ABUAD INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES
ISSN: 2955-1021
AIJNAS Volume 3, Issue 1, April 2023 pp 28–33
https://doi.org/10.53982/aijnas.2023.0301.06-j

https://journals.abuad.edu.ng/index.php/aijnas

AIJNAS

Experimental Research on Natural Pozzolan as Cement Replacement

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Abstract
This paper presents the properties of mortar and concrete with NBRRI pozzolan as partial replacement of cement. In this research, NBRRI pozzolan from NBRRI and local cement (Dangote) are used. Firstly, chemical composition of NBRRI pozzolan and Dangote cement are analyzed. And then the physical properties of local materials used in this research are determined according to ASTM procedure. Partial replacement percentages of pozzolan are considered 10%, 20%, 30% and 40%. The strength of mortar and concrete with NBRRI pozzolan (0%, 10%, 20%, 30%, and 40%) is tested at 7 days, 14 days and 28 days. From the trial mix design, the water-cement ratio (0.555) is obtained by using the least square method. To get target strength (4000 psi), by using water-cement ratio (0.555) and 68% of maximum aggregate size (20 mm), the concrete mix proportion (1:1.9:3) is obtained. The compressive strength of concrete with various percentages of NBRRI pozzolan at 21 days and 28 days are more than 7 days and 14 days strength. Therefore, it can be concluded that NBRRI pozzolan can be used as cement replacement material when high strength performance in structures is not required.
Keywords: *NBRRI pozzolan; physical properties; partial replacement; mortar; concrete; strength.*

INTRODUCTION

Cement is the most essential requirement in concrete mix for the constructions of structure all over the world. So, every construction in all countries needs few or much cement. However, rural area in developing countries, because of transportation difficulties and high relative cost is difficult to achieve much cement.

Recent Research (Annune *et al*, 2020; Annune *et al*, 2022), In an attempt to find an alternative building material for construction industry, they considered the use of wood ash from two different hardwoods namely: Melina wood ash and Cashew wood ash as a pozzolan in cement production. The study investigated the chemical composition (silica (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), sulphur trioxide (SO_3), sodium oxide (Na_2O) and potassium Oxide (K_2O)) of the ashes and the clinker. The production of blended cements was carried out in the factory by replacing 5- 50% by weight of Ordinary Portland Cement Clinker with the ashes during the manufacturing process. The cement without wood ash serves as the control. The physical characteristic (fineness, initial and final setting times, heat of hydration and residue on 45µm sieve), and the chemical composition of the blended cements were also investigated. It was discovered that the wood ash used in this work was suitable to be used as pozzolan and suitable to be used as raw material in cement production. The compressive strength of concrete with 20% wood ash content increased appreciably at greater number of days. The optimum replacement of cement by wood ash therefore is at 20%. All wood ash samples showed almost similar properties.

The behavior of concrete produced with pozzolanic additives in the presence of sulphate ion containing solution. Pozzolanic admixtures of micro and nano size silica and biomass ashes were used Annune *et al* (2022) in their work investigating the chemical durability of concretes produced with pozzolanic additives. Cementitious properties of pozzolanic materials and crystallization of sulphate salt in pores decrease the number of pores in the range 0.5-10-3µm.This research showed that the pozzolanic additives reduce porosity, increase density and as a consequence and also increase the chemical durability of concrete in the presence of sulphate ion containing solution.

Pozzolan

Pozzolan is defined as a siliceous and aluminous materials, which in itself possess little or no cementitious properly, but will in finely divided form and in the present of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Pozzolan can be divided into two groups: NBRRI pozzolan such as volcanic ash and diatomite, and artificial pozzolan such as claimed clay, pulverized fuel ash, and ash from burnt agricultural waste. Many plant ashes have high silica content and are therefore suitable as a pozzolan. NBRRI pozzolan mixed with lime were used in concrete construction long before the invention of Portland cement because of their contribution to the strength of concrete and mortar. Today, NBRRI pozzolan are used with Portland cement not only for strength, but also for economy and beneficial modification of certain properties of fresh and hardened Portland cement concrete. Generally, pozzolans contain 50% to 70% silica (SiO_2), 20% to 35% alumina (Al_2O_3), 3% to 10% hematite (Fe_2O_3), 2% to 7% lime (CaO), 1% to 7% magnesium oxide (MgO), and 1% to 5% potassium oxide (K_2O) (Annune et al, 2020). Chemical composition of NBRRI pozzolan is shown in Table 1. Fineness value of pozzolan is 29%. The maximum value for fineness is 34% to be used as cement replacement. The total composition percentages of silica, alumina, ferric oxide, calcium oxide and sulphur trioxide of NBRRI pozzolan are 89.08%. This test result is within the acceptable range. It conforms to the requirements of ASTM C 618-03 Class N and its appearance is yellowish color. Therefore, NBRRI pozzolan can be used as cement replacement. Then, generally the pozzolan content is limited to between 15 and 40 percent by weight of cement.

Table 1: Chemical composition of pozzolan (NBRRI)

Oxide	Content (%)		Class N Acceptable ranges
Silica (SiO2)	58.23	Total (%) 89.08	Min: 70
Alumina (Al_2O_3)	27.98		
Ferric Acid (Fe_2O_3)	2.87		
Calcium Oxide (CaO)	4.28		-
Sulphur Trioxide (SO_3)	0.32		Max: 4

Source: Annune et al (2020)

Testing of materials used in this research

In this study, chemical composition and the physical properties of Dangote cement with replacement percentage of pozzolan are tested. Then, the physical properties of fine aggregates and coarse aggregates are tested. Test results are shown in Table 2 to Table 7. The properties of the materials are within the standard limit.

Table 2: Chemical composition of local portland cement

Oxide	Content (%)	Approximate Composition Limits of Portland Cement (%)
Calcium Oxide (CaO)	61.93%	17-25
Silica (SiO_2)	20.08%	3-8
Alumina (Al_2O_3)	5.26%	0.5-6.0
Ferric Oxide (Fe_2O_3)	3.15%	60-67
Manganese Oxide (MgO)	3.39%	0.1-4.0
Sulphur Trioxide (SO_3)	2.43%	1-3
Others	1.73%	1
Loss	2.03%	2
Total	**100**	

Table 3: Physical properties of local Portland cement

Sr. No.	properties		Result value	ASTM Standard range
1	Specific gravity		3.15	3.1 to 3.25
2	Finess Modulus		6.5%	<10%
3	Normal Consistency		27%	26% to33%
4	Setting time (min)	initial	53min	<45 min
		final	142min	<375 min
5	Soundness			<10min

Table 4: Setting time of local Portland cement with replacement % of pozzolan

Replacement % of pozzolan	0%	10%	20%	30%	40%
Initial Setting Time (min)	53	72	80	85	97
Final Setting Time (min)	142	152	180	185	192

Table 5: Normal consistency and Soundness of local Portland cement with different replacement % of pozzolan

Replacement Percentage of Pozzolan	0%	10%	20%	30%	40%
Normal Consistency (%)	27%	26.5%	26%	25.5%	25.3%
Soundness (mm)	0.7	0.5	0.3	0.2	0.1

Table 6: Physical properties of fine aggregates

Sr. No.	properties	Result value	ASTM Standard range
1	Specific gravity (Kg/m^3)	2.66	2.5 to 2.9
2	Finess Modulus (µm)	2.18	2 to 3.1
3	Water Absorption (%)	1.01	<3

Table 7: Physical properties of coarse aggregates

Sr. No.	properties	Result value	ASTM Standard range
1	Specific gravity (Kg/m^3)	2.74	2.5 to 2.9
2	Finess Modulus (µm)	7.17	6 to 8
3	Water Absorption (%)	0.73	<3

Testing of mortar

Mortar is a mixture of cement and sand in a specified ratio on which the strength of the mortar depends. Mortar is a workable paste used to bind building blocks such as stones, bricks, and concrete masonry units together, fill and seal the irregular gaps between them, and sometimes add decorative colors or patterns in masonry walls. Mortar's adhesive characteristics vary, depending on the amount of water added to the mixture. Strength tests are made to check on the quality of mortar. The following tests are performed.

Compressive Strength Test

For the compressive strength test, water-cement ratio can be determined by using the flow table test. Water content for other cements is that sufficient to obtain a flow of 110 ± 5 % in 25 drops of the flow (Table 1). Table 8 shows the flow table test results of Dangote cement and with replacement percentage of NBRRI pozzolan.

Table 8: Flow of crown cement with different replacement perentages of pozzolan

Replacement Percentage of Pozzolan	Flow (%)
0%	106
10%	109.2
20%	110.6
30%	112.1
40%	114.6

According to the results of flow table test, the values of normal consistency decreases and the values of slump will be increased with the increase of replacement percentage of pozzolan. For the compressive strength test, cement and standard sand are taken in ratio of 1:2.75. Two-inch (50-mm) test cubes are compacted by tamping in two layers. The cubes are cured one day in the moulds and stripped and immersed in water until tested. The temperature of the air in the vicinity of the mixing slab, the dry materials, moulds, base plates and mixing bowl, shall be maintained between 73.5 ± 5.5°C The temperature of the mixing water, moist closet or moist room, and water in the storage tank shall be set at 73.5 ± 3.5°F. The relative humidity of the laboratory shall be not less than 50% (Abdullahi, 2006). Water-cement ratio for compressive strength test is 0.5. Compressive strength test results of mortar with various replacement percentage of pozzolan are shown in Table 9 and Figure 1 describes the comparison of these results.

Table 9: Compressive strength test of mortar with different replacement percentages of pozzolan

Replacement Percentage of Pozzolan	Compressive Strength, psi 7days	14days	28days
0	3355	4124	4383
10	2641	3285	3453
20	2513	3039	3078
30	2009	2894	2991
40	1855	2414	2419

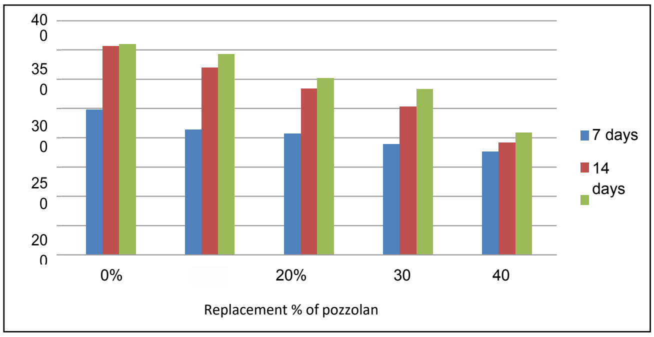

Figure 1: Comparison of compressive strengths of mortar with cement replacement percentage of pozzolan

Tensile Strength Test

The objective of this test is to determine the tensile strength of the (1:3) cement-mortar composed of the cement and fine aggregates. The percentage of water is determined by the following equation.

$Y = 2/3[p/(n+1)] + K$ (1) (Thwe win, 2016)

Where, Y = water required for the sand mortar, %

P = water required for neat cement paste of normal consistency, %

N = number of parts of sand to one of cement by weight, K = a constant which for the standard sand has the value 6.5.

Water-cement ratio for tensile strength test is 0.44. The cubes are cured one day in the moulds and stripped and immersed in water until tested. The temperature of the mixing water, moist closet or moist room, and water in the storage tank shall be set at 73.5 ± 3.5 °F (23.0 ± 2.0°C), (Abdullahi, 2006). The relative humidity of the laboratory shall be not less than 50%. The cubes are then tested under a compression testing machine after 7, 28 and 91 days of immersion. At each period interval, three cubes are tested and average tensile strength of the three is taken as the tensile strength. Tensile strength test results of mortar with various replacement percentage of pozzolan are shown in Table 10 and Figure 2 describes the comparison of these results.

Table 10: Tensile strength test of mortar with different replacement percentages of pozzolan

Replacement Percentage of Pozzolan	Tensile Strength, psi		
	7days	14days	28days
0%	248	357	360
10%	214	320	343
20%	207	284	302
30%	189	253	283
40%	176	192	209

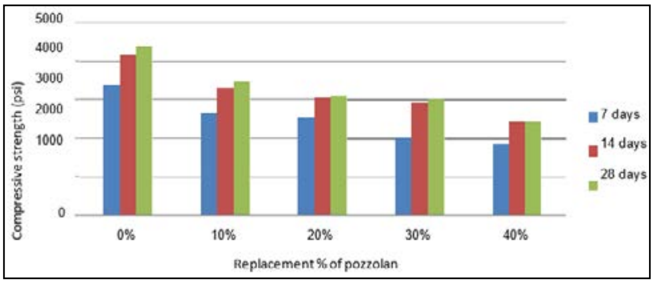

Figure 2: Comparison of tensile strengths of mortar with cement replacement percentage of pozzolan

Concrete

Concrete has been one of the most widely used building materials because of its compressive strength, resistance to water, and its ability to be easily formed and placed according to need, many advanced construction techniques and materials are required. Concrete is any product or mass made by the use of a cementing medium (Annune *et al*., 2022). Generally, this medium is the product of reaction between hydraulic cement and water. The quality of concrete depends on materials, mix design, production, transporting, placing and curing. The main constituents of concrete are cement, fine and coarse aggregates. Nowadays, concrete is made with several types of cement and also containing pozzolan, fly ash, blast-furnace slag, micro-silica, additives, recycled concrete aggregate, admixtures, polymers, fibers and so on. Pozzolan can be used as partial replacement of cement in concrete without compromising strength (Annune *et al*., 2022).

Calculation of Trial Mixes Design

The required properties of hardened concrete are specified by the designer of the structure and the properties of fresh concrete are governed by the type of construction and by the techniques of placing and transporting. These two sets of requirements make it possible to determine the composition of the mix, taking also account of the degree of control exercised on site. Mix design can, therefore, be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties, notably workability, strength and durability (Thwe Win, 2016). In order to obtain a satisfactory mix, the estimated proportions of the mix must be checked by making trial mixes and, if necessary, make appropriate adjustments to the proportions until a satisfactory mix has been obtained. The American (ACI-C211) method of mix design for normal weight aggregate concrete is used. ACI-C211 also covers heavy weight and mass concrete. In this study, calculation of trial mix design will be considered with two cases. They are 73% of max: aggregate size (25mm) and 68% of max: aggregate size (20mm) with three water-cement ratio. Batch weight per cubic yard of fresh concrete of trial mix design for desired strength 3000psi is shown in Table 11.

Table 11: Batch weight per cubic Feet of fresh concrete

Item	Coarse Aggregate 73%			Coarse Aggregate 68%		
Max agg; size	25mm			20mm		
Water-cement ratio	0.55	0.6	0.5	0.55	0.6	0.5
Water (lb/ft^3)	350	350.5	349.5	361.5	362.5	361.5
Cement (lb/ft^3)	591	543	650	613.6	562.5	675
Sand, (lb/ft^3)	1098	1146.5	1039.6	1156.8	1207	1096
Aggregate (lb/ft^3)	1971	1971	1971	1836	1836	1836
Total Weight (lb/ft^3)	4010	4010	4010	3968.3	3968	3968.5
Unit Weight of Concrete (lb/ft^3)	148.5	148.5	148.5	147	147	147

Slump of fresh concrete are determined. Strength tests are made to check on the quality of concrete. The average compressive strength of each trial mix design is tested at 7 and 28 days. The test results are shown in Table 12 and illustrated in Figure 3.

Table 12: Compressive strength of trial mix

Aggregate volume %	Water –cement ratio	Compressive strength (psi)	
		7 days	28 days
73% (max 1in size)	0.5	2807	4140
	0.55	2637	3743
	0.6	2161	3232
68% (3/4 in size)	0.5	3828	4905
	0.55	3119	3828
	0.6	2570	3516

The relation between compressive strength and water to cement ratio is calculated by using least square method and shown in Figure 3.

From the trial mix design results, it is found that the 7 days and 28 days concrete strength of 68% aggregate volume is higher than 73% aggregate volume. According to Table 13, the maximum compressive strength is obtained from trial mix design with water-cement ratio 0.5 and maximum aggregate volume 68%.

Calculation of Field Mix Design

By using trial mix design data, the optimum value of w/c (0.555) and 68% of maximum aggregate size (20mm) is obtained for the target compressive strength (4000 psi) from figure 3.

And then the field mix design is calculated and batch weight per cubic yard of fresh concrete for field mix design is shown in Table14 and slump test of fresh concrete are presented in Table 15. And then, compressive strength test results are described in Table16 and Figure 4.

Table 14: Batch weight per cubic feet of fresh concrete for field mix design

Replacement % of Pozzolan	Wt: of Unit (lb/ft^3)					Water-cement ratio
	Cement (lb)	Pozzo-lan (lb)	Sand (lb)	Ag-gre-gates (lb)	Wa-ter (lb)	
0%	608	-	1162.36	1836	362	0.555
10%	547.2	60.8	1162.36	1836		
20%	486.4	121.6	1162.36	1836		
30%	426.5	182.4	1162.36	1836		
40%	364.8	243.2	1162.36	1836		

Table 15: Slump test result of fresh concrete for field mix design

Replacement Percentages of Pozzolan	0%	10%	20%	30%	40%
Value of Slump (in)	3.15	3.35	3.74	3.86	3.94

DISCUSSION

Local product Dangote cement and local materials such as fine aggregates and coarse aggregates are used in this research. Local available pozzolan (NBRRI) is considered as cement replacement material. Physical properties of materials are tested according to the ASTM procedures and the result values are within the allowable limit. According to Table 4, the initial and final setting time of pozzolan as cement replacement are slower than that of cement alone. Therefore, pozzolan can be used as the retarder. In Table 5, it is found that the more percentage of pozzolan as cement replacement, the less value of normal consistency. So, percentages of flow and slump values are high and then water to cement ratio can reduce for mix design. From Table 6, the percentage of pozzolan as cement replacement is increased, the value of soundness is decreased. Therefore, expansion can decrease with the aid of pozzolan. According to the test results, the compressive strength of the mortar with replacement percentages of NBRRI pozzolan 0%, 10% and 20% reaches to the standard limit at 7 days strength 2500 psi of mortar with pure cement and then gradually decreases at other percentages. It is found that 21 days and 28 days strength are not different obviously. In this research, the tensile strength of mortar with *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) (2018) Volume 44, No 1, pp 290-301* replacement 10%, 20% and 30% are within the 5% to 10% of the compressive strength of cement alone. Moreover, it is observed that 10% pozzolan replacement in concrete 28 days compressive strength isnearly65.9% of pure cement concrete strength. Compressive strength of concrete with various percentages of NBRRI pozzolan at 21 days and 28 days are more than 7 days and 14 days strength.

CONCLUSIONS

This research hereby concludes that the more percentage of pozzolan as cement replacement, the higher the value of slump and the more workable. Pozzolan may also be used as the retarder because of increasing of setting time with various percentages of pozzolan as cement replacement. The more percent of pozzolan as cement replacement, the less value of soundness. Therefore, expansion will be decreased. The pozzolan may be used as the cement replacement up to 30% by weight of cement for mortar. It is observed that (10%) pozzolan replacement in concrete at 28 days compressive strength is nearly 65% of pure cement concrete strength. The NBRRI pozzolan is suitable for low-cost building construction and large concrete project when it is not required high strength performance in structures.

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