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Proceeding Paper

An Evaluation of the Compressive Strength of Nanosilicate Hollow Crete Blocks †

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Abstract: The need for significant infrastructure development in Nigeria; the high demand for cement; the challenges associated with the disposal of agricultural waste; and—most significantly—the emission of CO_2 associated with cement production and use, which has a negative impact on the environment, have created opportunities for research in the construction sector. The urgent need for researchers to explore substitute materials that may sustainably replace cement in the construction sector has also been prompted by the necessity to manage Nigeria's natural resources. This paper investigates the properties of hollow blocks produced by replacing cement with nanosilica produced from rice husk waste at 1%, 2%, 3%, 4%, and 5% in order to assess the impact on the hollow block's strength. The hollow blocks have four mixes: cement-to-sand ratios of 1:4, 1:6, 1:8, and 1:10 for different curing durations (1, 3, 7, 14, 28, and 56 days by spraying water). The results from the findings showed that the nanosilica produced from rice husk ash and used in this study are a good reactive pozzolana with particle sizes in the range of 1–49 nm, with majority of the particles within 1–7 nm. Hollow blocks produced at 1, 2, 3, 4, and 5% replacement by weight of cement (nanosilica-crete) proved stronger than hollow blocks produced at 0% cement replacement (conventional sandcrete), with an optimal nanosilica percentage replacement of 3% by weight of cement.

Keywords: nanosilica; nanosilica-crete; cement; rice husk ash; compressive strength

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1. Introduction

One human activity known to have both actual and prospective negative impacts on the environment is construction. These negative implications include using over 40% of Nigeria's natural resources and producing more than 45% of waste. One of the biggest energy users is thought to be buildings. Commercial and residential buildings account for up to 25% of the world's greenhouse gas emissions and around 40% of the energy used globally [1]. Transitioning to low-carbon fuels and reducing energy use and embodied energy in buildings with a greater use of renewable energy, or reducing carbon IV oxide (CO_2) and non-CO_2 greenhouse gas emissions, which are produced in large quantities through the production of building materials, building construction, renovation, and demolition, are current actions to lower the greenhouse gas emissions from structures that fit into one of these three categories [2]. Extensive studies on alternative materials that might lessen the environmental effect of construction processes have been made necessary by the demand for sustainable and energy-efficient construction materials. By substituting artificial pozzolanas, clay, agricultural waste, and other geo-based materials for OPC, embodied energy and CO_2 emissions can be reduced [3]. Cement is the most widely utilized produced good in modern civilization [4]. The method used to make Portland cement (PC) is known to produce around 7% of the world's total CO_2 emissions from clinker production [5]. In addition, it is one of the materials that consumes the most energy after steel and aluminum [6]. The manufacture of cement is responsible for 8 to 10% of the world's total emissions of greenhouse gases [7].

In Nigeria and other west African countries, over 90% of the physical infrastructures are being constructed using sandcrete blocks [8]. The Nigerian industrial standard defines sandcrete block as a composite material made up of cement, sand, and water, molded into different sizes. Sandcrete blocks can be either solid or hollow rectangular types, with 450 mm × 225 mm × 225 mm and 450 mm × 150 mm × 225 mm being the most common sizes [9]. The major energy-consuming and environmentally degradable component of sandcrete blocks is cement, since sand is readily available and can be obtained from rivers and streams. Therefore, any reduction in the cement content would have a noticeable reduction in its negative effect on the environment. The introduction of cleaner cementitious materials in the production of sandcrete blocks is therefore necessary. The use of some selected agricultural wastes has proven very effective, with one of these being rice husk.

Rice husk is one of the agricultural wastes created during the rice milling operation and makes up around 20–23% of the total paddy rice weight [10]. Significant amounts of rice husk are produced each year in the vicinity of the milling centers. Since the 1960s, huge piles of these rice husks have accumulated and are now causing a number of environmental issues [10]. To prevent the looming environmental risks, deterioration, and pollution it causes to the population and the environment, it is imperative to urgently dispose of and evacuate these rice husk dumps. Rice husk, which is created during the rice-growing process and contains silica, which is the main inorganic component, may be used to create nanosilica using the sol–gel technique. Because of the obvious advancements made at the interface between cement paste and an aggregate, the use of nanosilica in the creation of high-strength mortar components has drawn a lot of interest. By making the interfacial zone denser, nanosilica, which is made up of ultra-fine (10^{-9}) particles, strengthens the binding between cement paste and fine and coarse aggregates. It also plays an important role in increasing the mechanical strength of sandcrete blocks because of pozzolanic activity [11].

Numerous studies examined the use of nanosilica as a cement substitute in concrete, and the majority of these studies came to the conclusion that such a substitution would enhance the mechanical qualities of concrete. One cannot, however, overstate the importance of researching the use of nanosilica made from rice husk ash to substitute cement in order to improve the characteristics of sandcrete blocks. In order to increase the strength of hollow blocks made of sandcrete using the standard curing procedure, this study uses nanosilica as a partial replacement of ordinary Portland cement to produce nanosilicate hollow crete blocks.

2. Materials and Methods

2.1. Materials

2.1.1. Cement

Locally produced cement was obtained from the open market and used for the experiment.

2.1.2. Fine Aggregate

The fine aggregate used was river sand, which was sieved through a BS 4.75 mm sieve to remove some of the contained coarse aggregates.

2.1.3. Water

Clean water was used for the concrete batching for adequate workability and ease of compaction. To ensure durability of concrete structures, the mixing and curing water must be free from impurities as the compressive strength of materials will otherwise be affected [12]. Clean water from the Civil Engineering Department was used, and it conformed with the recommendations of [13].

2.1.4. Nanosilica

Nanosilica was produced using the sol–gel process. The sol–gel process utilizes silica from rice husk ash (RHA) to produce nanosilica, which can be achieved locally at minimal cost.

2.2. Methods

2.2.1. Production of Nanosilicate Hollow Crete Blocks

The nanosilicate hollow crete blocks were produced by volume using standard molds of 450 × 225 × 225 mm. The adopted mix proportions were cement-to-sand ratios of 1:4, 1:6, 1:8, and 1:10 with a water–cement ratio of 0.45 by weight of cement. Cement was replaced partially with nanosilica at replacement levels of 0, 1, 2, 3, 4, and 5% by weight. In the production, machine mixing was employed and materials were thoroughly mixed for 3 min until a homogenous color was attained. The mixture was then poured into the 450 × 225 × 225 mm metal molds and compacted. The excess material was then stripped, leaving a flat surface. Following these procedures, 108 blocks of 450 × 225 × 225 mm size were cast. The blocks were removed from the molds and left on the pallets with a space between two blocks for the period of curing.

2.2.2. Curing

Curing of the hollow blocks was performed according to [14]. The hollow blocks were left on wooden pallets throughout the curing period, and the blocks were cured by keeping them wet by spraying with water for 1, 2, 3, 4, 7, 14, 28, and 56 days. Clean water at a temperature of 23 ± 2 °C, which was free from salt and other deleterious materials, was used for curing.

2.2.3. Compressive Strength Test

The compressive strength of the blocks was determined after the required curing days of 1, 3, 7, 14, 28, and 56 days using the compressive testing machine, in accordance with [15].

3. Discussion of Results

3.1. Chemical Characterization of Nanosilca and Cement

The results for the oxide composition of nanosilica, the TEM distribution of nanosilica particles, and the chemical composition of ordinary Portland cement (OPC) are presented in this section.

The oxide composition result of nanosilica, as shown in Table 1, shows that the combination of SiO_2, Al_2O_3, and Fe_2O_3 is approximately 95.71% (i.e., 93.611 + 1.399 + 0.700), which is greater than the minimum of 70%, which is an indication that the nanosilica used in this study is a good reactive pozzolana. The presence of siliceous and aluminous material in the nanosilica indicates that, in its finely grounded form, it can react with calcium hydroxide to form calcium silicates hydrate (CSH), which is a strength-forming product in cement [16]. It is also observed that the SO_3 value is 0.156%, which is lower than the 4% specified value that indicates the possibility of improved durability and of soundness when used in the production of nanosilicate hollow crete blocks.

Figure 1 shows the TEM distribution of nanosilica particles based on the area selected, as seen in Scheme 1. It can be observed that the particles sizes for the selected area ranges from 0 to 49 nm. It can also be seen that, from the selected area of the TEM images, the highest frequencies are between 0 and 7 nm; this is an indication that the sample is made of mostly a nanoparticle size of 0.7 nm and is qualified as a nanomaterial.

Table 1. Oxide composition of nanosilica.

Element	Content (%)	Element	Content (%)
SiO_2	93.611	CaO	0.463
V_2O_5	0.021	MgO	0.000
Cr_2O_3	0.023	K_2O	1.183
MnO	0.105	BaO	0.006
Fe_2O_3	0.700	Al_2O_3	1.339
Co_3O_4	0.002	Ta_2O_5	0.006
NiO	0.001	TiO_2	0.291
CuO	0.050	ZnO	0.011
Nb_2O_3	0.006	Ag_2O	0.003
WO3	0.002	Cl	0.992
P_2O_5	1.018	ZrO_2	0.011
SO_3	0.156	SnO_2	0.000

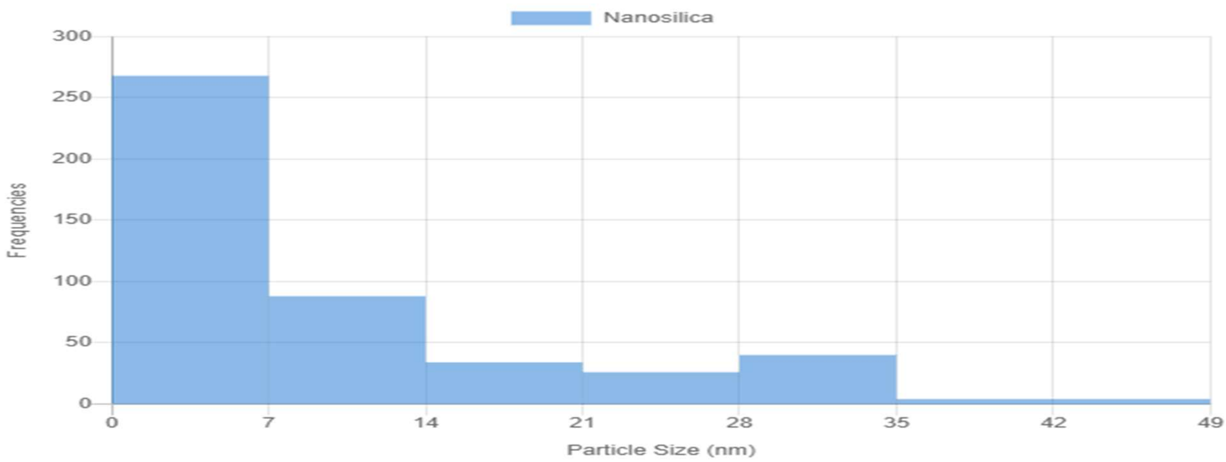
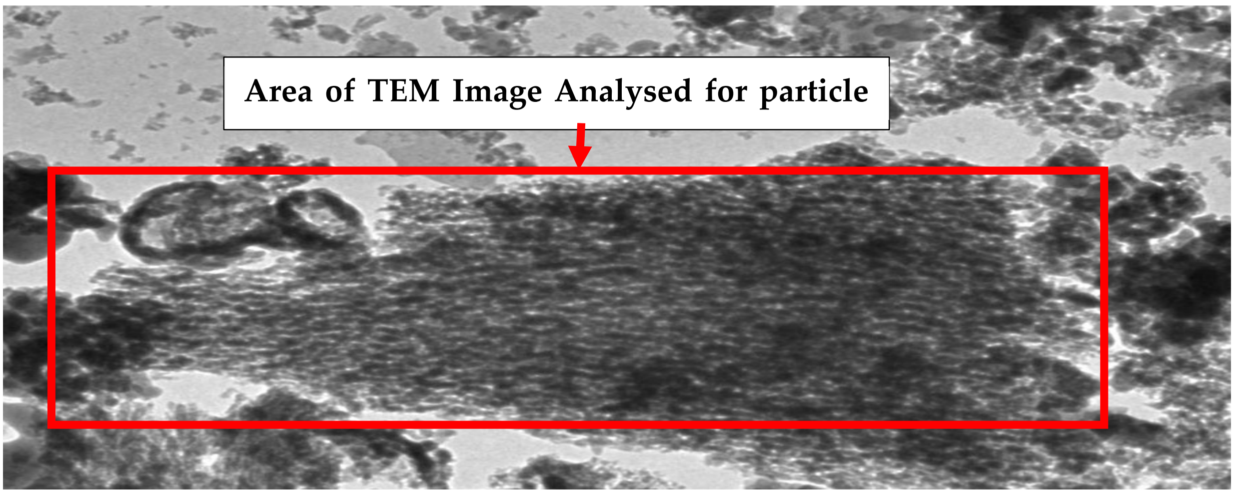


Figure 1. TEM distribution of nanosilica particles.



Scheme 1. Area of TEM image analyzed for nanoparticle size.

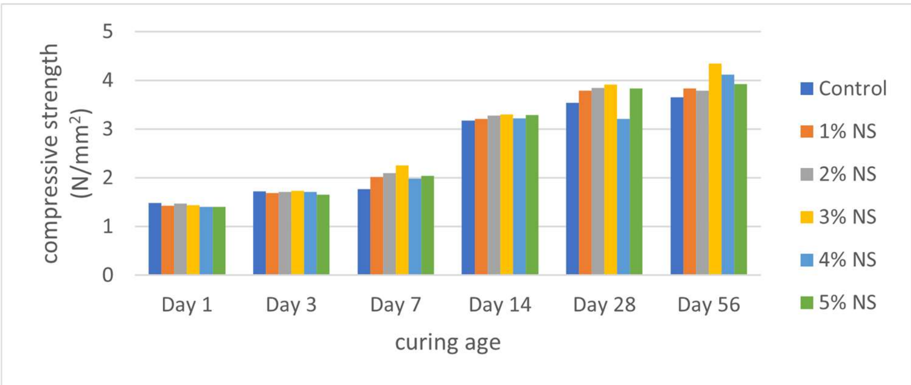
Table 2 presents the results of the chemical analysis of cement. The oxide content of the cement compared with the standard shows compliance. The calcium oxide (CaO) fell within the specified limit, while silicate oxide (SiO_2) was also within the allowable limit of 35.5% max, as specified by [17].

Table 2. Chemical composition of OPC with standard requirement.

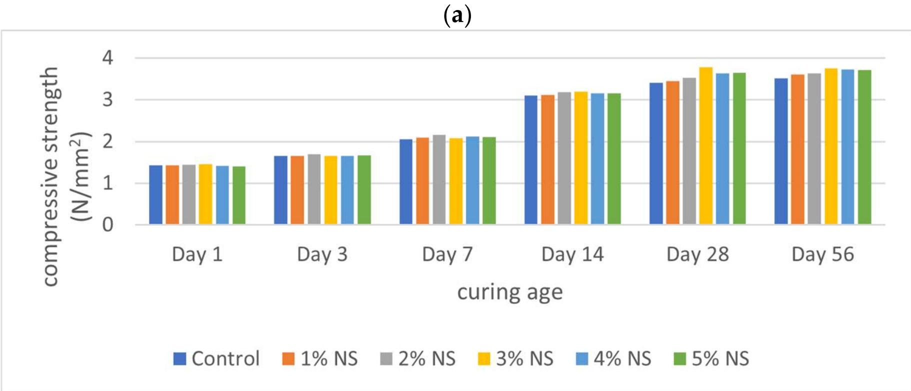
Oxide Composition	Percentage (%) of Oxide Composition	BS EN 197-1 (2011)
CaO	64.45	Limit not specified
SiO_2	21.55	Max. 35.5%
Al_2O_3	5.28	Max. 6.3%
Fe_2O_3	3.95	Max. 6.5%
MgO	1.85	Max. 4.0%
SO_3	1.50	Max. 3.0%
Loss of ignition	1.44	Max. 5.0%
Insoluble residue	0.65	Max. 1.5%

3.2. Compressive Strength

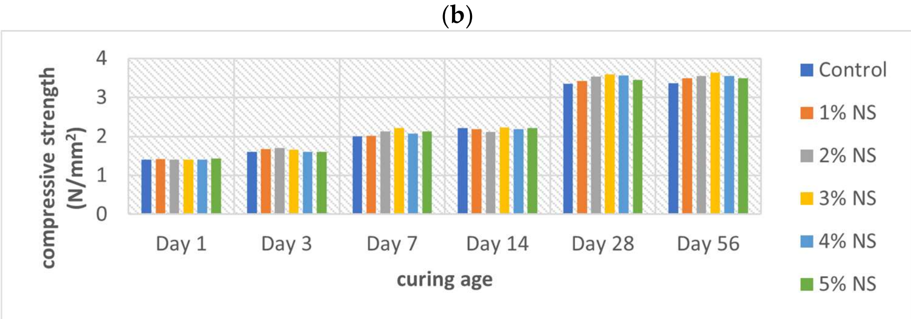
The variation in the compressive strength of the nanosilicate hollow crete blocks at varying percentages of nanosilica for the cement-to-sand-mix ratios of 1:4, 1:6, 1:8, and 1:10 are shown in Figure 2a–d, respectively.



(**a**)

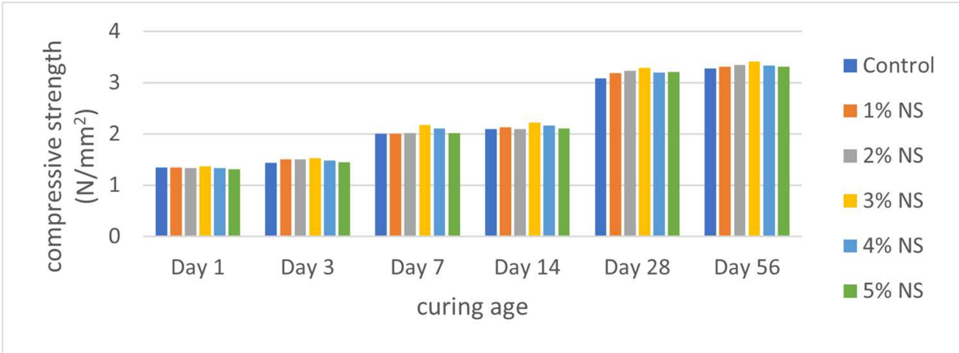


(**b**)



(**c**)

Figure 2. *Cont.*



(**d**)

Figure 2. Variation in compressive strength with varying percentages of nanosilica: (**a**) 1:4 cement-to-sand-mix ratio; (**b**) 1:6 cement-to-sand-mix ratio; (**c**) 1:8 cement-to-sand-mix ratio; (**d**) 1:10 cement-to-sand-mix ratio.

From Figure 2a–d, the compressive strength is seen to increase with curing time in the following order, as expected: 1, 3, 7, 14, 28, and 56 days. Hollow blocks produced at 1, 2, 3, 4, and 5% replacement by weight of cement (nanosilica-crete) proved stronger than hollow blocks produced at 0% cement replacement (sandcrete); this can be attributed to the fact that nanosilica can act as an activator to promote pozzolan reaction from nanosilica and calcium hydroxide, which promotes the formation of hydrated calcium silicate, which is one of the important elements that provide strength. So, blocks without nanosilica can only rely on cement to hydrate only a small amount of calcium silicate hydrate. Also, the highest compressive strengths were recorded at 3% nanosilica replacement by weight of cement, except in a few cases, for all the mix ratios and curing durations considered; this optimal nanosilica percentage replacement by weight of cement is in line with the optimal nanosilica range of 2–4% according to a state-of-the-art review by [18]. Also, using 3% nanosilica replacement by weight of cement improved the compressive strength, and this can reduce greenhouse gas emissions by 3%.

4. Conclusions

1. The effect of nanosilica produced from rice husk ash on the compressive strength of hollow blocks (nanosilicate hollow crete blocks) mixed at different cement-to-sand-mix ratios, 1:4, 1:6, 1:8, and 1:10, and cured for 1, 3, 7, 14, 28, and 56 days were explored, and the compressive strength of the hollow blocks were tested. The results of this study showed that nanosilica produced from rice husk ash has a SiO_2, Al_2O_3, and Fe_2O_3 combination of approximately 95.71%, which is greater than the minimum recommended of 70%. This is an indication that the nanosilica produced from rice husk ash and used in this study is a good reactive pozzolana. Also, the produced nanosilica consists of particle sizes ranging from 1 to 49 nm, with the majority of the particle size within 1–7 nm, which is an indication that the produced nanosilica contains nanoparticles. Hollow blocks produced at 1, 2, 3, 4, and 5% replacement by weight of cement (nanosilica-crete) proved stronger than hollow blocks produced at 0% cement replacement (sandcrete).
2. In conclusion, the compressive strength results showed that the best percentage of nanosilica replacement by weight of cement was 3%. It is therefore recommended that, in order to produce nanosilicate hollow crete blocks with satisfactory compressive strength, nanosilica should replace cement by not more than 3% by weight.

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