

UNIOSUN Journal of Engineering and Environmental Sciences. Vol. 1, No. 1. March 2019

DOI: 10.36108/ujees/9102.10.0170

Effect of Partial Replacement of Cement with NBRRI Pozzolan on the Mechanical Properties of Concrete

Olawale S. O. A., Tijani M. A., Kareem M. A. and Alabi O.

Abstract: The cost of cement has been on a steady increase in Nigeria making it difficult for mass housing developments. The possibility of this price hike abating is not envisaged under the current socio-economic situation in the country. One of the ways to reduce dependence on cement in construction of houses is the partial replacement of cement with pozzolanic material which are readily available with little or no cost such as the one developed by Nigeria Building and Road Research Institute (NBRRI). This study inspected the mechanical attributes of concrete made with fractional replacement of cement with NBRRI pozzolan. Concrete mix, 1:1.5:3 was designed for all specimens with w/c of 0.45. NBRRI pozzolan (0%, 3%, 6%, 9%, 12% and 15%) by weight of cement were used for concrete production. The mechanical properties were measured at 7, 14, 21 and 28 days. It was obtained from the results that workability of concrete reduces from 62.5 to 50.5 mm as the percentage of NBRRI pozzolan increases from 0 - 15% respectively. The 28-day compressive, split tensile and flexural strengths of concrete at 12% replacement of cement by NBRRI pozzolan (30.92, 3.11 and 5.48 N/mm²) were found to be comparable to control (34.93, 3.2 and 5.12 N/mm²). It is concluded that 12% replacement of cement by NBRRI pozzolan in concrete (at 28-day curing) will reduce the amount of cement, decrease the cost of concrete production and give desired strength.

Keywords: Pozzolan, Cement, Concrete, Mechanical properties, NBRRI: Nigerian Building and Road Research Institute.

I. Introduction

The main factor that contributes to rising cost of buildings in developing countries such as Nigeria is high cost of cement [1]. It has become absolutely necessary to find ways of reducing the cement content of concrete without compromising safety. Many scholars and organisations alike have embarked on solving this problem. Notable among such organisation in Nigeria is The Nigeria Building and Road Research Institute (NBRRI), a Governmental Institute in Nigeria, responsible

Olawale S. O. A., Tijani M. A., Kareem M. A. (Department of Civil Engineering, Osun State University, Osogbo, Nigeria.)

Alabi O. (Department of Physics, Osun State University,

Alabi O. (Department of Physics, Osun State University Osogbo, Nigeria.)

Corresponding author's email address: murtadha.tijani@uniosun.edu.ng

for researching and developing road and building materials for the benefit of Nigerians. In the course of their research works, the institute developed a pozzolanic material called NBRRI pozzolan. This pozzolan was produced from abundantly locally available clayey material. Although, there have been some efforts to characterise the material, however, little or nothing have been done in the field of partial replacement of cement with NBRRI pozzolan in concrete.

Concrete is the worlds most consumed artificial material. Many researchers have confirmed the use of pozzolans such as sorghum husk ash, rice husk ash and palm oil fuel ash as suitable for improving the mechanical properties of concrete whilst decreasing the amount of cement required and

the resulting CO₂ emission [2], [3], [4], [5]. The amounts of carbon dioxide produced in concrete is predominantly a function of the cement content in the mix designs [6].

According to [7] aggregates, water and other constituents make up approximately 90% of the concrete blend by mass. The manner of quarrying aggregates, mixing the materials in a concrete plant and moving concrete to the construction site requires very little energy and therefore only discharges a fairly minor into quantity of carbon dioxide atmosphere. Reducing the quantity of cement used in concrete production is one of the ways to encourage a sustainable construction. Crow [8] suggested the development of concrete additives that can produce a tougher and extra practicable concrete while dropping the quantity of cement needed and the subsequent carbon dioxide emissions.Malhotra [9] also propose the reduced usage of cement in concrete by the adoption of blended and pozzolanic cements.

ASTM [10] stated that pozzolanas are siliceous and aluminous material that normally have little cementitous characteristics but in finely distributed form, in the existence of dampness can react with calcium hydroxide that liberated during the hydration of cement to form compounds having cementitous attributes. The use of pozzolanas with ordinary Portland cement enhance the properties of mortal and concrete at a well reduced cost of production [11]. The advantages of pozzolans in concrete include improved workability; improved resistance to sulphate attack; improved resistance to freezing and thawing; increased concrete bonding strength; increased longterm strength; reduced water content of mortar concrete mixes; increased advantage in hot weather concreting; decreased permeability and water tightness; and reduced resistance to alkaline-aggregate reactions [2], [12]. Many Nigerian researchers have established the fitness of agricultural and construction wastes as pozzolanic materials that can enhance the strength and reduces the expansion of concrete while lowering the CO₂ emission [3], [4], [5].

This study, aimed at reducing the cost of concrete as well as environmental pollution due to cement production, investigated the effect of partial replacement of cement with NBRRI pozzolan on mechanical properties of concrete.

II Materials And Methods

A. Materials

The materials used for this study were locally sourced so as to replicate the near condition of operation in the construction industry in Nigeria. The materials used are cement, coarse and fine aggregates, NBRRI pozzolan and water.

C. Cement

The cement used was Portland cement (Dangote brand) purchased in Osogbo which is in accordance with [13].

D. Aggregates

Both fine and coarse aggregates were obtained from the stockpile of rubbles on the ongoing construction site at Osun State University, Osogbo and they were air dried before the sieve analysis was carried out in accordance with [14].

E. Water

Water which is equally suitable for human consumption gotten from the Departmental Laboratory of the Osun State University was used for mixing and curing of specimens. The water conformed to the requirement of [15].

F. NBRRI pozzolan

Different kinds of locally manufactured NBRRI pozzolan available include Ifenitedo, Calcined clay, ImotoYewa and Raw clay. The pozzolan used in this study was raw clay obtained from NBRRI pilot plant located at Idiroko, Ogun State, Nigeria. The chemical composition of NBRRI pozzolan are presented in Table 1.

III Methods

A. Experimental Procedure

Sieve analysis was carried out on the samples of fine and coarse aggregates utilized for the study. M30 grade concrete was considered appropriate for the purpose of experimental work. The original mix was 1:1.5:3 and 0.45 water-cement ratio. NBRRI pozzolan (0%, 3%, 6%, 9%, 12% and 15%) by weight of cement were used for concrete production. The slump test was carried out on fresh concrete samples determine to workability. Mechanical properties (compressive, tensile and flexural strength) were measured at 7, 14, 21 and 28 days of curing.

B. Sieve Analysis

Materials were prepared and weighed accordingly; the sieves were arranged in descending order with the largest sieve size opening at the top and the pan at the bottom, pouring the aggregate at the top and shaking thoroughly, determining individual weights to the nearest 0.1g of aggregate retained on each sieve. The sieve apertures used for fine aggregates were 2.36, 1.18, 0.60, 0.30, 0.15 and 0.075mm while that of coarse aggregates include 37.5, 20, 14, 10 and 4.5mm.

C. Slump test

Slump test is an in situ test used to determine how hard and consistent a given sample of concrete is before casting and curing. The workability of fresh concrete with NBRRI pozzolan as partial substitutes of cement was determined in accordance with [17].

D. Compressive strength test

The compressive strength was determined according to [18]. 3-samples were tested and the average strengths were compared to mix M30 grade. In total, 72-cubes of size 150 x 150 x 150 mm were cast and tested at 7, 14, 21 and 28 days of curing for 0, 3, 6, 9, 12, and 15% NBRRI pozzolan replacement of cement in concrete. The test cubes were made in agreement with [19]. Figure 1 shows the compressive strength arrangement.

Table 1: Chemical Composition of Materials of NBRRI Pozzolan

Sample	CaO%	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	MgO%	SO ₃ %	Na ₂ O%	K ₂ O%	LOI%
Ifenitedo	0.5	55.03	24.51	2.17	0.24	0.03	0.04	0.18	15.29
Calcined clay	2.57	65.45	19.07	6.38	0.6	0.13	0.85	0.19	2.2
Imoto Yewa	0.48	63.36	16.36	5.44	0.4	0.04	0.58	0.1	9.78
Raw clay	0.53	56.28	18.84	6.08	0.58	0.08	0.92	0.15	12.48

Source: [16]



Figure 1: Compressive strength test setup.



Figure 2: Split tensile strength test setup



Figure 3. Flexural Strength Test Setup

E. Split tensile strength test

The split tensile strength of concrete were determined by casting cylinder of size 150 x 300 mm and cured for 7, 14, 21 and 28 days. A total of 72 specimens were cast for M30 grade and for 0, 3, 6, 9, 12, and 15% NBRRI pozzolan replacement of cement in concrete. For each mix 3 samples were tested and the average values were taken as tensile strength of

concrete. The test was carried out according to [20] and the arrangement is shown in Figure 2.

F. Flexural strength test

Flexural strength was carried out in agreement with the procedure of [21]. It is measured by loading $150 \times 150 \times 700$ mm concrete beams which is a span length of at least three times the depth. The test setup is shown in Figure 3.

IV. Results And Discussion

A. Sieve Analysis

Figures 4 and 5 showed the results of particle size distribution for fine and coarse aggregates. It can be seen from the figures that both the fine and coarse aggregates are uniformly graded, conform to near single sized particles and satisfy the requirements of [22]

B. Slump test

Table 2 shows the decreasing of the slump with the increasing content replacement of Ordinary Portland Cement (OPC) with NBRRI pozzolan. This demonstrates that the more the replacement of cement the more the quantity of water required to improve the workability of the concrete. However, the rate of steady decrease in the slump with increasing amount of NBBRI pozzolan is not large to warrant change of water—cement ratio. The decrease in slump with increase in NBRRI pozzolan content may be attributed to its high specific surface area and high carbon content as noted by [23].

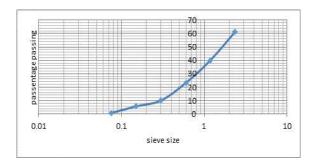


Figure 4: Curve of Sieve Analysis of Fine Aggregate

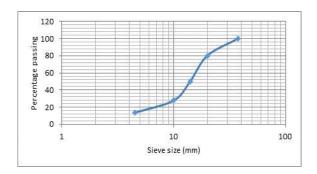


Figure 5: Curve of Sieve Analysis for Coarse Aggregate

C. Compressive strength

The result of the compressive strength tests are presented in Table 3. The compressive strength increases as the percentage of NBRRI pozzolan increases up to 12% and finally declined at 15%. However, the compressive strength increased as the number of days of curing increased for each percentage of NBRRI pozzolan replacement. It can be seen from the Table 3 that for the control cube of 0% replacement, the compressive strength increased from 23.49 N/mm² at 7 days to 34.93 N/mm² at 28 days (i.e about 49% increment). The 28 day strength was above the specified value of 30 N/mm² for M30 concrete specified by [24].

compressive strength of the replacement is observed to be between 15.62 N/mm² at 7 days and 26.16 N/mm² at 28 days (68% increment). The same trend is observed for all other replacements. The optimum compressive strength at 12% replacement is between 21.85 N/mm² at 7 days and 30.92 N/mm² at 28 days (42% increment). The 28 day strength is above the specified value of 30 N/mm^2 for M30 Further concrete. replacement above 12% shows decline in the compressive strength. The result implies that NBRRI pozzolan replacement at 9 and 12% gave satisfactory compressive strength requirement.

D. Split tensile strength

The results of tensile strength are presented in Table 4. The replacement of cement by NBRRI pozzolan resulted to a reduction in the tensile strength of the concrete mixes at all percentages when compared with control. However, the tensile strength increased as the number of days of curing increased for each percentage of NBRRI pozzolan replacement. The optimum values for 7, 14 21 and 28 day tensile strength were observed at 12% replacement which is marginally lower than control specimen as shown in Table 4. This suggests that NBRRI pozzolan does not increase the concrete cracking due to the tension failure at optimum replacement level.

D. Split tensile strength

The results of tensile strength are presented in Table 4. The replacement of cement by NBRRI pozzolan resulted to a reduction in the tensile strength of the concrete mixes at all

Table 2: Slump of Fresh Concrete

% Replacement	Slump Test (mm)
0% NBRRI, 100% OPC	62.5
3% NBRRI, 97% OPC	61.0
6% NBRRI, 94% OPC	59.5
9% NBRRI, 91% OPC	57.5
12% NBRRI, 88% OPC	54.0
15% NBRRI, 85% OPC	50.5

Table 3: Compressive strength

% Replacement	Compressive Strength (N/mm²)			
	7 DAYS	14 DAYS	21 DAYS	28 DAYS
0%NBRRI	23.49	25.63	31.45	34.93
3% NBRRI	15.62	21.76	24.95	26.16
6% NBRRI	19.01	23.67	25.60	27.47
9% NBRRI	21.30	26.30	28.12	30.57
12% NBRRI	21.85	26.56	28.75	30.92
15% NBRRI	19.79	21.31	25.78	26.60

Table 4: Split tensile strength

% Replacement	Split Tensile Strength (N/mm2)				
	7 DAYS	14 DAYS	21 DAYS	28 DAYS	
0%NBRRI	2.34	2.52	2.63	3.20	
3% NBRRI	1.98	2.30	2.53	2.68	
6% NBRRI	2.11	2.36	2.58	2.77	
9% NBRRI	2.24	2.50	2.66	2.94	
12% NBRRI	2.40	2.64	2.79	3.11	
15% NBRRI	2.36	2.58	2.66	2.88	

Table 5: Flexural Strength

	Flexural Strength Test (N/mm²)			
% Replacement	28 DAYS			
0% NBRRI	5.12			
3% NBRRI	3.08			
6% NBRRI	4.08			
9% NBRRI	5.40			
12% NBRRI	5.48			
15% NBRRI	4.84			

percentages when compared with control. However, the tensile strength increased as the number of days of curing increased for each percentage of NBRRI pozzolan replacement. The optimum values for 7, 14 21 and 28 day tensile strength were observed at 12% replacement which is marginally lower than control specimen as shown in Table 4. This suggests that NBRRI pozzolan does not increase the concrete cracking due to the tension failure at optimum replacement level.

E. Flexural Strength

The result of flexural strength test is shown in Table 5. The Modulus of Rupture which is a measure of flexural strength reduced from 5.12 N/mm² to 3.08 and 4.08 N/mm² when 3% and 6% of NBRRI pozzolan were added. With further addition of the pozzolan at 9 and 12%, the values of flexural strength slightly increased above the control. However, a flexural strength of 4.84 N/mm² was achieved for 15% NBRRI pozzolan content. From Table 8, it is evident that the optimum flexural strength which is slightly higher than the control was recorded at 12% NBRRI pozzolan content. This suggests that NBRRI pozzolan reduced the brittleness of concrete at optimum replacement level.

V. Conclusion

The purpose of this research was to investigate the effect of partial replacement of cement with NBRRI pozzolan on mechanical properties of concrete in order to reduce the cost of concrete production as well as environmental pollution due to cement production. Concrete mix, 1:1.5:3 designed for all specimens with w/c of 0.45. NBRRI pozzolan (0%, 3%, 6%, 9%, 12% and 15%) by weight of cement were used for concrete production. The slump test was carried out on fresh concrete samples to determine workability. Mechanical properties (compressive, tensile and flexural strength) were measured at 7, 14, 21 and 28 days of curing.

It was observed that workability of concrete reduces slightly as percentage of NBRRI pozzolan increases. The 28-day compressive, split tensile and flexural strengths of concrete at 12% replacement of cement by NBRRI pozzolan (30.92, 3.11 and 5.48 N/mm²) were

found to be comparable to control (34.93, 3.2 and 5.12 N/mm²). It is concluded that 12% replacement of cement by NBRRI pozzolan in concrete will reduce the amount of cement, decrease the cost of concrete production and give desired strength.

References

- [1] Williams, F. N., Anum, I., Isa, R. B. and Aliyu, M. "Properties of Sorghum Husk Ash Blended Cement Laterized Concrete", *International Journal of Research in Management, Science and Technology*, Vol. 2, Number 2, 2014, pp 73 79.
- [2] Tijani, M. A., Ogunlade, C. A., Ajagbe, W. O., Olawale, S. O. A., Akinleye, M. T. and Afolayan, O. D. "Development of Green Concrete Using Agricultural and Construction Wastes in Nigeria: A Review", Adeleke University Journal of Engineering and Technology, Vol. 1, Number 1, 2018, pp 40-50.
- [3] Oyejobi, D. O., Abdulkadir, T. S. and Ahmed, A. T. "A Study of Partial Replacement of Cement with Palm Oil Fuel Ash in Concrete Production", *International Journal of Agricultural Technology*, Vol. 12, Number 4, 2018, pp619-631.
- [4] Raheem, A. A. and Kareem, M. A. "Chemical Composition and Physical Characteristics of Rice Husk Ash Blended Cement", *International Journal of Engineering Research in Africa*, Vol. 32, 2017, pp 25-35.
- [5] Tijani, M. A., Ajagbe, W. O. and Agbede, O. A. "Recycling Wastes for Sustainable Pervious Concrete Production", *Proceedings of the 17th National Conference of the Nigeria Institution of Environmental Engineers*(NIEE),Ogba, Lagos Nigeria, October 25, 2018, pp 1-7.
- [6] Mehta, P. K. and Monteiro, P. J. M. Concrete: Microstructure, Properties, and Materials. http://www.ce.berkeley.edu/~paulmont/CE 60New/Concrete%20and%20the%20Environment.pdf of the vital major construction primary materials is cement. (19th August 2017).

- [7] National Ready Mixed Concrete Association (NRMCA). Concrete Carbon Dioxide Fact Sheet. National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, MD 20910, 888-84-NRMCA. USA, 2012.
- [8] Crow, J. M. *The concrete conundrum*, 2008 http://www.rsc.org/images/Construction_tc m18-114530.pdf.
- [9] Malhotra, V. M. "Role of supplementary cementing materials and superplasticizers in reducing greenhouse gas emissions. Proceedings of International Conference on Fiber Reinforced Composites (ICFRC), High-Performance Concrete, and Smart Materials, Indian Institute of Technology, Chennai, India, 2004, pp 489– 499.
- [10] ASTM C 618 "Specification for coal fly ash and raw or calcined natural pozzolanas for use as a mineral admixtures in Portland cement concrete, Annual book of ASTM standards, USA, 2008.
- [11] Neville, A. M. *Properties of concrete*, Fourth edition, Pearson Education, Singapore, 2003.
- [12] Tijani, M. A., Ajagbe, W. O. and Agbede, O. A. "Modelling the Effect of Burning Temperature and Time on Chemical Composition of Sorghum Husk Ash for Optimum Pozzolanic Activity", Journal of Engineering and Engineering Technology (FUTAJEET), Vol. 12, Number 2, 2018, pp 273 281.
- [13] BS EN 197, Part 1. Cement composition, specification and conformity criteria for common cements, British Standard Institution, London, 2011.
- [14] BS 410. Specification for Sieve Analysis, British Standard Institution, London, 1986.
- [15] BS 3148. Methods of test of water for making concrete, British Standards Institution, London, 1980.
- [16] Danladi S. M. "Roads and Building Research in Nigeria: Panacea to Nigeria's Quest for Infrastructural Development", Nigerian Academy of Engineering (NAE) 2014 Academy Lecture, Lagos – Nigeria, 2014.
- [17] BS EN 12350, Part 2. Slump test, British Standard Institution, London, 2009.

- [18] BS 1881, Part 116. Method for determination of compressive strength of concrete cubes, British Standards Institution, London, 1983.
- [19] BS1881, Part 108. Testing concrete, method for making test cubes from fresh concrete, British Standards Institution, London, 1983.
- [20] BS 1881, Part 117. Method for determination of tensile splitting strength of concrete, British Standards Institution, London, 1983.
- [21] BS 1881, Part 118. Method for determination of flexural strength of concrete, British Standards Institution, London, 1983.
- [22] BS EN 12620. Aggregate for Concrete, British Standard Institution, London, 2008.
- [23] Cordeiro, G., Filho, R. D. T. and Fairbairn, E. M. R. "Use of ultrafine rice husk ash with high carbon content as pozzolan in high performance concrete", *Materials and Structures*, Vol. 42, 2009, pp 983-992.
- [24] BS 8110 Part 1. Structural use of concrete, British Standard Institution, London, 1997.