elemental oxide	Composition (%)					
	Metakao lin MK	Olive Ash OSA	Seed	Maize Ash MCA	Cob Millet Husk Ash MHA	Guinea Corn Husk Ash (GCHA)
SiO_2	56.48	65.17		61.53	63.7	52.1
Al_2O_3	36.09	4.25		18.28	3.80	0.03
Fe_2O_3	0.59	1.50		8.67	2.60	7.30
$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	93.16	70.92		88.48	70.10	59.43
CaO	0.28	6.17		3.03	0.02	7.04
MgO	0.67	-		-	0.03	0.10
Na_2O	0.02	-		-	1.14	-
K_2O	0.06	-		2.56	20.1	23.8
TiO_2	5.15	-		0.54	0.16	-
SO_3	0.33				2.06	
Loss of ignition	2.39	-		4.59	11.20	0.50
<div style="display: flex; justify-content: space-between; width: 100%;"> Anowai <i>et al.</i> (2023) Anowai <i>et al.</i> (2020) Solomon and Jonas (2017) Tahomah <i>et al.</i> (2017) </div>						

The percentage composition of magnesium oxide (MgO) for metakaolin is 0.67%, for millet husk ash and guinea corn husk ash is 0.03% and 0.10% respectively, for which that of olive seed ash and millet husk ash was not detected. The results obtained were within the

range specified by ASTM C618 requirement, which has a maximum range of 5% for Magnesium oxide. The percentage composition of sodium oxide (Na_2O) of metakaolin and other supplementary cementitious materials is all within the limit of 1.5% specified by the ASTM C618

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specification. According to BS EN 197-1:2000 the reactive silicon dioxide content shall be not less than 25.0 % by mass, Metakaolin and other supplementary cementitious materials use for this study meets requirements as a pozzolana which has 56.48%, 65.17%, 61.53%, 63.7% and 52.1 for Metakaolin (MK), Olive Seed Ash (OSA), Maize Cob Ash (MCA), Millet Husk Ash (MHA), and Guinea Corn Husk Ash (GCHA) respectively.

Compressive Strength Test Results

The average compressive strength results of the tested metakaolin Sandcrete blocks, utilizing a mix ratio of 1:6 (one part cement to six parts fine aggregate (sand)), at curing intervals of 1, 3, 7, 14, 21, and 28 days are presented in figure 1, Table 4 presents the 28-day compressive strength of hollow Sandcrete blocks at 0%, 10%, and 20% replacement levels of cement with Metakaolin and some selected supplementary cementitious materials (SCM).

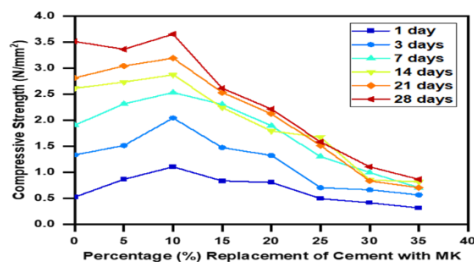


Figure 5: Compressive Strength of Metakaolin Sandcrete Blocks with varying curing days

According to the results of the compressive test conducted on Sandcrete blocks made with varying percentages of cement replaced with metakaolin, the blocks' compressive strength increase as the percentage of metakaolin increases from 5% to 20% and decreases as the percentage of metakaolin increases from 25% to 35% (Ibrahim and Ocholi 2020). As shown in Figure 2, metakaolin Sandcrete blocks with a 10% metakaolin replacement level show the highest strength development, indicating that 10% metakaolin replacement is optimum. After 28 days of curing, the average compressive strength of 3.65 N/mm² was achieved at a 10% cement replacement level using metakaolin.

This met the standards for compressive strength set out in Nigeria Industrial Standard NIS 87 (2000), which is 3.45 N/mm² for load-bearing walls and 2.5 N/mm² for non-load-bearing walls. Additionally, this meets BS 6073, which recommends 2.80 N/mm² for the mean strength and 2.59 N/mm² for the lowest individual strength. 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 range from 0.23 N/mm² and 0.58 N/mm².

Table 3: Compressive Strength of Hollow Sandcrete Blocks

Compressive Strength (N/mm ²) at Various Levels of Replacement of Cement with Metakaolin			
Supplementary Cementitious Materials	0%	10%	20%
Metakaolin	3.51	3.65	2.21
Olive Seed Ash (Anowai et al, 2023)	3.82	3.53	3.00
Maize Cob Ash (Anowai et al, 2020)	4.30	4.05	2.65
Millet Husk Ash (Solomon and Jonas 2017)	4.50	4.00	3.15
Guinea Corn Husk Ash (Tahomah et al, 2017)	2.16	1.73	1.50

The compressive strength of metakaolin hollow Sandcrete blocks and some selected supplementary cementitious materials at 10% replacement with cement gives a strength of 3.65 N/mm² which performs better than olive seed ash

with 3.53 N/mm² strength (Anowai et al., 2023) and guinea corn husk ash with a strength of 1.70 N/mm² (Tahomah et al., 2017). However, Maize Cob Ash (Anowai et al., 2020) and Maize Cob Ash (Anowai et al, 2020) with compressive strengths of



4.05 N/mm² and 4.00 N/mm² respectively, perform better than metakaolin Sandcrete block at the same replacement level with cement.

All the supplementary cementitious materials used for this study met the minimum compressive strength requirement of 3.45 N/mm² for Sandcrete blocks for use in load-bearing walls and 2.5 N/mm² for non-load bearing walls specified NIS 87 (2004), except for guinea corn husk ash, which met both strength requirements for bearing and non – bearing load. At 20% replacement levels, the compressive strengths of metakaolin hollow Sandcrete blocks and some selected supplementary cementitious materials-based Sandcrete hollow blocks fall below the minimum specification for non-load bearing walls, which specifies 2.5 N/mm² in accordance NIS 87 (2004), except for Olive Seed Ash, Maize Cob Ash and Guinea Corn Husk Ash.

CONCLUSION

This paper presented a comparative analysis of the compressive strength of hollow Sandcrete blocks made from metakaolin and some selected supplementary cementitious materials. Kaolin, a byproduct of the Kankara kaolin clay deposit in Katsina state, Nigeria's Kankara Local Government Area, is calcined (under controlled conditions) to produce Metakaolin 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. The selected supplementary cementitious materials of olive seed ash, maize cob ash, millet husk ash, and guinea corn husk ash have oxide composition combination of SiO₂, Al₂O₃, and Fe₂O₃ as 70.92%, 88.48%, 70.10%, and 59.43% respectively met the 70% minimum recommended limit as stipulated by ASTM C 618-05 except guinea corn husk ash which fall short of the minimum specification. This indicates that the metakaolin and other selected supplementary cementitious materials used in this study, is a reactive pozzolana of high quality, except guinea corn husk ash.

The compressive strength results indicate that the metakaolin and some selected

supplementary cementitious materials (OSA, MCA, MHA, and GCHA) replacement by weight of cement at 10% have a strength of 3.65 N/mm², 3.53 N/mm², 4.05 N/mm², 4.00 N/mm² and 1.73 N/mm² respectively at 28 days of curing which meets Nigeria Industrial Standard NIS 87 (2000), BS 6073, and National Building Code (2006) stipulated requirement except guinea corn husk ash which do not met the minimum specification of 3.45 N/mm² and 2.5 N/mm² for both load bearing and non-load bearing walls. At 20% replacement levels, only OSA, MCA, and MHA met the minimum requirement of 2.5 N/mm² for non-bearing load as stipulated in NIS 87 (2000).

It is recommended that Metakaolin and some selected supplementary cementitious materials (OSA, MCA, MHA, and GCHA) Sandcrete blocks produced at 10% cement replacement are adequate for use as load-bearing and non-load-bearing structures in areas where they may be subjected to moisture ingress. Commercial hollow Sandcrete block production requires sensitization to prevent the production of low-quality blocks. Metakaolin and some selected SCMs in this study can be used as a partial cement substitute to meet structural standards and obtain the necessary profit margin.

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