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Effect of Elevated Temperatures on Mechanical Properties of Concrete Blended with Nanosized Sawdust Ash and Rice Husk Ash

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Abstract
The need for sustainable greener concrete structures has necessitated the adoption of pozzolanic materials to serve as alternatives to conventional cement whose production contributes to carbon dioxide emissions which advances global warming, apart from its cost implications and environmental pollution. The desire for concrete with improved performance has prompted more studies and attention to development of nano-concrete. However, there is minimal information available on the structural behaviour of concrete that is based on nanosized replacement materials. At elevated temperature, concrete experiences severe deterioration with significant physio-chemical transformations which leads to the breakdown of the cement gel structure, strength loss and structural-cracking. In fire resistance design, compressive strength and modulus of rupture of concrete at high temperatures, is of basic interest. This study analyzed the effect of high temperatures of 25 °C, 200 °C, 400 °C, 600 °C, 800 °C and 1000 °C on blended concretes made with nanosized sawdust ash (NSDA) and nanosized rice husk ash (NRHA). Blended concretes of mixes containing 10% of NSDA with 5%, 10%, 15% and 20% NRHA were produced. Six varied mixes were produced for the concrete cubes and beams. Workability test was carried out on each of the six mixes. Concrete cubes of sizes 150mm x 150mm x 150mm and concrete beams of sizes 150mm x150mm x 500mm were produced to determine the compressive strengths and modulus of rupture respectively. The concretes were cured for 21, 28, 60 and 90 days by total immersion in water. Generally, it was observed that there was reduction in strength with increase in temperature and NRHA content from the ambient temperature (25 ºC) up to 200 ºC. The concretes' compressive strength reduced with increase in temperature but increased with increase in NRHA replacement, at temperatures of 400 ºC and beyond. At all temperatures, the modulus of rupture (MOR) values reduced as the percentages of NRHA increased. After 28 curing days at NRHA 5% NSDA 10% replacement when compared to the strength of control specimen, strength exhibited decrease of 10.02%, 5.81% with an increase of 18.67%, 12.40%, 13.85% and 15.36% at temperatures of 25 ºC, 200 ºC, 400 ºC, 600 ºC, 800 ºC and 1000 ºC respectively, while the modulus of rupture, (NRHA 5% NSDA 10%) at ambient temperature showed a decrease of 8.60%, 10.85%, 19.84%, 31.18% and 34.21% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. The results revealed the beauty of nanosization, hence it is suitable for adoption as it improves the mechanical properties of concrete.

Keywords: Concrete, nanosization, compressive strength, modulus of rupture, high temperatures, nanosized sawdust ash (NSDA), nanosized rice husk ash (NRHA)

1. Introduction

The utilization of concrete in engineering practice and infrastructural development of many nations due to its commercial and economic benefits, cannot be overplayed (Nwa-David *et al.*, 2023a). Considerable quantity of cement is required for concrete production. The production of cement has posed environmental issues such as abiotic depletion, marine eco-toxicity and acidification due to increased emission of carbon dioxide in the atmosphere coupled with the cost of its production, consistent noise and release of toxic metals (Nwa-*David et al.*, 2023b; Ayuba *et al.*, 2022). To reduce the production cost of concrete, eradicate the environmental effects of cement production and improve the service life of concrete structures, the use of supplementary cementitious materials such as metakaolin, cassava peel ash, bambara nutshell ash, sawdust ash, rice husk ash, fly ash, corn cob ash, periwinkle shell ash and ground granulated blast furnace slag, have gained favorable reception in developing countries (Nwa-David and Ibearugbulem, 2023; Olorunmeye *et al.,* 2017).

Sawdust is the lightweight and portable waste product generated from sawing and milling wood, whose physical and chemical characteristics vary from one tree to another (Gopinath *et al.,* 2015). Sawdust is occasionally disposed through either open burning, open dumping or landfilling and the environment impact of these practices has necessitated its application in concrete production for sustainable development. Rice husk is an available and renewable agricultural residue generated from the external covering of rice grains during milling process. When burnt, it contains 20% as ash (RHA) and more than 70% as silica (Makinta *et al.,* 2021). In addition to its utilization in the silica extraction process (Mor *et al.,* 2017), it is a good pozzolanic material. The potential and efficiency of applying these materials in their nanosized form for concrete subjected to high temperatures, are evaluated.

The use of nanomaterials has gained more attention in engineering practices and particularly in the construction industry due to their ability to improve durability, air-quality, self-sensing and weight reduction (Shah et al., 2015; Nwa-David, 2023). Nanosization implies customizing the behaviour and performance of matter at the nanoscale, which is between 1 and 100 nanometres (Sanchez and Sobolev, 2010). Nano silica, nano alumina, nano clay and nano kaolin are often employed in construction works (Olafusi *et al.,* 2019) but the concept of incorporating nano-sized materials in concrete is scarce in literature and this is worth consideration.

Studies on the adoption of nanostructured materials in concrete production is not yet prevalent in Nigeria. The behaviour of nanosized concrete under elevated temperatures are still wrapped in incertitude. Research on the structural use of concrete containing nanosized rice husk and sawdust ashes is scarce. In the absence of ample investigation on the NSDA-NRHA-based concrete material, its mix expression and performance characteristics as concrete product, it would be virtually unfeasible to produce an operational commercialization of the product as a realistic alternative to Portland cement and a greener solution in the construction industry. Hence this study is imperative.

Contemporary concrete structures are encompassed with ignition objects obtained from highly flammable materials; hence the risk of fire outbreak is intensified as well as the tendency of material and human losses (Umeonyiagu and Unamba, 2023; Abdullahi *et al.,* 2017). In structural design, safety is critical. Therefore, adequate knowledge on the behaviour of concrete materials at high temperature is needful, if they must be employed as structural elements. These supplementary cementitious (NSDA and NRHA) has the potential to improve strength and durability of concrete due to their pozzolanic reaction with calcium hydroxide $Ca(OH)_2$ and accelerated hydration with ordinary Portland cement (OPC). However, there is need to investigate their fire resistance ability when combined with cement in concrete at varied temperatures. And this validates the significance of this study.

Onwuka *et al.,* (2013) employed Scheffe's model to predict and optimize the compressive strength of concrete containing sawdust ash. 20.44N/mm^2 was obtained as the maximum strength at 28th day curing duration corresponding to a mix ratio of 0.5: 0.95: 0.05: 2.25: 4 (water: cement: sawdust ash: sand: granites). The authors did not consider the blend of sawdust ash with rice husk ash. The ash that was used was not nanosized. Effect of elevated temperatures was not addressed in their study.

Ayuba *et al.,* (2022) investigated the effect of H_2SO_4, Na_2SO_4, elevated temperatures between 200 ˚C to 600 ˚C, water absorption and microstructural study on self-compacting concrete whose cement component was partially replaced with sawdust ash at 0 – 30% using water to binder ratio of 0.37. Rice husk ash was not employed in the blend. Nanosization was not adopted.

Naveen *et al.,* (2015) studied the effect of rice husk ash on compressive strength of concrete M30 and M60 grade with varying rice hush ash content of 0%, 5%, 10%, 15% and 20% at 7 days and 28days. The strength of M30 concrete grade improved up to 10% replacement level for both curing age. The effect of high temperatures was not considered. Nanosization was not adopted. The authors did not add sawdust ash in their mix and they didn't cure beyond 28 days.

Knowing that rice-husk ash is a very reactive pozzolana, Adinna *et al.,* (2019) investigated the effect of adding rice-rusk-ash in small percentages of 2, 4, 7, 10 and 12% to concrete mix. The authors concluded rice-husk-ash can be added up to 7% to achieve up to 20% increase in the compressive strength, for concretes of slump within 50-

100mm. However, the authors did not examine the impact of elevated temperatures on strength of concrete. Their study was limited to only 28days curing and there was no consideration for ash nanosization. Sawdust ash was not included to their mix. Pam *et al.*, (2023) reported the compressive strength and elastic modulus of concrete blended with rice husk ash subjected to different high temperatures. The authors replaced OPC with RHA at 0-20%, cured by immersion in water for 28, 56, 90 days and subjected 450 concrete samples to temperature scale of 25ºC, 400ºC, 600ºC, 800ºC and 1000ºC. The authors did not consider the effect of blending RHA with SDA and there was no form of nanosization.

Although the pozzolanic materials applied in this study are common and has been used by previous authors but the ones employed in this study differs due to nanosization. The concept of blending two supplementary cementitious materials in concrete is also scarce neither has combination of NSDA and NRHA been addressed. The concrete grade and mix ratio employed in this work is also scare in literature. These gaps are worth filling. Consideration of other properties of concrete such as elastic modulus, makes this study exceptional. The peculiarity of this study is quite clear and cannot be neglected. The objective of this study is to experimentally determine the effect of elevated temperatures on fresh and hardened behaviour of concrete containing NRHA and NSDA as partial replacement of cement. Most studies on SDA and RHA – based concrete are limited to variational studies and the impact of various mix parameters on the features of the concrete material. Studies on the blended nanosized materials (NSDA + NRHA) and high temperature effect on mechanical properties of concrete are very scarce. Such mechanical properties such as compressive strength and modulus of rupture were captured in this study.

2.0 Material and methods

2.1 Materials

The *BUA* brand of Portland Cement that is in accordance with the specification of BS 12 (1996) was used. The BUA cement is a CEM II type of cement with strength grade 42.5 R and specific gravity of 3.02. It was procured from the community market in Ikwuano LGA, Abia State.

The coarse aggregate and fine aggregates employed in the study are locally available. The coarse aggregates were of angular-shape. The maximum size of the granite used for this work was 20mm diameter, which conformed to the requirements of BS 882 (1992). Fine aggregates were sieved through 10mm British Standard test sieve to eliminate cobbles to satisfy the requirements of BS 882 (1992).

The water used for the experiment during mixing and curing operation was fit for drinking and it conformed to the stipulations in BS 3140 (1980). The water was obtained from the borehole at the concrete laboratory, civil engineering department, Michael Okpara University of Agriculture, Umudike.

Sawdust was collected from new timber market along Ikot Ekpene road, Umuahia in Abia State, Nigeria. The sawdust was obtained mainly from Obeche, Mansonia, black Afara and Mahogany species of timber. Nanosized Sawdust Ash (NSDA) was obtained by incineration of sawdust at a temperature of 650 ºC under a control combustion set-up for 2hours and the ash was allowed to cool before sieving through with a nano-sieve of size 200 nm.

Rice husk was obtained from rice mills in Afikpo, Ebonyi State in South Eastern Nigeria. This material was air-dried and calcined into ash using furnace calcination which was done using local pit crucible furnace fired with coke at a temperature of 700 ºC. The ash was sieved and particles passing 200nm nano-sieve were used as the nanosized rice husk ash (NRHA).

2.2 Methods

2.2.1 Specimen Preparation

In this study, a mix ratio of 1: 1.5: 3 with water-cement ratio of 0.48 was used to prepare the concrete cube specimens. Concrete cubes and beams were produced employing the six (6) mix proportions presented in Table 1. Batching was done by weight. To ensure uniform proportioning, the replacement of cement with the nanosized materials (NRHA and NSDA), were done by weight.

Table 1: Mix Proportion of constituent materials used for NSDA-NRHA concrete production

Mix	Concrete Ingredients					
	Aggregates		Water	Binders		
	Fine (Kg/m^3)	Coarse (Kg/m^3)	(Kg/m^3)	NSDA (Kg/m^3)	NRHA (Kg/m^3)	Cement (Kg/m^3)
NRHA 0 NSDA 0	670	1350	209	0	0	435
NRHA 0 NSDA 10	670	1350	209	36	0	392
NRHA 5 NSDA 10	670	1350	209	36	17	372
NRHA 10 NSDA 10	670	1350	209	36	30	352
NRHA 15 NSDA 10	670	1350	209	36	44	333
NRHA 20 NSDA 10	670	1350	209	36	58	314

The concrete mixture was placed in slump cone for slump test after which it was remixed and placed in respective moulds for each of compressive strength test (150mmx150mmx150mm), modulus of rupture test (150mmx150mmx500mm). The constituent materials were uniformly blended and was introduced into cubes and beams; in three layers and compacted with the tamping rod 25 stroke per layer and the top finish with the trowel and label accurately conforming to BS EN 12390 – 3, 2002. The concrete was de-moulded after 24 hours and immersed in a curing tank for adequate hydration.

NSDA and NRHA were employed as cement replacement in the concrete production. The replacement levels of cement with NRHA were 0, 5, 10, 15 and 20 percent while NSDA was kept constant at 10% cement replacement in line with the recommendations of Elinwa and Mahmood (2002) and Matawal (2005). A total of four hundred and thirty-two (432) samples of concrete cubes were cast, cured, heated and tested. For each temperature, at each curing period, three (3) cubes were produced and their average was recorded and presented. Four hundred and thirty-two (432) concrete cubes of 150mm x 150mm x 150mm and beams of sizes 150mm x150mm x 500mm were produced to determine the compressive strength and modulus of rupture (before and after heating the hardened samples).

2.2.2 Test Method

At each period of testing for average of three concrete specimens, relevant standards were adopted as guide in ascertain the influence of high temperatures on the concrete samples. Table 2 captured the details of the test program.

Table 2: Test program for effect of high temperatures on NSDA-NRHA-concrete

Reference Standards	Type of test	Temperature range (^0C)	Test period (days)
BS EN 12390 – 3, 2002	Compressive Strength	25^0c, 100 ^{0}C, 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C and 1000 ^{0}C	21, 28, 60 and 90
BS EN 12390 – 5, 2000	Modulus of rupture	25^0c, 100 ^{0}C, 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C and 1000 ^{0}C	21, 28, 60 and 90

The cubes were cured for 21days, 28 days, 60 days, 90 days and were heated at 100 0C, 200 0C, 400 0C, 600 0C, 800 0C and 1000 0C; the temperature being sustained for a period of 60 minutes to achieve the thermal constant state. The heating was done in accordance with BS 8110 Part 1: (1997) specification. The heating was done at the Structural Laboratory of Hartland Construction Company, Umudike, Abia State. The compressive strengths of the concrete cubes and modulus of rupture (MOR) of the concrete beams measured in Newton per millimeter square (N/mm2) were obtained using equation 1 and 2.

$$\text{Compressive Strength} = \text{Failure Load} / \text{Area of Specimens} = P/A \qquad (1)$$

where failure load is measured in Kilo Newton KN and area of the specimen is measured in millimeter square (mm^2).

$$\text{Modulus of rupture (MOR)} = PL/bd^2 \qquad (2)$$

where P = Maximum Load measured in Kilo Newton (kN)
L = Span of the beam = 500mm
d = Depth of the beam = 150mm
b = Breadth of the beam = 150mm

3.0 Results and Discussions

3.1 Chemical and Physical Properties of Nanosized Sawdust Ash (NSDA) and Nanosized Rice Husk Ash (NRHA)

Table 3 captured the test results for the chemical analyses of NSDA and NRHA. The result showed that the pozzolanas can be used for replacement of cement due to the presence of similar oxides to those of cement. The sum of the oxides of silicon, iron and aluminum was 72.73% and 90.26 % for NSDA and NRHA respectively, which exceeds the 70% minimum specified by ASTMC 618 (2012) for raw or calcined pozzolana (class N). The presence of these oxides determine the amount of C_3S, C_2S and C_3A, hence the performance of the NSDA-NRHA blended concrete.

The presence of SO_3 which is 1.01% and 0.11% in NSDA and NRHA respectively, is below the maximum of 4% specified by ASTM C618 (2012) which indicates the tendency for enhanced durability and absence of paste unsoundness. The index of the degree of carbonation and hydration of free lime and free magnesia due to atmospheric exposure, is captured by the loss on ignition (LOI). The LOI obtained for NSDA and NRHA were 4.01% and 6.05% respectively, which falls below the maximum of 10% specified by ASTMC 618 (2012). The low LOI of these pozzolans is an indication of the presence of very small amount of impurities, these impurities are mainly carbon which may increase the water demand of the concrete (Umeonyiagu and Unamba, 2023).

The specific gravities of NRHA and NSDA were 2.75 and 2.54 respectively while that of *BUA* cement was 3.06. This indicates that NRHA and NSDA are lighter than cement and more volume of these supplementary materials will be required to substitute same weight of cement in concrete.

Table 3: Chemical composition of NRHA and NSDA

Oxide	NSDA (%)	NRHA (%)	*BUA* cement(%)
SiO_2	65.60	89.18	17.40
Al_2O_3	3.12	0.48	3.26
Fe_2O_3	4.01	0.60	4.47
CaO	2.22	0.62	68.72
MgO	1.29	0.42	1.34
SO_3	1.01	0.11	2.01
Na_2O	2.45	0.32	0.24
K_2O	16.29	2.22	0.55
LOI	4.01	6.05	2.01

3.2 Workability Test Results of the Blended Concrete

In Table 4, the results of the slump test conducted on the concrete with varying percentage of nanosized rice husk ash (NRHA) as cement replacement were presented. The amount of work required for placing and compacting concrete is considered as its workability. The obtained slump values showed that they were suitable for concrete works as they were the true type of slump. The slump reduced with increase in NRHA content which implies that more water is needed to maintain the same consistency as the amount of NRHA increases. NRHA content decreased slump by 21.43%, 46.43%, 57.14% and 64.29% at 5%, 10%, 15% and 20% respectively. Cement composites containing NRHA of 5%, 10% and 15% with slump values of 22mm, 15mm and 12mm respectively falls within the limit of class S1 (10mm – 40mm) specified by BS 12350 (1999) and approved for concrete works.

Table 4: Slump Test Results

Mix Percentage (%)		Slump (mm)
NRHA 0	NSDA 0	28
NRHA 0	NSDA 10	25
NRHA 5	NSDA 10	22
NRHA 10	NSDA 10	15
NRHA 15	NSDA 10	12
NRHA 20	NSDA 10	10

3.3 Compressive strength test

Figures 1, 2, 3 and 4, captured the outcome of the compressive strength test on OPC-NSDA-NRHA concrete. Generally, the results reveal that the compressive strength decreases as the NRHA content increases, but increases as the curing period increased. From the ambient temperature (25 ^{o}C) up to 200 ^{o}C, there was reduction in strength with increase in temperature and NRHA content. At temperatures of 400 ^{o}C and above, the compressive strength of the concrete reduced with increase in temperature but increased with increase in NRHA replacement.

Across the elevated temperatures in figure 1, the compressive strength for the control specimen at ambient temperature is 32.83 N/mm^2. This value reduced by 4.17%, 34.05%, 37.74%, 42.95% and 52.60% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively, as shown in figure 1. Similarly, (NRHA0% NSDA10%) at ambient temperature showed a decrease of 2.51%, 21.51%, 32.36%, 35.31% and 41.62% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. (NRHA5% NSDA10%) at ambient temperature showed a decrease of 2.74%, 18.81%, 27.41%, 31.30% and 40.03% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. At 21 curing days and across the percentage replacement; (NRHA5% NSDA10%) replacement when compared to the strength of control specimen, strength exhibited decrease of 5.42%, 4.01% with an increase of 16.44%, 10.27%, 13.88% and 19.67% at temperatures of 25 ^{o}C, 200 ^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C respectively. Similarly, (NRHA20% NSDA10%) showed a reduction of 14.99%, 14.81% with an elevation of 25.91%, 21.57%, 28.99% and 49.10% at temperatures of 25 ^{o}C, 200 ^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C respectively.

In figure 2, the compressive strength for the control specimen at ambient temperature is 55.70 N/mm^2. This value reduced by 4.58%, 45.57%, 55.42%, 61.88% and 69.03% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. Similarly, (NRHA0% NSDA10%) at ambient temperature showed a decrease of 1.84%, 39.46%, 52.43%, 57.74% and 65.50% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. (NRHA5% NSDA10%) at ambient temperature showed a decrease of 0.12%, 28.21%, 44.31%, 51.78% and 60.30% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. At 28 curing days and (NRHA5% NSDA10%) replacement when compared to the strength of control specimen, strength exhibited decrease of 10.02%, 5.81% with an increase of 18.67%, 12.40%, 13.85% and 15.36% at temperatures of 25 ^{o}C, 200 ^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C respectively. Similarly, (NRHA20% NSDA10%) showed a reduction of 22.96%, 23.52% with an elevation of 46.90%, 26.26%, 28.59% and 47.07% at temperatures of 25 ^{o}C, 200 ^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C respectively.

At (NRHA5% NSDA10%) replacement in figure 3 when compared to the strength of control specimen, strength exhibited decrease of 3.98%, 6.21% with an increase of 15.82%, 18.61%, 11.82% and 21.04%; Similarly, (NRHA20% NSDA10%) showed a reduction of 15.30%, 17.32% with an elevation of 40.45%, 31.38%, 32.77% and 51.57% at temperatures of 25 ^{o}C, 200 ^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C respectively. At 90 curing days and (NRHA5% NSDA10%) replacement when compared to the strength of control specimen, strength exhibited decrease of 6.32%, 6.01% with an increase of 10.28%, 11.96%, 11.73% and 18.89%; Similarly, (NRHA20% NSDA10%) showed a reduction of 16.60%, 17.70% with an elevation of 29.13%, 30.83%, 37.69% and 45.67% at temperatures of 25 ^{o}C, 200 ^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C respectively.

The reduction of compressive strength observed with increasing NRHA content between 25 ^{o}C and 200 ^{o}C was attributed to the reduction of tricalcium silicates. This reduction is due to the formation of the portlandite obtained from the hydration of tricalcium and dicalcium silicates which occupies 25% volume of ordinary Portland cement paste. For temperatures of 400 ^{o}C and above, the increase in strength is traceable to the hydrothermal relationship between the particles of NRHA-NSDA and cement coupled with the emission of free lime during the hydration process as temperature rises. Nanosization of these pozzolanic materials also contributed to higher strength values when compared to other literatures whose materials were not nanosized.

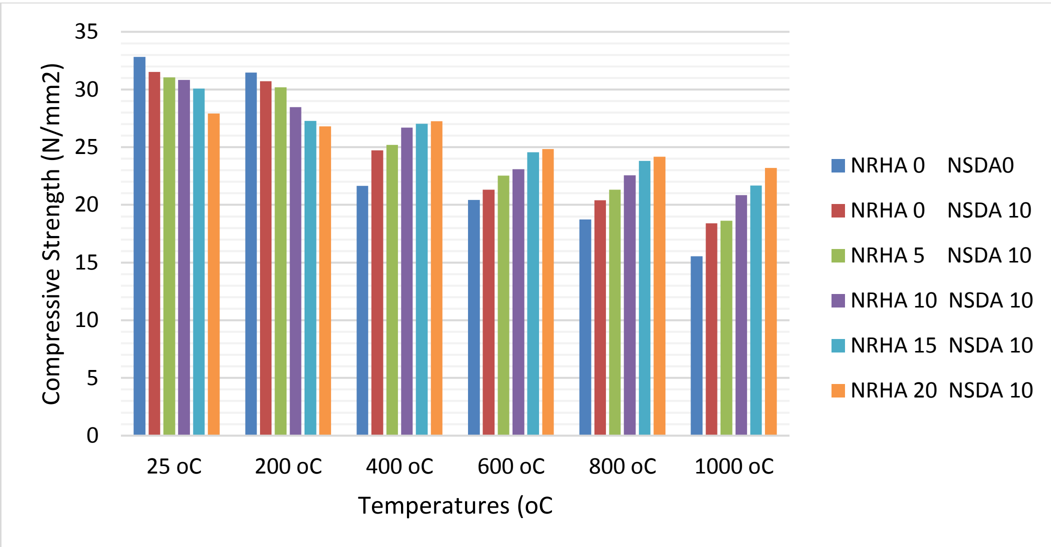

Figure 1: 21 days' compressive strength test results for OPC-NSDA-NRHA blended concrete

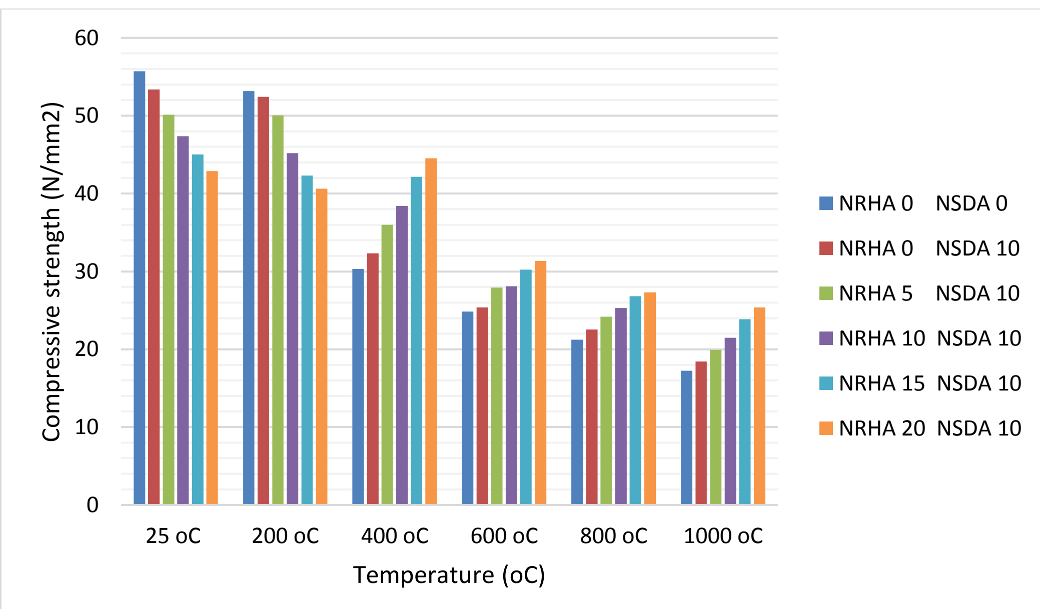

Figure 2: 28 days' compressive strength test results for OPC-NSDA-NRHA blended concrete

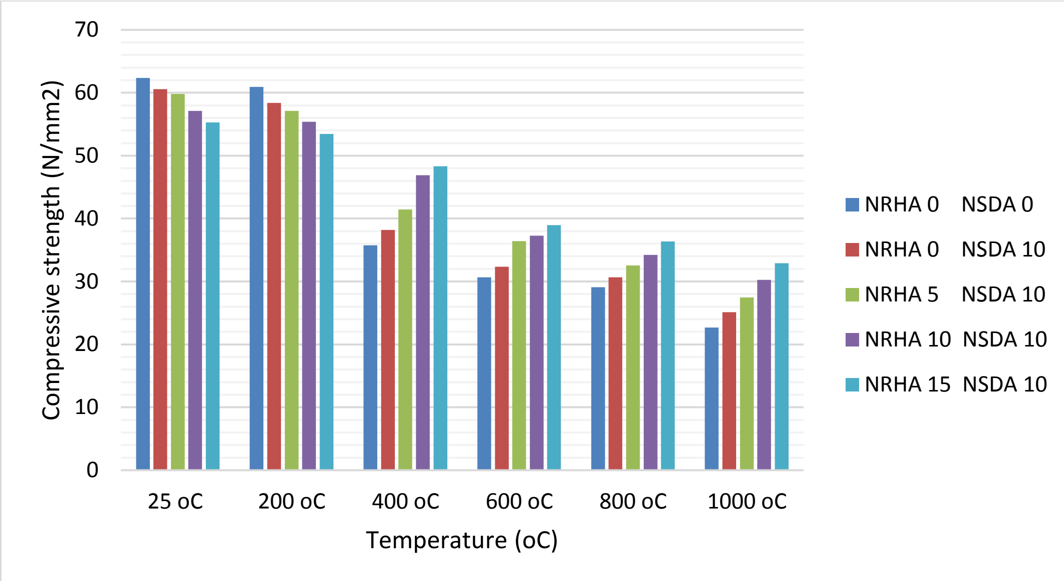

Figure 3: 60 days' compressive strength test results for OPC-NSDA-NRHA blended concrete

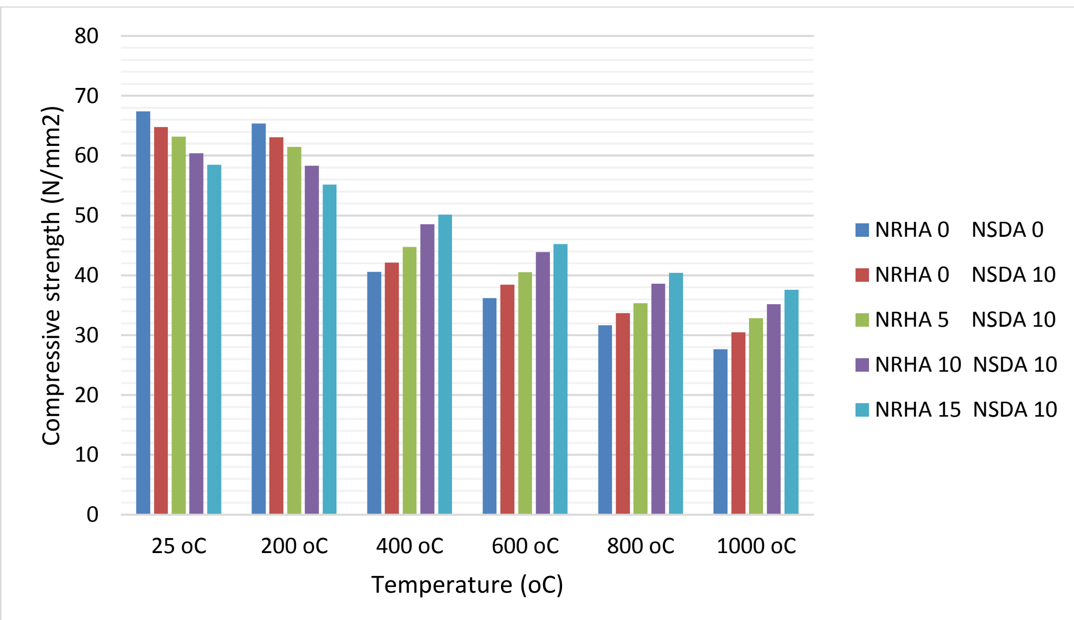

Figure 4: 90 days' compressive strength test results for OPC-NSDA-NRHA blended concrete

3.4 Modulus of rupture test

Figures 5, 6, 7 and 8 shows the outcome of modulus of rupture for OPC-NSDA and NRHA concrete versus percentages of NRHA used to replace cement. At all temperatures, the modulus of rupture (MOR) values reduced as the percentages of NRHA increased. This occurrence is traceable to the inclusion of NRHA content which contributed to the depletion of tri-calcium silicates (C_3S), moisture reduction and elimination of strength-giving components (cement and aggregates) as a result of increase in temperature (Chandan *et al.*, 2013). The modulus of rupture obtained in this study is higher than the values derived by other scholars due to nanosization. The modulus of rupture reduced with an increase in NRHA replacement due to the low specific gravity of NRHA compared to OPC, in conformity with Sata *et al.*, (2007).

From figure 5, the modulus of rupture for the control specimen at ambient temperature is 8.36 N/mm^2. This value reduced by 4.07%, 12.68%, 25.60%, 34.45% and 43.54% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. Similarly, (NRHA0% NSDA10%) at ambient temperature showed a decrease of 4.56%, 8.32%, 19.33%, 32.21% and 42.28% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. (NRHA5% NSDA10%) at ambient temperature showed a decrease of 2.11%, 8.73%, 15.92%, 33.66% and 42.11% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively.

The modulus of rupture for the control specimen at ambient temperature is 11.30 N/mm^2, after 28days curing as shown in figure 6. This value reduced by 4.25%, 7.79%, 16.64%, 26.46% and 32.21% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. Similarly, (NRHA0% NSDA10%) at ambient temperature showed a decrease of 5.80%, 9.20%, 19.68%, 31.74% and 33.03% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively. From Figure 6, (NRHA5% NSDA10%) at ambient temperature showed a decrease of 8.60%, 10.85%, 19.84%, 31.18% and 34.21% at temperatures of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C, and 1000^{0}C respectively.

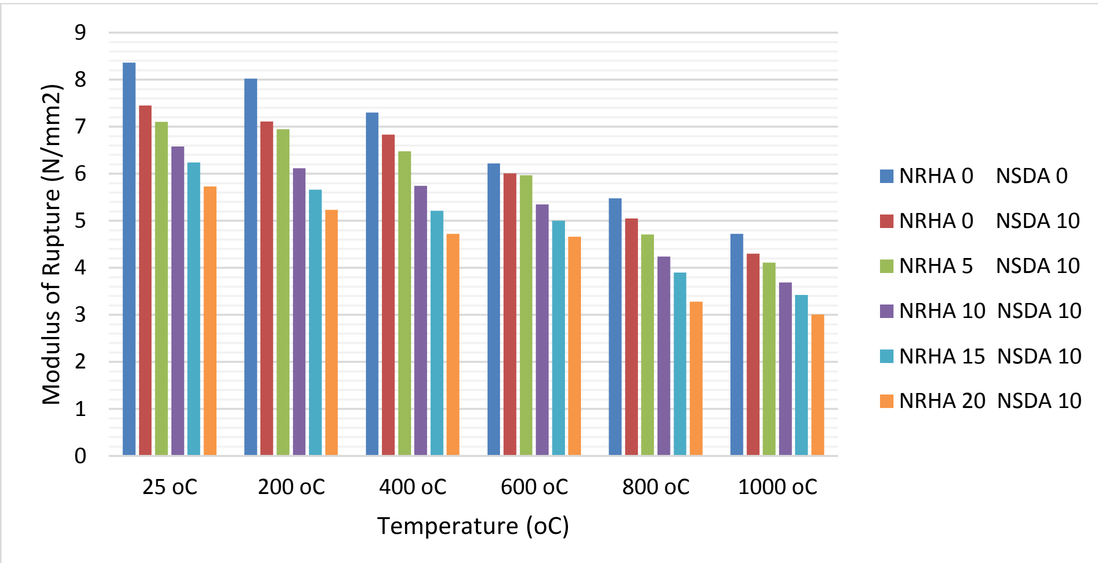

Figure 5: 21 days' Modulus of rupture test results for OPC-NSDA-NRHA blended concrete

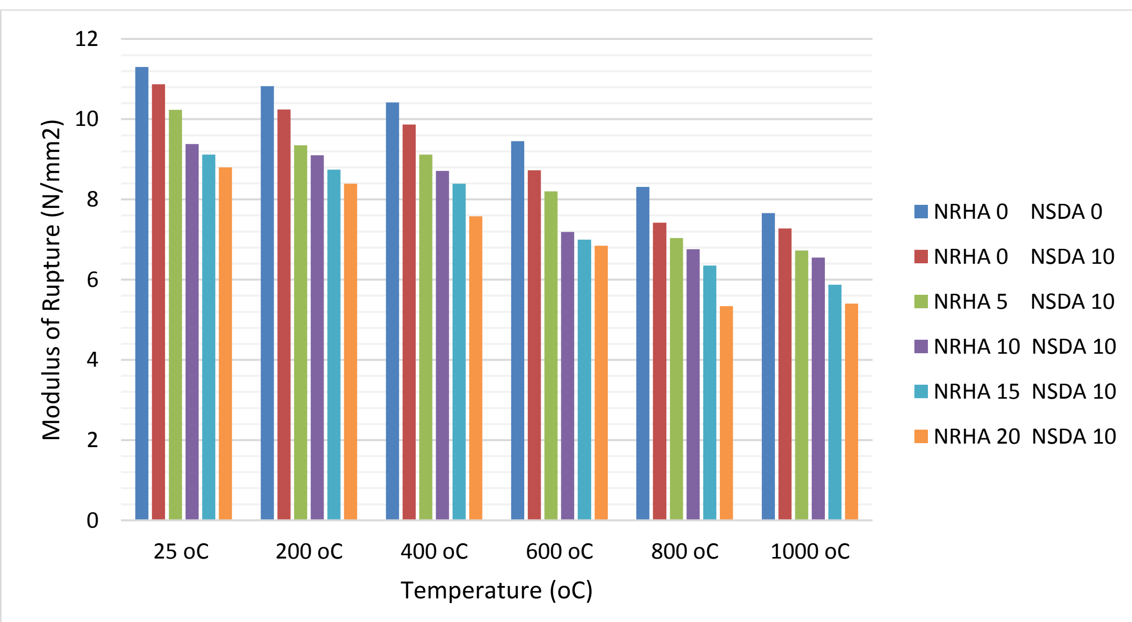

Figure 6: 28 days' Modulus of rupture test results for OPC-NSDA-NRHA blended concrete

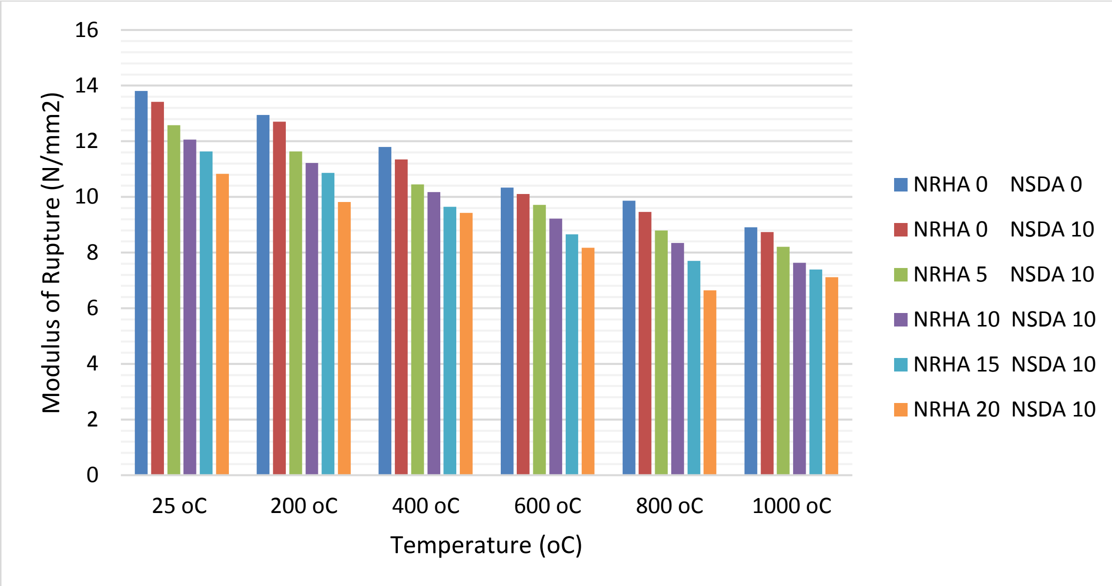

Figure 7: 60 days' Modulus of rupture test results for OPC-NSDA-NRHA blended concrete

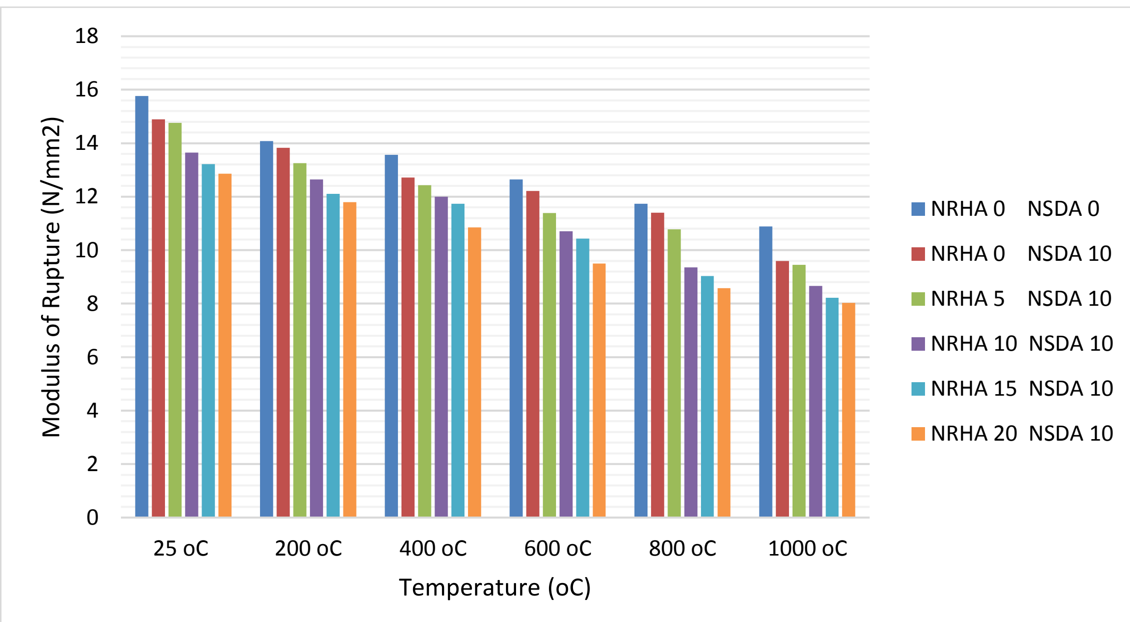

Figure 8: 90 days' Modulus of rupture test results for OPC-NSDA-NRHA blended concrete

4.0. Conclusion

This study investigated the effect of elevated temperatures on mechanical properties of concrete containing the blend of nanosized sawdust ash and rice husk ash as partial replacement of cement, with a view to ascertain its potential implications as a construction material and suitability for critical structural application. The findings in this work showed the relevance of nanosization in concrete production as it improved reactivity of the pozzolanic materials and the strength of the concrete as the pores existing in the matrix were filled which provided a unique surface area to volume ratio. It was also observed that there was reduction in strength with increase in temperature and NRHA content from the ambient temperature (25 ^{o}C) up to 200 ^{o}C. The concretes' compressive strength reduced with increase in temperature but increased with increase in NRHA replacement, at temperatures of 400 ^{o}C and beyond. For all the temperatures and in all the curing periods, modulus of rupture decreased as NRHA content increased. It was established that the influence of elevated temperatures on the mechanical properties of NRHA-NSDA-concrete was better than those of conventional concrete due to the presence of nanosized materials. Increase in curing periods of all the concrete samples yielded an improved behaviour of the samples when exposed to high temperatures thus strength is greatly enhanced at a later curing age. This implies that the use of NRHA and NSDA blended with cement in concrete for construction will be beneficial in minimizing the peril of fire on concrete elements.

5.0 Recommendation

The concept of nanosization is recommended and should be embraced in the construction industry as it boosts concrete performance. The effect of elevated temperature on other mechanical properties of concrete such as creep and drying shrinkage, can be taken into consideration in future studies. Further investigation with respect to durability – related behaviour and comprehensive microstructural study on NRHA-NSDA– based concrete would enhance increased knowledge on the general characteristics of the concrete for general and specific uses.

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