

Proceeding Paper

# An Evaluation of the Compressive Strength of Nanosilicate Hollow Crete Blocks <sup>†</sup>

Juliana N. Tyoden <sup>\*</sup>, Adamu Lawan and Sp Ejeh

Department of Civil Engineering, Ahmadu Bello University Zaria; email1@email.com (A.L.); email2@email.com (S.E.)

<sup>\*</sup> Correspondence: jemglint77@yahoo.co.uk

<sup>†</sup> Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: <https://asec2023.sciforum.net/>.

**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<sub>2</sub> 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 issue for researchers to explore into 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 Nano-silica 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 (4) mixes: [Cement to sand ratios of 1:4, 1:6, 1:8, and 1:10] at different curing days (1, 3, 7, 14, 28, and 56 days by spray of water). The result from the findings showed that the Nanosilica produced from rice husk ash and used in this study, is 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 Sand-crete), with an optimum Nanosilica percentage replacement of 3% by weight of cement.

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

**Citation:** Tyoden, J.N.; Lawan, A.; Ejeh, S. An Evaluation of the Compressive Strength of Nanosilicate Hollow Crete Blocks. *Eng. Proc.* **2023**, *52*, x. <https://doi.org/10.3390/xxxxx>

Academic Editor(s): Name

Published: date



**Copyright:** © 2023 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 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<sub>2</sub>) and non-CO<sub>2</sub> 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 study on alternative materials that might lessen the environmental effect of construction processes has 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<sub>2</sub> 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<sub>2</sub> 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 either be 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 environmental 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 sand-crete blocks is therefore necessary. The use of some selected agricultural wastes has proven very effective, 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 urgently imperative to 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 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 sand-crete blocks because of pozzolanic activity [11].

Numerous researches examined the use of Nanosilica as a cement substitute in concrete, and the majority of these studies came to the conclusion that doing so enhanced 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 sand-crete blocks. In order to increase the strength of hollow blocks made of sand-crete using the standard curing procedure, this research 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, mixing and curing water was free from impurities as the compressive strength of materials will be affected if otherwise [12].

Clean water from Civil Engineering Department was used and it was in conformity with recommendation 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 moulds of 450 × 225 × 225 mm. The mix proportions adopted are 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 is attained. The mixture was then poured into the 450 × 225 × 225 mm metal moulds and compacted. The excess material was then stripped, leaving a flat surface. Following these procedures, 108 numbers 450 × 225 × 225 mm blocks were cast. The blocks were removed from the moulds 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 done according to [14]. The hollow blocks were left on wooden pallets throughout the curing period, 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  $23 \pm 2$  °C, which is 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 Nanosilica and Cement

The results for oxide composition of Nano-silica, TEM distribution of Nano-silica particles, and 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<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> 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 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<sub>3</sub> value is 0.156% which is lower than the 4% specified value which indicate the possibility of improved durability and of soundness when use in production of Nanosilicate-hollow crete blocks.

**Table 1.** Oxide Composition of Nano-silica.

Element	Content (%)	Element	Content (%)
SiO <sub>2</sub>	93.611	CaO	0.463
V <sub>2</sub> O <sub>5</sub>	0.021	MgO	0.000

Cr <sub>2</sub> O <sub>3</sub>	0.023	K <sub>2</sub> O	1.183
MnO	0.105	BaO	0.006
Fe <sub>2</sub> O <sub>3</sub>	0.700	Al <sub>2</sub> O <sub>3</sub>	1.339
Co <sub>3</sub> O <sub>4</sub>	0.002	Ta <sub>2</sub> O <sub>5</sub>	0.006
NiO	0.001	TiO <sub>2</sub>	0.291
CuO	0.050	ZnO	0.011
Nb <sub>2</sub> O <sub>3</sub>	0.006	Ag <sub>2</sub> O	0.003
WO <sub>3</sub>	0.002	Cl	0.992
P <sub>2</sub> O <sub>5</sub>	1.018	ZrO <sub>2</sub>	0.011
SO <sub>3</sub>	0.156	SnO <sub>2</sub>	0.000

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 as ranges from 0–49 nm. It can also be seen that, from the selected area of the TEM images, the highest frequencies are between 0–7 nm, this is an indication that, the sample is made of mostly nanoparticle size of 0.7 nm and is qualified as a nano material.

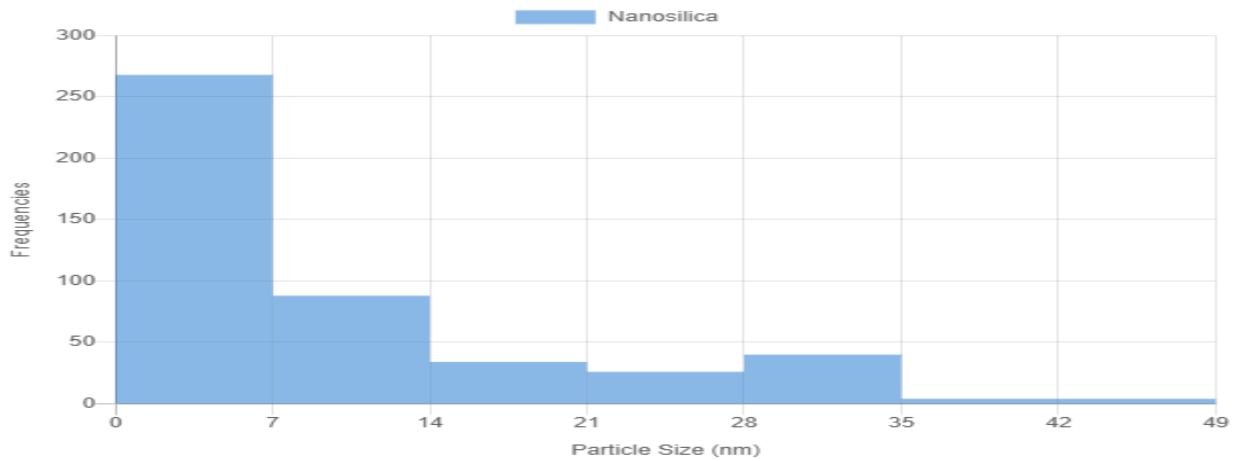
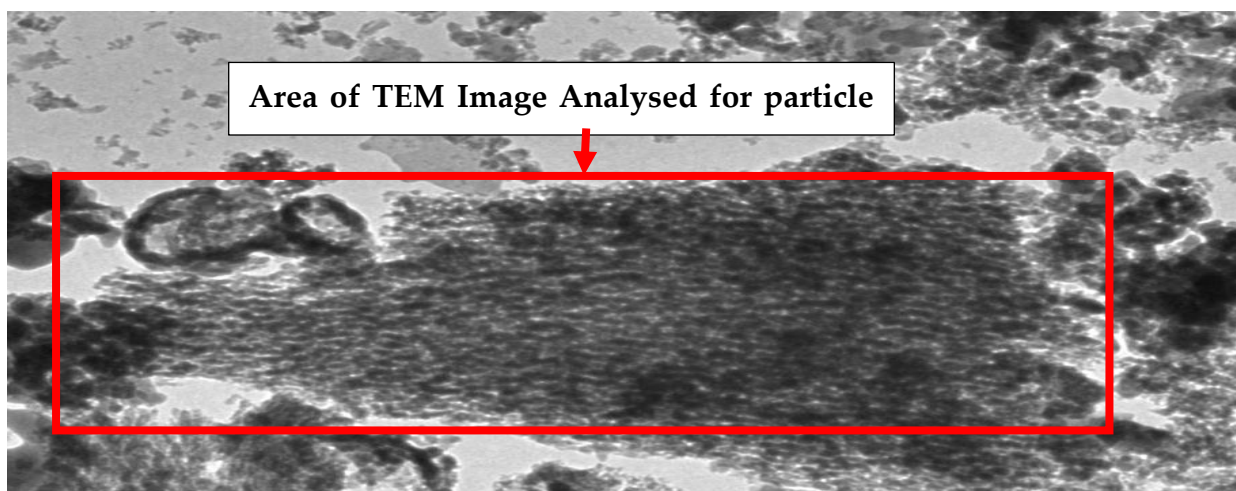


Figure 1. TEM Distribution of Nano-silica Particles.



Scheme 1. Area of TEM Image Analysed for nano-particle size.

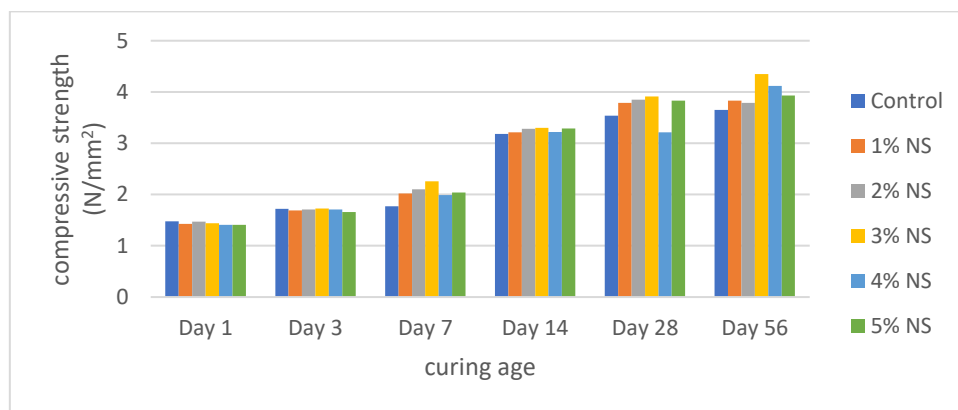
Table 2 presents the result of the chemical analysis of cement. The oxide content of the cement compared with standard shows compliance. The calcium oxide (CaO) fell within limit specified, while silicate oxide (SiO<sub>2</sub>) was also within the allowable limit for 35.5% max as specified by [17].

**Table 2.** Chemical Composition of OPC with Standard Requirement.

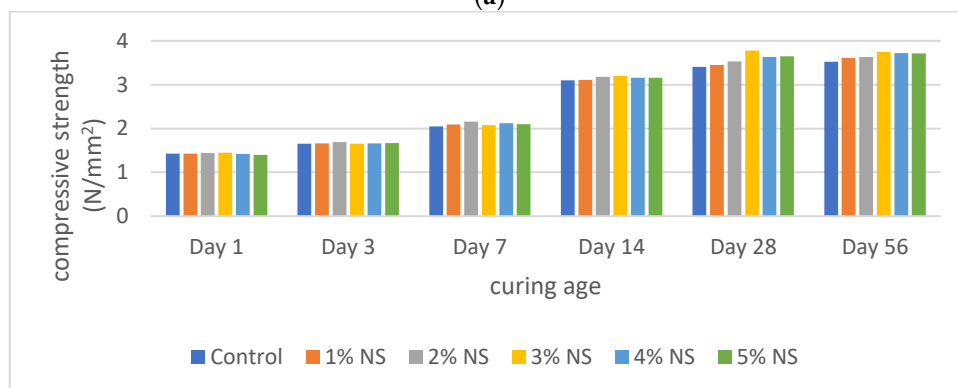
Oxide Composition	Percentage (%) of Oxide Composition	BS EN 197-1 (2011)
CaO	64.45	Limit not specified
SiO <sub>2</sub>	21.55	Max. 35.5%
Al <sub>2</sub> O <sub>3</sub>	5.28	Max. 6.3%
Fe <sub>2</sub> O <sub>3</sub>	3.95	Max. 6.5%
MgO	1.85	Max. 4.0%
SO <sub>3</sub>	1.50	Max. 3.0%
Loss of ignition	1.44	Max. 5.0%
Insoluble residue	0.65	Max. 1.5%

### 3.2. Compressive Strength

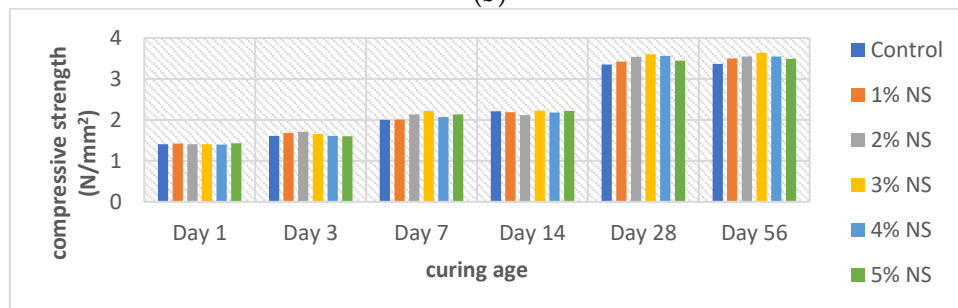
The variation in compressive of Nanosilicate hollow crete block at varying percentages of Nanosilica for the cement to sand mix ratios of 1:4, 1:6, 1:8 and 1:10 are shown in Figure 2a–d respectively.



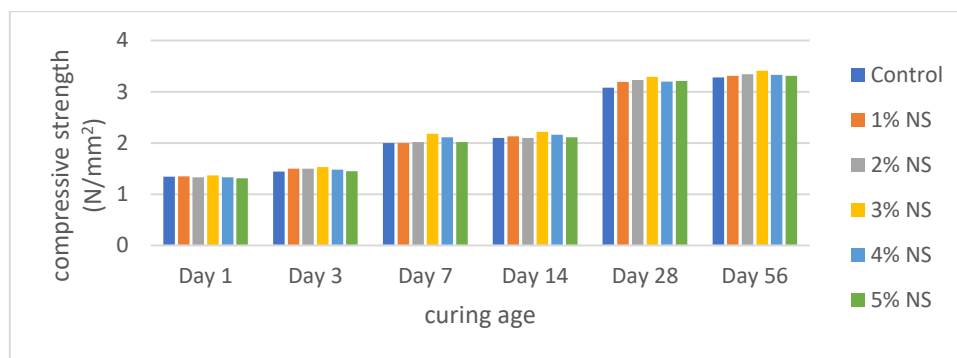
(a)



(b)



(c)



(d)

**Figure 2.** Variation of 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 ages in the order of 1, 3, 7, 14, 28 and 56 days as expected. 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 (Sand-crete), this can be attributed to the fact that Nanosilica can act as an activator to promote pozzolan reaction from nano-silica 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, highest compressive strengths were recorded at 3% Nanosilica replacement by weight of cement, except in few cases, for all the mix ratios and curing ages considered, this optimum Nanosilica percentage replacement by weight of cement is in line with the optimum Nanosilica range of 2–4% according to a state-of-art review by [18]. Also, using 3% Nanosilica replacement by weight of cement improved 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, cured for 1, 3, 7, 14, 28 and 56 days were explored, the compressive strength of the hollow blocks were tested. Results of this study showed that Nanosilica produced from Rice husk ash has  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  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 consist of particle sizes ranging from 1–49 nm with majority of the particles size within 1–7 nm which is an indication that the produced Nanosilica contains Nano-particles. 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 (Sand-crete).
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.

**Author Contributions:** J.N.T.: Conceptualization, methodology, validation, data curation, writing (original draft), writing (review and editing), visualization, and project administration. A.L.: Validation, data curation, writing (review and editing), Visualization and supervision. S.E. Validation, data curation, writing (review and editing), Visualization and supervision. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data availability statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Mulki, S.; Hinge, A. *Green Investment Horizons: Effects of Policy on the Market for Building Energy Efficiency Technologies*; World Resources Institute: Washington, DC, USA, 2010.
2. Joseph, P.; Nally, S.M. Sustainable Non-Metallic Building Materials. *Sustainability* **2010**, *2*, 400–427.
3. Milne, G.; Reardon, C. Embodied Energy, in Your Technical Manual. 2008. Available online: <http://www.yourhome.gov.au/technical/fs52.html> (accessed on 12 December 2009).
4. Mehta, P.K.; Monteiro, J.M. *Concrete Microstructure Properties and Materials*, 4th ed.; McGraw-Hill Education: New York, NY, USA, 2014.
5. Kaura, J.M.; Amartey, Y.D.; Shuaibu, A.A.; Rabi, A. Strength microstructure of Cement mortar Containing Metakaolin. In Proceedings of the NBRRI International Conference, Abuja, Nigeria, 2016.
6. van Oss, H.G.; Padovani, A.C. Cement Manufacture and the Environment, Part I: Chemistry and Technology. *J. Ind. Ecol.* **2002**, *6*, 89–105.
7. Suhendro, B. Toward Green Concrete for Better Sustainable Environment. *Procedia Eng.* **2014**, *95*, 305–320.
8. Aitcin, P.-C.; Mindess, S. *Sustainability of Concrete (Modern Concrete Technology Series)*; CRC Press: London, UK, 2011.
9. *NIS 2000*; NIS 87: Nigeria Industrial Standard: Standard for Sandcrete Blocks. Standards Organization of Nigeria: Lagos, Nigeria, 2004.
10. van Oss, H.G.; Padovani, A.C. Cement Manufacture and the Environment, Part II: Chemistry and Technology. *J. Ind. Ecol.* **2003**, *7*, 93–126.
11. Köksal, F.; Altun, F.; Yiğit, İ.; Şahin, Y. Combined effect of silica fume and steel fiber on the mechanical properties of high strength concretes. *Constr. Build. Mater.* **2008**, *22*, 1874–1880.
12. Ejeh, S.P.; Abubakar, I. Sandcrete Hollow Blocks in Zamfara State. *Int. J. Sci. Technol. Res.* **2008**, *5*, 135–143.
13. British Standard Institutions. *BS 3148: Method of Test for Water for Making Concrete*; British Standard Institutions: London, UK, 1980.
14. *BS 812*; Method for Determination of Water Absorption in Concrete; Part 2. British Standard Institution: London, UK, 1995.
15. *BS 1881*; Method for Determination of Compressive strength of Concrete Cubes; Part 116. British Standard Institution, London, UK, 1983.
16. *ASTM C618*; Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolanas for Use as Mineral Admixtures in Ordinary Portland Cement of Concrete; Annual Books of ASTM Standards vol 4. West Conshohocken, PA, USA, 2008.
17. *BS EN 197-1*; Cement—Part 1: Composition, Specifications and Conformity Criteria for Common Cements. British Standard Institution: London, UK, 2011.
18. Fadi, A.; Osama, Z.; Rebeca, M.G.; Fahad, A.; Mohd, A.; Mohammed, M.A. Impact of Nanosilica on the hydration, strength, durability and Microstructural properties of concrete: A state-of-the-art review. *J. Build. Eng.* **2023**, *18*, e01997.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.