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Performance Evaluation Of Concrete With Nano Rice Husk Ash As A Partial Cement Replacement

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ABSTRACT : *This study examines the performance of concrete using Nano Rice Husk Ash (NRHA) as a partial cement replacement. To produce nano-sized particles, NRHA, a byproduct of milling rice, was ball milled for three hours after being carefully burned at 700°C. Using X-ray diffraction (XRD) and X-ray fluorescence (XRF), the chemical characteristics of NRHA were found to be quartz SiO2, which made up 79 mg/cm2 (%) of the sample weight. To assess workability, compressive strength, splitting tensile strength, modulus of elasticity, and Poisson's ratio, laboratory experiments were conducted on concrete mixes made with different NRHA replacement amounts (0%, 5%, 10%, and 15%). The findings showed that 10% NRHA replacement produced NRHA-modified concrete with sufficient mechanical qualities, including tensile and compressive strengths of about 3.20 N and 19.5 N/mm2, respectively. The study verified that FEA provides a trustworthy method for assessing and forecasting concrete performance and that NRHA satisfies the chemical requirements of a Class F pozzolan. By confirming NRHA's efficacy as an additional cementitious ingredient and demonstrating the use of simulation in concrete design optimization, this study advances sustainable construction methods.*

KEYWORDS: *Concrete, NRHA, Cement, Pozzolana*

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1. INTRODUCTION

Almost one ton of concrete is used annually for every person on the planet, making it the second most utilized material after water (Nguyen et al., 2019). The employment of a wide range of additives and admixtures has led to a significant advancement in concrete technology in recent years, opening the door for the successful creation of new-generation concrete mixtures (Kantar et al., 2011). With recent advancements in nanotechnology, several researchers made an attempt to incorporate nanoparticles in concrete. Agricultural waste such as rice husk when converted to ash, will help to make environmentally friendly concrete, rice husk is proven to be a natural supply of silica (Faried et al., 2021).

The use of pozzolanic materials in cementitious materials has been regarded as significant because it can improve the mechanical and durability characteristics of mortar or concrete, which can lead to a number of positive performances (Hossain et al., 2016; Miyandehi et al., 2016). This improves not only the properties of concrete but also the sustainability of buildings.

Tremendous achievements have been reported on nanotechnology adoption on sustainable construction, but there are so much more to explore than has been achieved. Some of the advents on the adoption of nanotechnology on sustainable construction, includes the enhancement of the rheology, strength and durability properties of concrete; which has been proved to be hinged on the nanoscopic characteristics of its constituent (Olafusi *et al.*, 2019b). Any modification at the nanoscopic level of concrete and its constituent influences its behavior, including its strength and durability characteristics. Hence, it is projected that the performance of concrete and sustainable construction materials in the future would be greatly enhanced by the application of nanotechnology to manipulate the atoms and molecules of these materials and their constituents at the nanoscale (Olafusi *et al.*, 2019a)

Much of the previous attention on the utilization of nanomaterials in construction materials were specifically devoted to the characterization of their fresh-state, hydration, microstructure, pore structure, mechanical, properties (Li *et al.*).

However, research into the Elastic properties of concrete made by incorporating nanomaterials is still in its infancy also that they are limited Finite Element Analysis of properties of construction materials (especially cementitious) with the use of nanomaterials.

II. MATERIALS AND METHOD

2.1. Materials

Throughout the study, Portland limestone cement (PLC), grade 42.5N that complies with BS EN 197-1:2004 was utilized. NRHA was used in place of cement in concrete at weight percentages of 0%, 5%, 10%, and 15%. To maintain consistency, hand mixing was used. Table 2 shows the absolute amounts of materials utilized for each blend. The size range of the fine aggregate particles was 150µm to 4.75 mm. Before being used, the sand was cleaned, let to air dry, and sieved to eliminate harmful substances. Coarse aggregate was made of crushed granite with a bulk density of 1530 kg/m³ and a nominal maximum size of 19.5 mm. The aggregate was dried to a saturated surface-dry state after being cleaned to get rid of surface contaminants. Silica makes up to 71% of the total mass of NRHA which makes up the majority of the NRHA. In order to produce nano-sized particles of 4000 and 7000 cm^2/g, the husk from a rice meal in Minna, Niger State, was calcined at 700°C for six hours then ball milled for three hours. Table 3 lists the amount of the oxide composition of the of the nanoparticles and Figure 1 shows amorphous nature of NRHA. It revealed that the samples exhibited similarities with a representative broad hump validating their amorphous structure and a distinct peak of SiO^2 in the form of cristobalite (Kang *et al.*, 2019) with minor amounts of other oxides such as P_2O_5, Fe_2O_3, K_2O, CaO, and Al_2O_3**.** (see Fig. 1)

This composition aligns well with the XRD analysis, which identified Quartz as the dominant crystalline phase. The minor impurities present could influence the material's properties depending on the intended application (Yuvakkumar *et al.*, 2014).

2.2. Testing Instruments

X-ray diffraction analysis was used to determine the mineralogical composition of NRHA. A Rigaku MiniFlex X-ray diffractometer with Cu-Kα radiation (λ = 1.5418 Å) running at 30 kV and 15 mA was used for the tests at the Central Research Laboratory of the National Steel Raw Materials Exploration Agency (NSREA), Kaduna. A 2θ range of 4° to 75° was used for scanning. Audu et al (2025). Beyond Burnt Bricks, reassessing Otukpo Soil for Sustainable Construction Applications used a Genius IF energy-dispersive X-ray fluorescence (EDXRF) spectrometer (Xenemetrix, Israel) to analyze the elemental composition of NRHA.

Powdered samples (<150 µm) were prepared in prolene-film-lined sample cups and analyzed using XRS-FP software to obtain oxide compositions

2.3. Mix design

COREN simplified method of concrete means design was adopted. The final mix proportion obtained was 1: 1.33: 2.71 (cement: fine aggregate: coarse aggregate) with water-cement ratio of 0.63 as shown in Table1.

Table 1: Mix Proportion

Ingredient	Cement	Fine aggregate	Coarse aggregate	Water
Quantity (kg/m³)	373	645	1147	235
Ratio	1	1.33	2.71	0.63

For compressive strength tests, 152 concrete cube specimens (150 mm × 150 mm × 150 mm) were cast at curing ages of 28, 56, and 91 days. Table 2 presented the batching by Absolute Volume of Concrete Constituents Materials.

Table 2: Absolute Volume of Concrete Constituents Materials

Mix Batch	Cement (%)	Cement (kg)	Nano Rice Husk Ash - NRHA- (%)	Nano Rice Husk Ash - NRHA- (kg)	Water (kg)	Coarse aggregate (kg)	Fine aggregate (kg)
M1	100	67.26	0	0	20.86	89.73	44.04
M2	95	63.90	5	3.36	20.86	89.73	44.04
M3	90	60.53	10	6.73	20.86	89.73	44.04
M4	85	57.17	15	10.09	20.86	89.73	44.04
Total		**248.86**		**20.18**	**83.44**	**358.92**	**176.16**

III. RESULT AND DISCUSSION

3.1 Minerology of NRHA

The oxide composition of the waste fired glass powder obtained through X-ray fluorescence (XRF) analysis is presented in Table 3. The material is predominantly composed of silicon dioxide (SiO_2) with a value of 79%, confirming its highly siliceous nature.

Table 3: XRF of Nano Rice Husk Ash

Sample Layer	Component	Type	Conc. mg/cm^2 (%)	Conc. in Mole (%)
1	SiO_2	Calc.	79.792	87.066
1	V_2O_5	Calc.	0.013	0.005
1	Cr_2O_3	Calc.	0.034	0.015
1	MnO	Calc.	0.291	0.269
1	Fe_2O_3	Calc.	23.086	1.267
1	Co_3O_4	Calc.	0.006	0.005
1	NiO	Calc.	0.006	0.005
1	CuO	Calc.	0.032	0.026
1	Nb_2O_3	Calc.	0.049	0.012
1	WO_3	Calc.	0.000	0.000
1	P_2O_5	Calc.	7.698	3.556
1	SO_3	Calc.	0.545	3.556
1	CaO	Calc.	1.749	0.446

1	MgO	Calc.	0.070	0.115
1	K_2O	Calc.	3.694	2.571
1	BaO	Calc.	0.000	0.000
1	Al_2O_3	Calc.	1.923	1.237
1	Ta_2O_5	Calc.	0.026	0.004
1	TiO_2	Calc.	0.0329	0.270
1	ZnO	Calc.	0.079	0.063

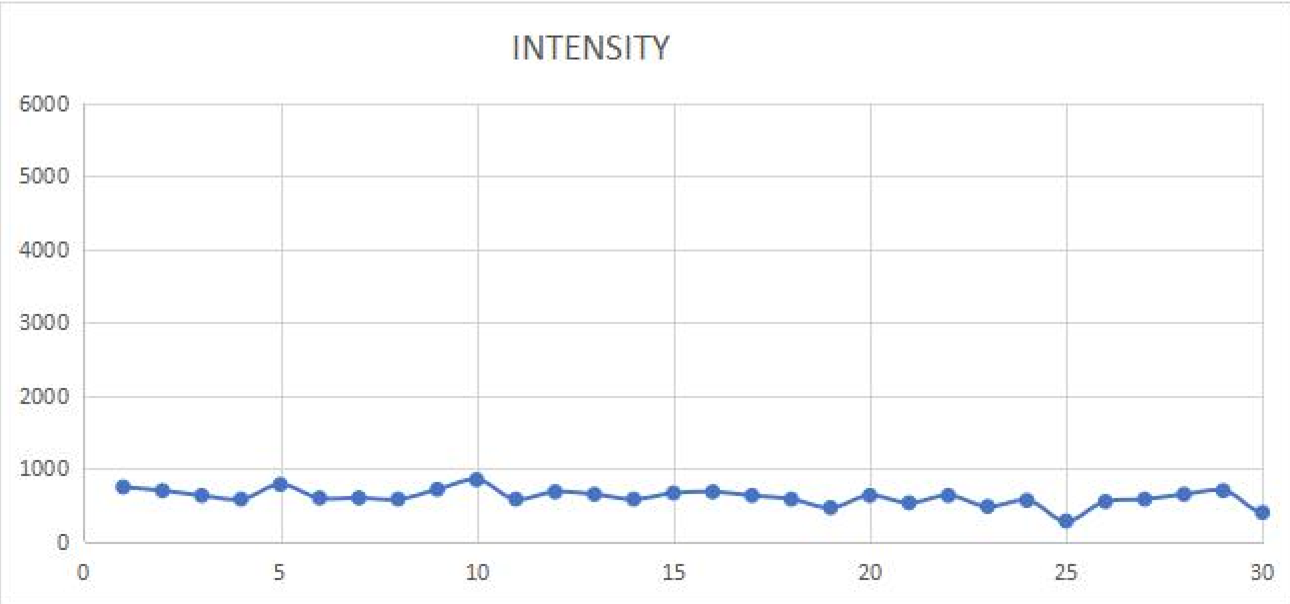

Fig.1: XRF of Nano Rice Husk Ash

3.2. Compressive strength

Compressive strength at 28, 56, and 91 days were determined in accordance with BS 812-2:1995. Figure 2: display the relation between the NRHA dosage, which ranged between 0 and 15% and the corresponding compressive strength for four different mixes at the ages of 28 days, 56 days and 91 days, respectively. At 28 and 91 days, the results of burnt NRHA at 300°C for 3 hours of ball milling with different percentages of NRHA (5, 10, and 15%), which was added to Portland Limestone Cement specimens, achieved a slight improvement compared to the control specimens. The reason for that can be explained due to the amount of SiO_2 that resulted from the burnt NRHA at 700°C for 3 hours ball milling, which is very small compared to Portland Limestone Cement. The noticeable improvement which are characterized by high strength and durability can cause further hydration process and lower pores. This effectively explain and justify the pozzolanic reaction $3Ca(OH)_2 + 2[SiO_2] \rightarrow [3(CaO).2(SiO_2).3(H_2O)]$ which involves the consumption of Calcium Hydroxide leading to its reduction which improves the durability of cement paste by making the paste dense and impervious. The experimental results of 10% dosage of NRHA at the age of 28 days agreed with the 56 days results at the dosage, achieving the optimum results. The results of the three ages indicated an increase in strength in all cases with a constant burning and ball milling hours. The burning degree, helped in the increment of amorphous silica production and this has led to low carbon content and, hence, more gel and strength was obtained. Also, the results are consistent with Faried *et al.* (2021) who reported that nano rice husk ash contains 96% SiO^2 at temperatures of 700°C of 3 hours ball milling.

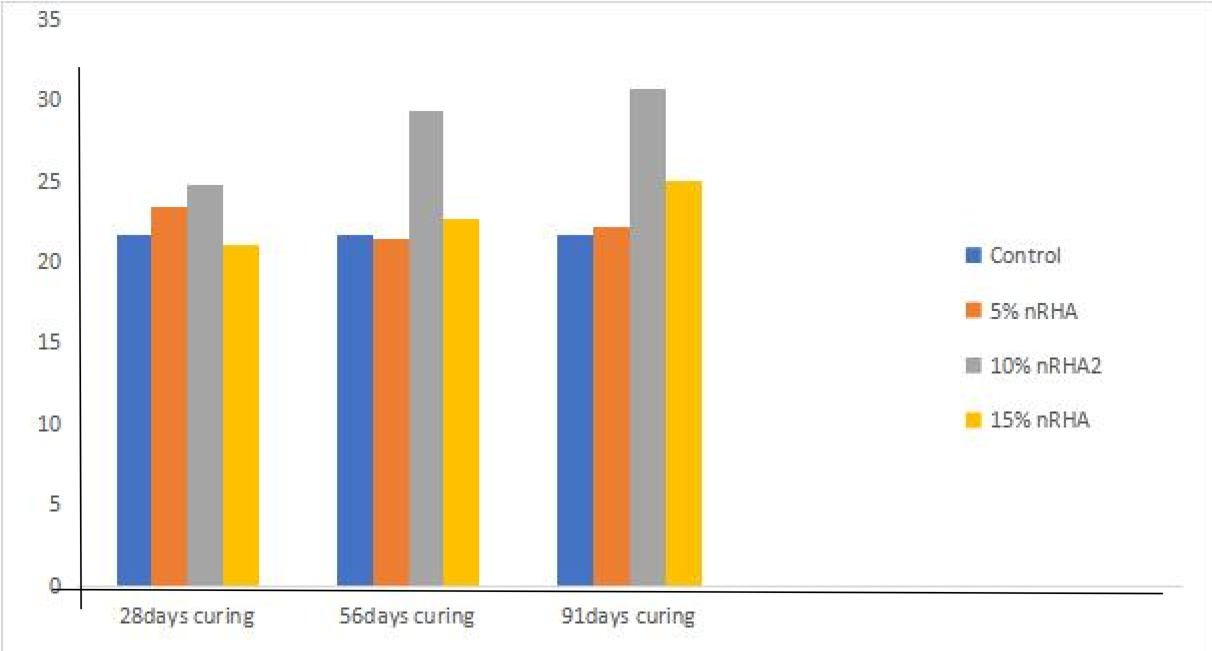

Fig. 2: Compressive strength of NRHA concrete

3.3. Elasticity properties

The modulus of elasticity of the nano rice husk ash (NRHA) concrete is presented in Figure 3. As illustrated in the figure, a clear improvement in elastic stiffness is observed with the incorporation of NRHA as a partial replacement for fine aggregate. The modulus of elasticity increases from 17.85 GPa for the control concrete mixture without NRHA to 25.42 GPa for concrete containing 10% NRHA. This improvement corresponds to a 42.41% increase in the strength capacity relative to the concrete without NRHA, demonstrating the significant contribution of NRHA to the enhancement of the elastic properties of the concrete matrix. With further inclusion of NRHA, the modulus of elasticity continues to increase. At an NRHA replacement level of 15%, the modulus of elasticity reaches 26.53 GPa, indicating a 48.63% increase in strength capacity compared to the control concrete without NRHA. This also represents a 4.37% increment relative to the concrete containing 10% NRHA. The observed trend suggests that the incorporation of NRHA improves particle packing density and promotes better interfacial bonding within the cementitious matrix, thereby enhancing the stiffness of the composite material.

However, despite the continued increase up to 15% NRHA, the rate of improvement beyond 10% replacement is comparatively marginal. This implies that 10% NRHA content may be considered an optimal replacement level for achieving substantial gains in modulus of elasticity. This behavior contrasts with the findings reported by Ahmed et al. (2019) for concrete containing ash and recycled coarse aggregates, as well as Ahmed et al. (2022) for concrete incorporating waste materials, where reductions or less pronounced improvements in elastic properties were observed at higher replacement levels.

Overall, the results indicate that the modulus of elasticity of concrete can be effectively and optimally enhanced through the incorporation of 10% NRHA, highlighting its potential as a sustainable material for improving the mechanical performance of concrete.

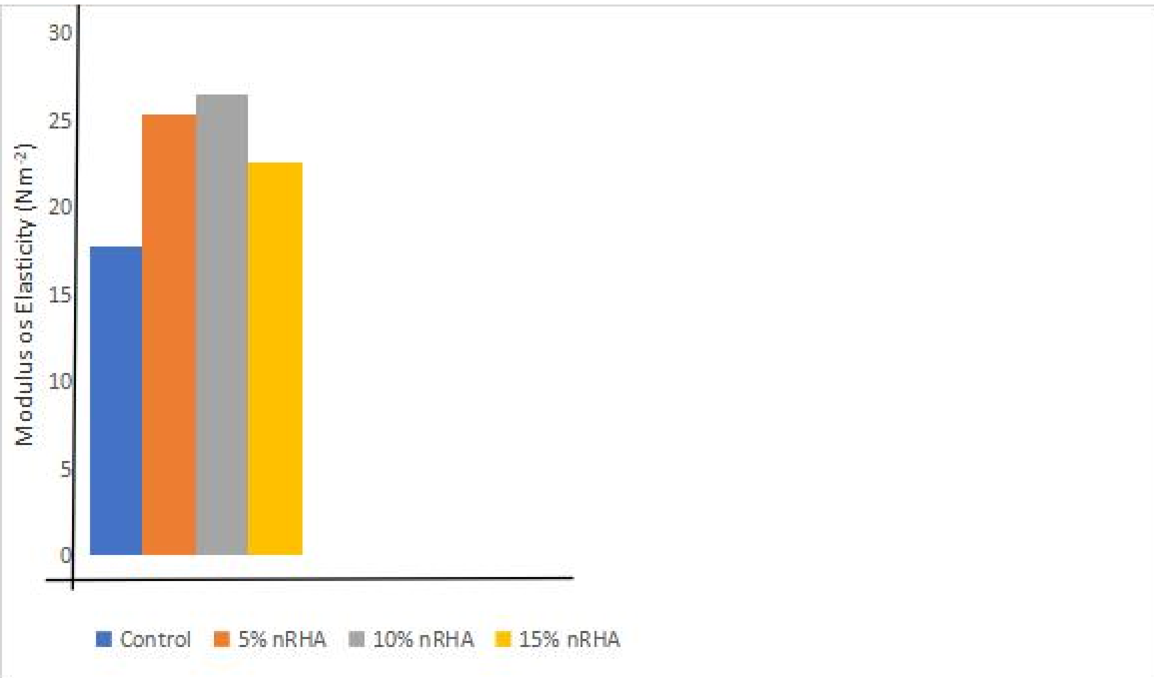

Fig. 3: Modulus of Elasticity of nRHA concrete

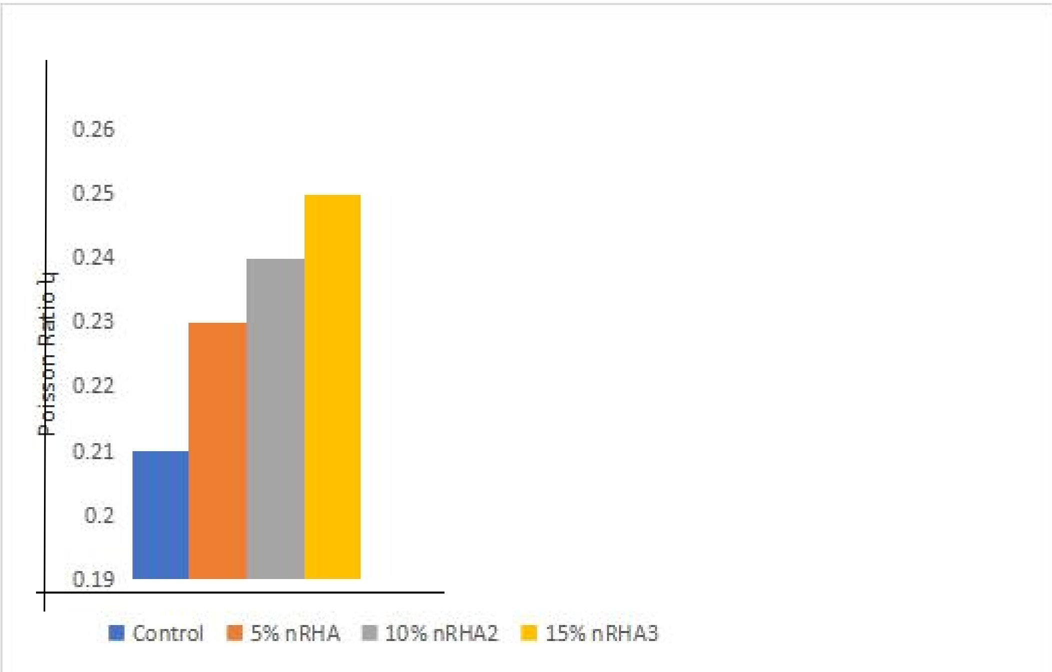

Fig. 4: Poisson Ration of NRHA concrete

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The study that was done led to the following conclusions.
The physical characteristics of the aggregates such as Fineness Modulus (Fine :3.20, Coarse:2.30), bulk density (Fine :1550, Coarse:1,500), specific gravity (Fine :2.67, Coarse:2.61), water absorption (Fine :0.89, Coarse:0.70), and free moisture content(Fine :10.03, Coarse:3.87) align with the range specified for natural aggregates by (BS, 1990). The chemical composition of NRHA calcined at 700°C and ball milled for three hours was amorphous with little crystallinity. XRF test result showed that the NRHA calcined at 700°C and ball milled for three hours is highly pozzolanic with 87% SiO_2 which falls within the P and F categories of pozzolanas. The NRHA modified concrete's 5% and 10% compressive strengths for 28, 56, and 91 days satisfied the structural requirements, with 10% being the best. Additionally, the splitting strength of NRHA-modified concrete with 5% and 10% NRHA was within the suggested range for structural application after 28, 56, and 91 days. The modulus of elasticity of the concrete can be optimally improved by the addition of 10% NRHA for cement, the modulus of elasticity is seen to be 22.42 kN/mm^2 for concrete without NRHA and 22.89 kN/mm^2 for concrete with 10% NRHA content while the Poisson ratio of 0.21 for concrete without NRHA content decrease to 0.19 when 10% portion of cement in the concrete mix is replaced

4.2 Research recommendation

Nano Rice Hush Ash burnt at 700°C and ball milled for 3 hours is recommended for use in ordinary concrete as pozzolans. 10% replacement of Nano Rice Hush Ash with compressive strength around 19.4 N/mm^2 experience 10% strength increment compare to control which is adequate for structural use. There effective uses of this amount in concrete production can lead to proper management of agricultural waste. Based on the parametric analysis performed with Abaqus/CAE, the FEA model produces realistic predictions of the response of the beam. The predictions obtained are recommended for various parameters required to fully define the majority of concrete material models, which frequently attribute concrete behavior that is not justified by the available experimental evidence. Further research should be carried out to assess the durability of the concrete made with NRHA in aggressive environment.

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