



## INVESTIGATION OF FRESH AND HARDENED BEHAVIOUR OF NANOSTRUCTURED CONCRETE

C. D. Nwa-David

Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria

\*Corresponding author's email address: [nwadavid.chidobere@mouau.edu.ng](mailto:nwadavid.chidobere@mouau.edu.ng)

### ARTICLE INFORMATION

Submitted 15 April, 2023  
Revised 13 July, 2023  
Accepted 20 July, 2023

### Keywords:

Nanostructured Cassava Peel Ash (NCPA)  
Concrete  
Workability  
setting time  
Compressive Strength,  
Splitting Tensile Strength

### ABSTRACT

The need for sustainable environment has triggered the deployment of supplementary cementitious materials (SCMs) which reduces the effect of carbon dioxide (CO<sub>2</sub>) emission emanating from cement production, as well as the cost implications. Cassava peel ash was adopted as a SCM but in a nanostructured form to investigate the properties of concrete. The experimental outcome of the compressive and splitting tensile strengths of nanosized cassava peel ash (NCPA)-cement concrete was presented in this paper. Materials employed for the concrete production were ordinary Portland cement, NCPA, river sand, granite chippings, and water. The compressive strength was obtained using 150 x 150 x 150 mm concrete cube specimens, while 150 x 300 mm cylindrical concrete specimens were used to assess the splitting tensile strength; both measured at 7, 14, 28, 56, 90 and 150 days of curing. The mixes were prepared for varying water cement ratios of 1.5% NCPA replacement intervals in a mix ratio of 1:1.5:3. The study revealed that the slump values increased as percentage of NCPA increased. The results showed that at a water-cement ratio of 0.75 and 19.5% NCPA replacement, the concrete attains excellent compressive strengths of 18.70 N/mm<sup>2</sup>, 22.10 N/mm<sup>2</sup>, 24.20 N/mm<sup>2</sup>, 30.10 N/mm<sup>2</sup>, 33.30 N/mm<sup>2</sup>, and 36.90 N/mm<sup>2</sup> at 7, 14, 28, 56, 90 and 150 days respectively with 5.96 N/mm<sup>2</sup>, 7.04 N/mm<sup>2</sup>, 7.71 N/mm<sup>2</sup>, 9.60 N/mm<sup>2</sup>, 10.61 N/mm<sup>2</sup>, and 11.75 N/mm<sup>2</sup> for splitting tensile strength. The results confirm the suitability and uniqueness of nanosization as adoption of NCPA enhances the properties of concrete in both the plastic and hardened states.

© 2023 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

### 1.0 Introduction

The increasing global consumption of cement in concrete production is extremely high due to expanded infrastructural development in recent times (Thomas, 2018; Zareei, 2017; Attah et al., 2020). Minimizing the cost of cement production including its carbon dioxide (CO<sub>2</sub>) emission to the atmosphere (Khan et al., 2012; Johnson et al., 2013; Mehta, 2001), reducing the cost of housing and the growing demand for environmental preservation, has intensified the efforts of researchers at seeking and developing affordable and available alternative local materials that could be employed for sustainable construction (Awodiji et al., 2018; Onwuka et al., 2013, Nwa-David et al., 2023a)

In order to provide sustainable and renewable materials, agro-industrial wastes also known as supplementary-cementitious-materials (SCMs) such as rice husk ash, sawdust ash, periwinkle shell ash, corncob ash, cassava peel ash, oyster shell ash, have been extensively applied to partly and wholly replace cement in concrete production (Kamau et al., 2016; Ogbonna et al., 2020; George et al., 2019; Olutoge et al., 2012).

One of the many alternative materials for cement in concrete production is the cassava peel ash—a by-product of cassava processing. Cassava peel ash has been applied in (Olonade *et al.*, 2014; Raheem *et al.*, 2015; Ofuyatan *et al.*, 2018; Etti *et al.*, 2013, Abdulwahab and Uche, 2021; Salau *et al.*, 2012) but the effect of its nanostructured status on compressive and splitting tensile strength of concrete which was not considered in previous studies distinguishes this study. Nanostructured materials incorporated in cement-composites improves its compressive and flexural strength at early age due to its high surface-to-volume ratio (Prasad, 2017; Sanchez and Sobolev, 2010) Eco-friendly concrete is produced with the use of nanosized-cassava-peel-ash (NCPA).

The quality of concrete structures is often captured by its compressive strength but in most applications such as in airfield slabs and highway pavements, knowing the tensile strength of concrete is essential because their design principle is based on flexural strength of concrete. Estimating the load under which cracking develops magnifies the usefulness of the knowledge of tensile strength (Neville, 2011).

Apart from the study carried out by Nwa-David *et al.*, (2023b), the theory of nanosization is scarce in literatures on concrete production. Antecedent authors did not consider tensile strength in their study. This gap in literature is addressed in this study. The aim of this work is to determine the strength relations between the splitting tensile strength and compressive strength of concrete produced with NCPA. The fresh properties of NCPA-cement concrete were obtained and the relationship between the splitting tensile and compressive strengths from the experimental data, is predicted.

## **2. Materials and Methods**

### **2.1 Materials**

The materials used for this study include, Ordinary Portland Cement, Nanostructured Cassava Peel Ash (NCPA), water, sharp-river sand, and granite chippings. The BUA brand of Ordinary Portland Cement that conformed to the requirements of BS 12 was used. It was purchased at the local market in Owerri Municipal area of Imo State.

Cassava peels as shown in Figure 1, were collected from cassava peels dump site at a garri processing centre in Owerri district of Imo State. The cassava peels were gathered and dried under the sun. The cassava peel was burnt in a kiln at a temperature of about 650 °C in 60 minutes in a control incineration set-up to prevent pollution. The burnt material was collected and sieved thoroughly with a nano-sieve of size 200nm, to produce fine nanostructured ash as shown in Figure 2.

A clean drinking water was obtained from a borehole at the laboratory. The water was clean, fresh, free from dirt, unwanted chemicals or rubbish that may affect the desired quality of concrete, and it conformed to the requirements of BS 3140.

The sand was obtained from Imo River, Imo State of Nigeria. It was sieved through 10mm British Standard test sieve to remove cobbles to satisfy the requirements of BS 882. The crushed granite

was sourced from the quarry site at Ishiagu, Ebonyi State, Nigeria. The maximum size of aggregate used for this work is 20mm diameter. It conformed to the requirements of BS 882.



**Figure 1.** Cassava Peels



**Figure 2.** Nanostructured Cassava Peel Ash

## 2.2 Methods

A mix proportion of 1:1.5:3 (blended cement: sand: granite) was used for the concrete. Batching was done by weight and varying water-binder ratios. Mixing was done manually on a smooth concrete pavement. The ash was first thoroughly homogenized with OPC at the desired proportion and the homogeneous blend was then mixed with the fine-coarse aggregate mix, also at the required proportion. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure uniformity. The mix proportion used for the study is presented in Table I. After mixing properly to a consistent state, the concrete was cast into the moulds and de-moulded after 24hrs. The cubes were cured for 7, 14, 28, 56, 90 and 150 days after which they were crushed in their saturated surface dry (SSD) state.

In accordance to the provisions of BS EN 12390-3 (2009), the compressive strengths of the concrete samples were determined using 150 x 150 x 150 mm cube specimens. The compressive strength test was done by placing the cubes on a crushing machine and recording the crushing load. Avery Denison Compression Machine of 2000 kN load-capacity, was adopted, at a constant rate of 15 kN/s. At each testing age, three specimens were tested, and the average used to evaluate the mean strength using the equation below;

$$f_c = \frac{\text{Average Failure load (N)}}{\text{cross – sectional area of concrete cube}(mm^2)} \quad (1)$$

To determine the splitting tensile strength of concrete samples, concrete cylinder specimens with dimensions 150 x 300 mm were used in accordance to the provision of BS 12390-6 (2009). The cylindrical concrete specimen having 12 inches' height and 6inches diameter, were axially loaded on the crushing device and the crushing load was recorded when the specimen collapsed. In order to obtain the splitting tensile strength (Ts), the expression in equation 2 was used.

$$\text{Splitting Tensile Strength } f_t = \frac{2P}{\pi ld} \quad (2)$$

Where P = maximum applied load (Newton)

l = length of specimen (mm)

d = diameter of specimen (mm)

**Table I.** Mix proportion of constituent materials for the investigation

Mixture Label	Mix Ratios	Water (kg)	Cement (kg)	NCPA (kg)	Sand (kg)	Granite (kg)
A1	1.000: 0.000: 1.5:3	15.25	25.42	0.00	38.38	76.09
A2	0.985: 0.015: 1.5:3	15.25	25.04	0.38	38.38	76.09
A3	0.970: 0.030: 1.5:3	15.25	24.66	0.76	38.38	76.09
A4	0.955: 0.045: 1.5:3	15.25	24.28	1.14	38.38	76.09
A5	0.940: 0.060: 1.5:3	15.25	23.89	1.53	38.38	76.09
A6	0.925: 0.075: 1.5:3	15.25	23.51	1.91	38.38	76.09
A7	0.910: 0.090: 1.5:3	15.25	23.13	2.29	38.38	76.09
A8	0.895: 0.105: 1.5:3	15.25	22.75	2.67	38.38	76.09
A9	0.880: 0.120: 1.5:3	15.25	22.37	3.05	38.38	76.09
A10	0.865: 0.135: 1.5:3	15.25	21.99	3.43	38.38	76.09
A11	0.850: 0.150: 1.5:3	15.25	21.61	3.81	38.38	76.09
A12	0.835: 0.165: 1.5:3	15.25	21.23	4.19	38.38	76.09
A13	0.820: 0.180: 1.5:3	15.25	20.84	4.58	38.38	76.09
A14	0.805: 0.195: 1.5:3	15.25	20.46	4.96	38.38	76.09
A15	0.790: 0.210: 1.5:3	15.25	20.08	5.34	38.38	76.09
A16	0.775: 0.225: 1.5:3	15.25	19.70	5.72	38.38	76.09
A17	0.760: 0.240: 1.5:3	15.25	19.32	6.10	38.38	76.09
A18	0.745: 0.255: 1.5:3	15.25	18.94	6.48	38.38	76.09
A19	0.730: 0.270: 1.5:3	15.25	18.56	6.86	38.38	76.09
A20	0.715: 0.285: 1.5:3	15.25	18.18	7.24	38.38	76.09
A21	0.700: 0.300: 1.5:3	15.25	17.79	7.63	38.38	76.09
A22	0.685: 0.315: 1.5:3	15.25	17.41	8.01	38.38	76.09
A23	0.670: 0.330: 1.5:3	15.25	17.03	8.39	38.38	76.09
A24	0.655: 0.345: 1.5:3	15.25	16.65	8.77	38.38	76.09
A25	0.640: 0.360: 1.5:3	15.25	16.27	9.15	38.38	76.09
A26	0.625: 0.375: 1.5:3	15.25	15.89	9.53	38.38	76.09
A27	0.610: 0.390: 1.5:3	15.25	15.51	9.91	38.38	76.09
A28	0.595: 0.405: 1.5:3	15.25	15.12	10.30	38.38	76.09
A29	0.580: 0.420: 1.5:3	15.25	14.74	10.68	38.38	76.09
A30	0.565: 0.435: 1.5:3	15.25	14.36	11.06	38.38	76.09
A31	0.550: 0.450: 1.5:3	15.25	13.98	11.44	38.38	76.09
A32	0.535: 0.465: 1.5:3	15.25	13.60	11.82	38.38	76.09
A33	0.520: 0.480: 1.5:3	15.25	13.22	12.20	38.38	76.09
A34	0.505: 0.495: 1.5:3	15.25	12.84	12.58	38.38	76.09
A35	0.490: 0.510: 1.5:3	15.25	12.46	12.96	38.38	76.09
A36	0.475: 0.525: 1.5:3	15.25	12.07	13.35	38.38	76.09
A37	0.460: 0.540: 1.5:3	15.25	11.69	13.73	38.38	76.09
A38	0.445: 0.555: 1.5:3	15.25	11.31	14.11	38.38	76.09
A39	0.430: 0.570: 1.5:3	15.25	10.93	14.49	38.38	76.09
A40	0.415: 0.585: 1.5:3	15.25	10.55	14.87	38.38	76.09
A41	0.400: 0.600: 1.5:3	15.25	10.17	15.25	38.38	76.09
A42	0.385: 0.615: 1.5:3	15.25	9.79	15.63	38.38	76.09
A43	0.370: 0.630: 1.5:3	15.25	9.41	16.01	38.38	76.09
A44	0.355: 0.645: 1.5:3	15.25	9.02	16.40	38.38	76.09
A45	0.340: 0.660: 1.5:3	15.25	8.64	16.78	38.38	76.09
A46	0.325: 0.675: 1.5:3	15.25	8.26	17.16	38.38	76.09
A47	0.310: 0.690: 1.5:3	15.25	7.88	17.54	38.38	76.09
A48	0.295: 0.705: 1.5:3	15.25	7.50	17.92	38.38	76.09
A49	0.280: 0.720: 1.5:3	15.25	7.12	18.30	38.38	76.09
A50	0.265: 0.735: 1.5:3	15.25	6.74	18.68	38.38	76.09
A51	0.250: 0.750: 1.5:3	15.25	6.36	19.07	38.38	76.09

### 3. Results and Discussion

#### 3.1 Physical and Chemical Evaluation of Constituent Materials

The chemical composition and physical characteristics of the NCPA was determined and presented in Table 2. From this table, it is observed that NCPA contains 61.70% SiO<sub>2</sub>, 12.50% Al<sub>2</sub>O<sub>3</sub> and 2.52% Fe<sub>2</sub>O<sub>3</sub>. This gives 76.72% of SiO<sub>2</sub>+ Al<sub>2</sub>O<sub>3</sub>+Fe<sub>2</sub>O<sub>3</sub> which is in line with ASTM C 618 requirement of 70% minimum for pozzolanas. Thus, NCPA meets the requirement for a pozzolana. The Loss of Ignition (LOI) of 5.07 and SO<sub>3</sub> of 2.10 all fall within agreeable limits of (ASTM C 618, 2008). NCPA has a lower specific gravity of 2.11 when compared with the specific gravity of cement (3.04). This implies that partially replacing OPC with NCPA will result to reduced weight of concrete members. The nanostructured cassava peel ash is 1.4 times lighter than cement.

The river sand has physical properties of 1650 kg/m<sup>3</sup>, 2.65 and 2.92 corresponding to its values of uncompacted bulk density, specific gravity and fineness modulus respectively. The river sand has coefficient of uniformity and coefficient of curvature values of 2.70 and 0.96 respectively obtained from Table 3. The granite has physical properties of 1520 kg/m<sup>3</sup>, 2.75 and 3.28 corresponding to its values of uncompacted bulk density, specific gravity and fineness modulus respectively. The coarse aggregate has coefficient of uniformity and coefficient of curvature values of 1.83 and 1.04 respectively obtained from Table 4.

The average specific gravity of majority of natural aggregate have been found to lie between 2.5 and 2.8. (Gambhir, 2013). The coefficient of curvature for both aggregates were confirmed to be close to 1 which indicates that the samples were well-graded, while the coefficient of uniformity of less than or equal to 4, which confirms that they were uniformly-graded (Iowa, 2020). Hence, these constituent materials are good for concrete production.

**Table 2.** Chemical Composition of BUA brand of OPC and NCPA

Materials	Chemical Composition (%)								
	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	SO <sub>3</sub>	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	LOI
Cement	18.22	2.72	5.11	60.14	3.31	1.25	0	0.08	7.23
NCPA	61.70	2.52	12.50	9.42	2.10	6.32	0.05	0.32	5.07

**Table 3.** Particle size distribution of Imo river sand

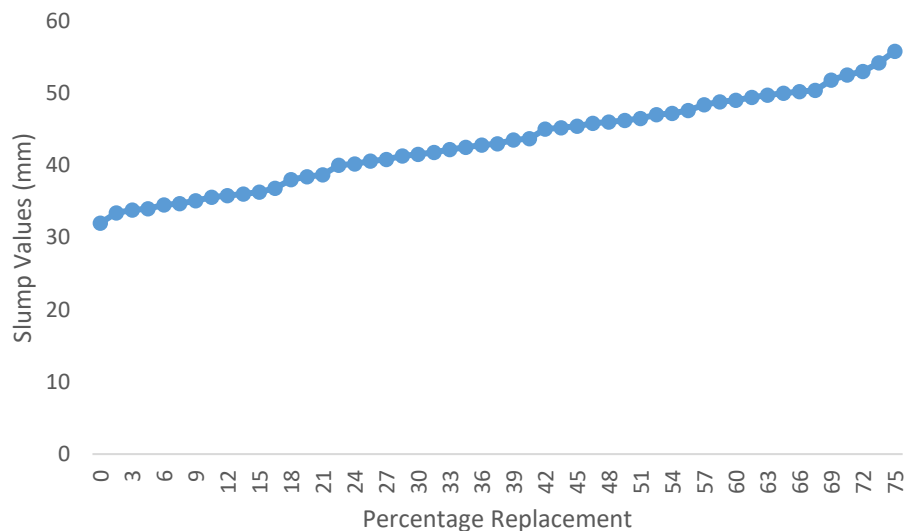
Sieve size (mm)	Mass of sand passing (g)	Mass of sand retained (g)	% passing
4.75	950	0	100
2.36	924.5	25.50	97.32
1.18	878.69	45.81	92.50
0.850	800.05	78.64	84.22
0.6	517.27	282.78	54.45
0.425	368.28	148.99	38.77
0.3	97.74	270.54	10.29
0.212	27.97	69.77	2.95
0.15	11.73	16.24	1.24
0.075	2.83	8.90	0.30
Pan	0	2.83	0
Total		950	

**Table 4.** Particle size distribution of Ishiagu granite chippings

Sieve size (mm)	Mass of granite passing (g)	Mass of granite retained (g)	% passing
31.5	3200	0	100
22.4	3118.78	81.22	97.46
19	2675.83	442.95	83.62
16	1697.87	977.96	53.06
12.5	803.72	894.15	25.12
9.5	354.21	449.51	11.07
6.3	57.41	296.80	1.79
04.75	14.74	42.67	0.46
Pan	0	14.74	0
Total		3200	

### 3.2 Workability of NCPA-concrete

The slumps of NCPA replaced mixes at different replacement levels were shown in Figure 1. The values obtained from the slump test correspond to the designed slump range of 30 - 60mm. It is observed from Figure 1, that the workability increased with increased replacement. This outcome was consistent with that of Le and Ludwig (2016). The improved workability is attributed to the filler effect of NCPA between aggregates and cement particles which reduces friction between particles and facilitates a better concrete flow. In line with Abram's law of water-cement ratio (Kamau *et al.*, 2016), the possibility of optimizing strength using less water in NCPA-concrete is highlighted.

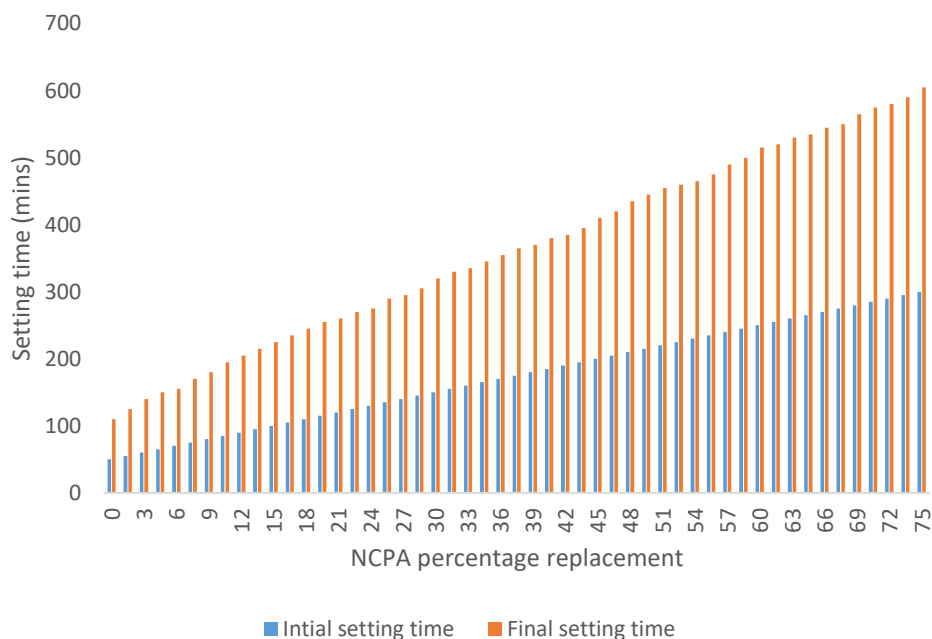


**Figure 1:** Workability of NCPA-Concrete mixes

### 3.3 Setting Time

It is observed from Figure 2, that the initial and final setting times increases as the NCPA replacement percentage increases, thereby retarding the hydration process. This implies that NCPA concrete is not susceptible to the problem of false set. This is due to reduction in the

strength-forming compounds,  $C_3S$ ,  $C_2S$ , and  $C_3A$  in the cement paste. This increased setting times become advantageous while concreting in hot weather. The results obtained satisfied the prescriptions of ASTM C 150-94.

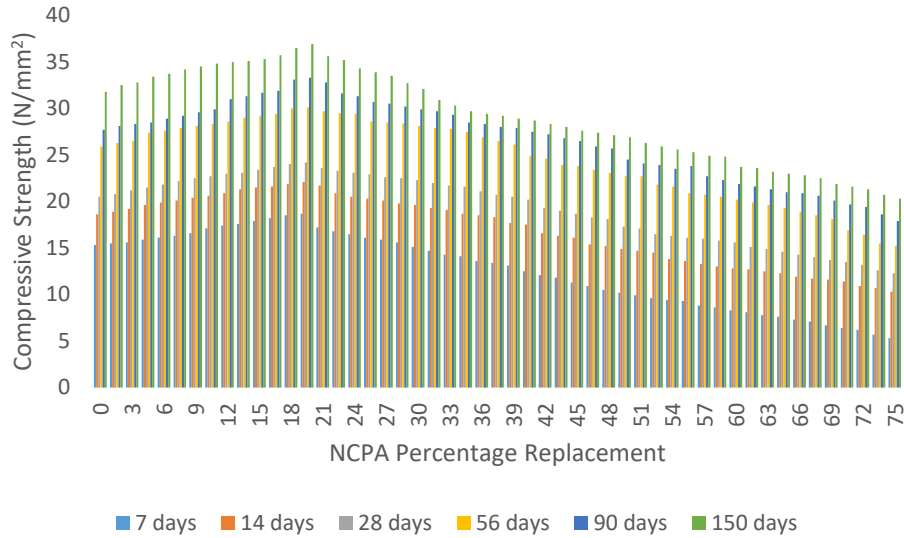


**Figure 2:** Setting time of NCPA-concrete

### 3.4 Effect of NCPA on Compressive Strength

The compressive strengths of the concrete samples cured for 7, 14, 28, 56, 90 and 150 days were presented in Figure 3. The result showed that the compressive strength increased as the percentage replacement of the Portland cement with nanostructured cassava peel ash (NCPA) increased and as the curing age increased. From the Figure 4, it can be seen that inclusion of NCPA in concrete mix is very effective in increasing the compressive strength of concrete. This could be attributed to silica ( $SiO_2$ ) and alumina ( $Al_2O_3$ ) of NCPA content being larger than those of OPC as indicated in Table I. The increasing strength is also traceable to the formation of strengthening gel (C-S-H) and bond (C-A-H) occurring from the reaction of NCPA's silica and alumina elements with the hydrating agents of OPC (Khan *et al.*, 2014). It can be seen that the compressive strength increases up to 19.5% replacement of cement with NCPA.

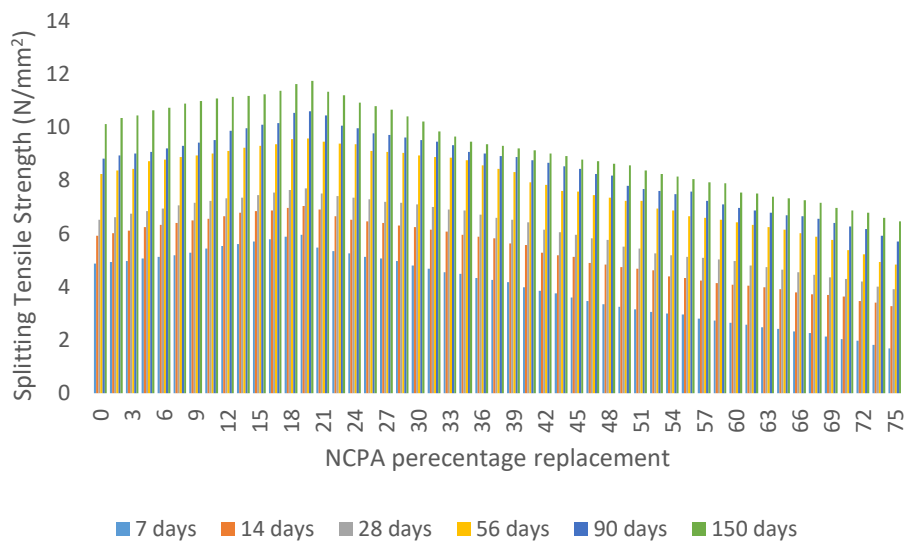
The addition of this nanomaterial (NCPA) to the concrete helped to fill the pores existing in the matrix in order to provide an exceptional surface area to volume ratio, improved basic property and reactivity of the material. This in turn enhanced the strength of the concrete. The strength improvement is believed to continue as long as the curing period is prolonged to allow completion of hydration. The optimum compressive strength of  $36.90 \text{ N/mm}^2$  was achieved at 19.5% replacement at 150 days of age.



**Figure 3:** Compressive Strength of NCPA-Cement Concrete with varying curing days.

### 3.5 Effect of NCPA on Splitting Tensile Strength

Figure 4 present the splitting tensile strengths of the concrete at 7, 14, 28, 56, 90 and 150 curing age. It is observed that the tensile strength of the concrete is much lower than its compressive strength. For each percentage replacement interval, as the curing days increased, the compressive strengths increased more slowly than the splitting tensile strengths. This is because the splitting tensile strength increases more slowly than the compressive strength so that the ratio  $f_t/f_c$  decreases with time (Neville, 2011). The distinguishing feature between NCPA and other SCMs was clearly shown in Figure 4. Above 20% NCPA replacement, the tensile strength of NCPA-concrete decreased with increasing NCPA replacement as shown Figure 4, consistent with the character of SCMs (Sengul and Tasdemir, 2009; Sumer, 2012).



**Figure 4:** Splitting tensile strength of NCPA-Cement Concrete with varying curing days.

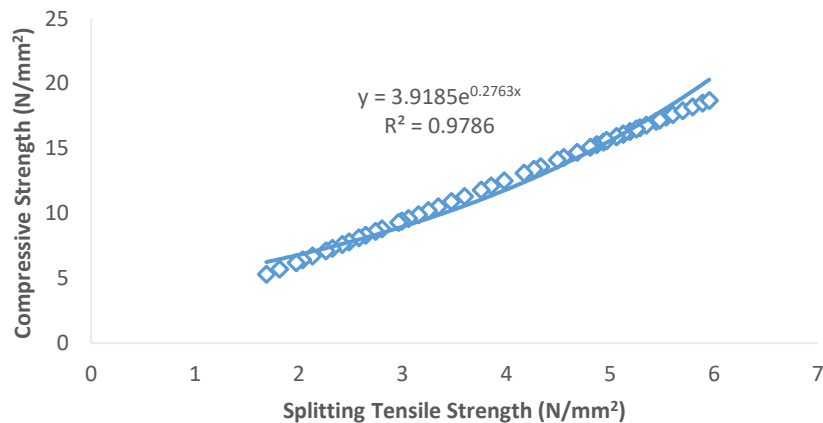
Figures 5-10 indicate that the values of the coefficient of determination  $R^2$  obtained from the regression analysis is quite large (least being 0.9786) for concrete made with NCPA at all the



percentage replacement. That is, approximately 97% and above of the test data correlated to the regression equations. This suggests a strong relationship of the models for NCPA-cement concrete.

The plot in Figure 5, indicates the steepness of the line of fit which is the curved line that best predicts the data sets provided. The exponential equation for the compressive strength response of the NCPA-concrete is presented in equation 3. It was observed that the compressive strength of the concrete was directly proportional to the splitting tensile strength.

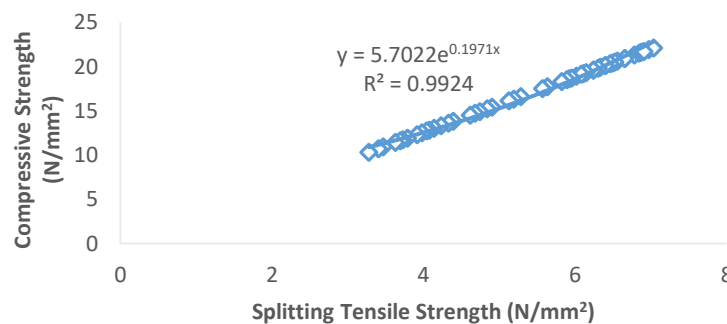
$$Y = 3.9185e^{0.2763x} \tag{3}$$



**Figure 5:** Relationship between the splitting tensile and compressive strengths of NCPA-cement concrete at 7 curing days.

The graph in Figure 6 captured the variation of splitting tensile strength with compressive strength of OPC-NCPA-concrete. It was observed that as the compressive strength increased, the splitting tensile strength increased too. The exponential relationship between these strengths were shown in equation 4.

$$Y = 5.7022e^{0.1971x} \tag{4}$$

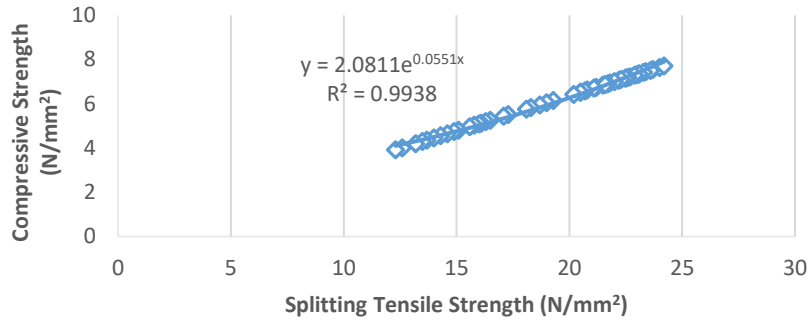


**Figure 6:** Relationship between the splitting tensile and compressive strengths of NCPA-cement concrete at 14 curing days.

Figure 7 presented a graphical illustration of the alliance between compressive strength and tensile strength of the concrete specimen after 28 days' period of curing. The line of fit was

almost a straight line and the coefficient of determination  $R^2$  was very close to 1. The exponential relationship for the concrete strength properties is given in equation 5. The least exponential coefficient for the variations was found to 2.1

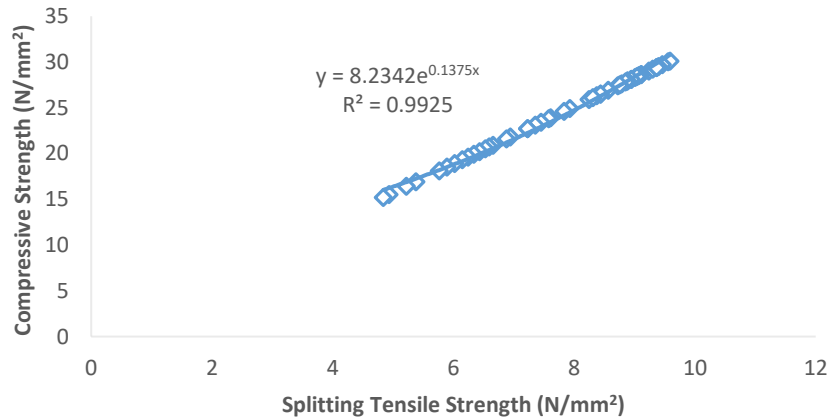
$$Y = 2.0811e^{0.0551x} \quad (5)$$



**Figure 7:** Relationship between the splitting tensile and compressive strengths of NCPA-cement concrete at 28 curing days.

The splitting tensile strength of the nanosized concrete cured for 56 days, varied directly to the compressive strength behaviour as shown in Figure 8. The exponential equation of the varied strengths is represented in equation 6. As compressive strength increased, the tensile strength advanced.

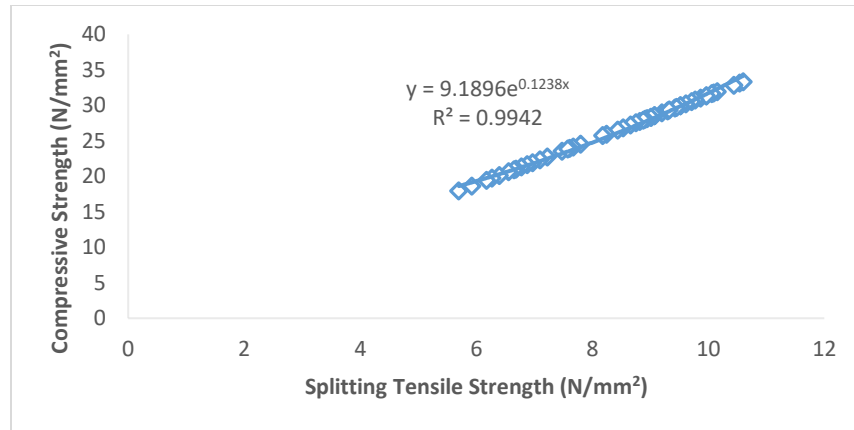
$$Y = 8.2342e^{0.1375x} \quad (6)$$



**Figure 8:** Relationship between the splitting tensile and compressive strengths of NCPA-cement concrete at 56 curing days.

At 90 days curing, it was observed in Figure 9, that the higher the splitting tensile strength, the more the compressive strength. The relationship between these concrete parameters were captured in equation 7.

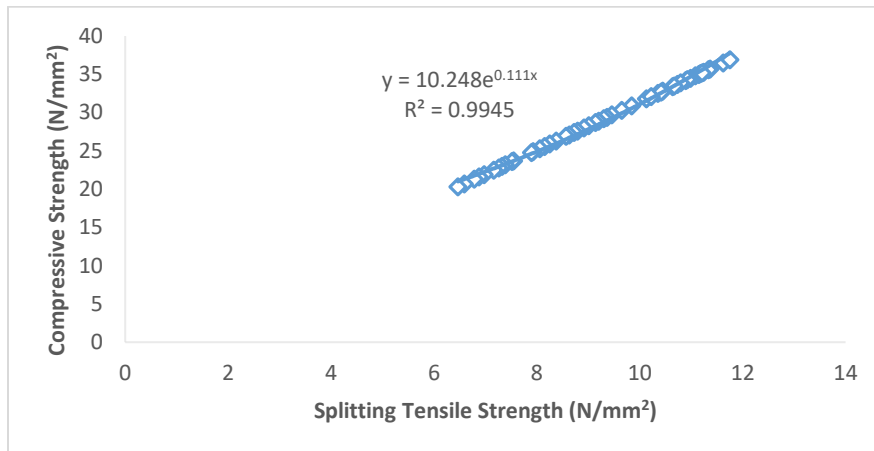
$$Y = 9.1896e^{0.1238x} \quad (7)$$



**Figure 9:** Relationship between the splitting tensile and compressive strengths of NCPA-cement concrete at 90 curing days.

The graph in Figure 10 captured the variation of splitting tensile strength with compressive strength of OPC-NCPA-concrete. It was observed that as the compressive strength increased, the splitting tensile strength increased too. The exponential relationship between these strengths were shown in equation 8.

$$Y = 10.248e^{0.111x} \quad (8)$$



**Figure 10:** Relationship between the splitting tensile and compressive strengths of NCPA-cement concrete at 150 curing days.

#### 4. Conclusion

The following conclusions were drawn from the outcome of the analysis done in this study.

- i. The workability of the NCPA-concrete increases with increase in NCPA content, hence, less water is required to achieve a workable mix.
- ii. NCPA can be used with replacements of up to 20% to achieve optimum strengths.
- iii. The exponential trends lines can be accepted to reliably express the relationship between the compressive strength and splitting tensile strength of NCPA-concrete samples at all the water/cement ratios considered.

- iv. Utilisation of NCPA in the construction industry could help in addressing the general construction cost and mitigate the technical and environmental nuisance associated with cement production. It could also reduce solid waste, conserve existing natural resources, thereby enhancing sustainability as well as improving the characteristics of fresh and hardened concrete.

## **References.**

Abdulwahab, MT., and Uche OAU., 2021. Durability Properties of Self-Compacting Concrete (SCC) Incorporating Cassava Peel Ash (CPA). *Nigerian Journal of Technology (NIJOTECH)*, 40(4): 584-590. <http://dx.doi.org/10.4314/njt.v40i4.4>.

ASTM C 618. 2008. Specification for coal fly ash and raw or calcined natural pozzolanas for use as mineral admixtures in Ordinary Portland Cement Concrete. Annual book of ASTM standards, West Conshohocken, USA.

Attah, IC., Etim, RK., Alaneme, GU., and Bassey, OB. 2020. Optimization of mechanical properties of rice husk ash concrete using Scheffe's theory. *SN Applied Sciences*, 2: 928-941 <https://doi.org/10.1007/s42452-020-2727-y>.

Awodiji, CTG., Onwuka, DO, Okere, C E, and Ibearugbulem OM. 2018. Anticipating the Compressive Strength of Hydrated Lime Cement Concrete Using Artificial Neural Network Model. *Civil Engineering Journal*, 4(12): 3005-3018. <http://dx.doi.org/10.28991/cej-03091216>.

BS 12, 1996, Specification for Portland cement, British Standards Institution, London.

BS 12390-6, 2009, Testing Hardened Concrete: Tensile Splitting Strength of Test Specimens. British Standard Institution, London.

BS 1881, 1983, Testing concrete: Method for determination of compressive strength of concrete, British Standards Institution, London.

BS 3140, 1980, Methods of Test for Water for Making Concrete, Including Notes on the Suitability of the Water, British Standards Institution, London.

BS 882, 1992, Specification for aggregates from natural sources for concrete, British Standards Institution, London.

BS EN 12390-3, 2009, Testing Hardened Concrete: Compressive Strength of Test Specimens. British Standard Institution, London.

Ettu, LO, Ezech, JC., Ibearugbulem, OM., Anya, UC., and Njoku, KO. 2013. Strength of Binary Blended Cement Composites Containing Cassava Waste Ash. *International Journal of Emerging Technology and Advanced Engineering*, 3(4): 15-20.

George, UA. and Elvis, M. 2019. Modelling of the mechanical properties of concrete with cement ratio partially replaced by aluminum waste and sawdust ash using artificial neural network. *SN Applied Sciences*, 1: 1514-1527. <https://doi.org/10.1007/s42452-019-1504-2>.

Johnson, ME., and Gonzalez, A. 2013. Estimating cost savings for aviation fuel and CO<sub>2</sub> emission reductions strategies. The Collegiate Aviation Review International, 31(2):1-12. <https://doi.org/10.22488/okstate.18.100513>

Iowa 2020. Class Notes: C.C. Swan, University of Iowa: Lecture 2: Grain Size Distributions and Soil Particle Characteristics. Available online at: <http://user.engineering.uiowa.edu/~swan/courses/53030/notes/gsd.pdf>.

Kamau, J., Ahmed, A., Hirst, P., Kangwa, J. 2016. Suitability of corncob ash as a supplementary cementitious material. International Journal of Materials Science and Engineering, 4(4): 215–228. doi:10.17706/ijmse.2016.4.4.215-228.

Khan, R., Jabbar, A., Ahmad I., Khan, W., Khan, A. N., and Mirza, J. 2012. Reduction in environmental problems using rice-husk ash in concrete. Construction and Building Materials, 30: 360-365.

Khan SU, Nuruddin, MF., Ayub, T., Shafiq, N. 2014. Effects of Different Mineral Admixtures on the Properties of Fresh Concrete. The Scientific World Journal, 14: 1-11. <https://doi.org/10.1155/2014/986567>.

Le, HT. and Ludwig, HM. 2016. Effect of rice husk ash and other mineral admixtures on properties of self-compacting high-performance concrete. Materials & Design, 89: 156-166.

Mehta, PK. 2001. Reducing the environmental impact of concrete. Concrete International, 23: 61-66.

Neville, AM. 2011. Properties of Concrete. 5th Edition, Pearson International, London, UK.

Nwa-David, CD., Onwuka, DO., Njoku, FC., Ibearugbulem, OM. 2023a. Prediction of Fresh and Hardened Properties of Concrete Containing Nanostructured Cassava Peel Ash Using Ibearugbulem's Approach. Engineering and Technology Journal, 41(5): 1-14, <http://doi.org/10.30684/etj.2023.138099.1374>.

Nwa-David, CD., and Ibearugbulem, OM. 2023b. Model for Prediction and Optimization of Compressive Strengths of Cement Composites using Nanostructured Cassava Peel Ash as Partial Replacement of the Binder. Nigerian Research Journal of Engineering and Environmental Sciences, 8(1): 82-91. <http://doi.org/10.5281/zenodo.8094024>.

Ofuyatan, O., Ede, A., Olofinnade, R., Oyebisi, S., Alayande, T., and Ogundipe, J. 2018, Assessment of Strength Properties of Cassava Peel Ash-Concrete. International Journal of Civil Engineering and Technology (IJCIET), 9(1): 965–974.

Ogbonna, C., Mbadike, E., and Alaneme, G. 2020. Characterisation and use of cassava peel ash in concrete production. Computational Engineering and Physical Modeling, 3(2): 11–20. <https://doi.org/10.22115/Cepm.2020.223035.1091>.

Olonade, KA., Olajumoke, AM., Omotosho, AO., and Oyekunle, FA. 2014. Effects of sulphuric acid on the compressive strength of blended cement cassava peel ash concrete. *Construction Materials and Structures*, 14(4): 764-771. doi:10.3233/978-1-61499-466-4-764.

Olutoge FA., Oriyomi, MO., & Olatunji, SO. 2012. Assessment of the suitability of periwinkle shell ash (PSA) as partial replacement for ordinary Portland cement (OPC) in concrete. *International Journal of Research and Reviews in Applied Sciences*, 10(3): 428–434.

Onwuka, DO., Anyaogu, L., Chijioke, C., Okoye, PC. 2013. Prediction and optimization of compressive strength of sawdust ash-cement concrete using scheffe's simplex design. *International Journal of Scientific and Research Publications*, 3(5):1-9

Prasad M. 2017, A Review on Nano Materials in Concrete, *Civil Engineering Research Journal*, 2(2): 555581, Doi: 10.19080/CERJ.2017.02.555581.

Raheem, SB., Arubike, ED., and Awogboro, OS. 2015. Effects of Cassava Peel Ash (CPA) as Alternative Binder in Concrete, *International Journal of Constructive Research in Civil Engineering (IJCRCE)*, 1(2): 27-32.

Salau MA, Ikponmwosa EE., Olonode KA. 2012. Structural Strength Characteristics of Cement-Cassava Peel Ash Blended Concrete. *Civil and Environmental Research*, 2(10): 68-78.

Sanchez, F., Sobolev, K. 2010. Nanotechnology in concrete – A review, *Construction and Building Materials*, 24: 2060–2071. doi: 10.1016/j.conbuildmat.2010.03.014.

Sengul, O., and Tasdemir, M. A. 2009. Compressive strength and rapid chloride permeability of concretes with ground fly ash and slag. *Journal of materials in civil engineering*, 21: 494-501.

Sumer, M. 2012. Compressive strength and sulfate resistance properties of concretes containing Class F and Class C fly ashes, *Construction and Building Materials*, 34: 531-536.

Thomas, BS. 2018. Green concrete partially comprised of rice husk ash as a supplementary cementitious material—a comprehensive review, *Renewable and Sustainable Energy Reviews*, 82: 3913–3923.

Zareei, SA., Ameri, F., Dorostkar, F., and Ahmadi, M. 2017. Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: evaluating durability and mechanical properties. *Case Studies in Construction Materials*, 7:73–81