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Compressive Strength of Volcanic Ash/Ordinary Portland Cement Laterized Concrete

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Abstract: This study investigates the effect of partial replacement of cement with volcanic ash (VA) on the compressive strength of laterized concrete. A total of 192 cubes of 150mm dimensions were cast and cured in water for 7, 14, 21, and 28 days of hydration with cement replacement by VA and sand replacement by laterite both ranging from 0 to 30% respectively, while a control mix of 28-day target strength of 25 N/mm^2 was adopted. The results show that the density and compressive strength of concrete decreased with increase in volcanic ash content. The 28-day, density dropped from 2390 kg/m^3 to 2285 kg/m^3 (i.e. 4.4% loss) and the compressive strength from 25.08 N/mm^2 to 17.98 N/mm^2 (i.e. 28% loss) for 0-30% variation of VA content with no laterite introduced. The compressive strength also decreased with increase in laterite content; the strength of the laterized concrete however increases as the curing age progresses.

Keywords: Volcanic ash, laterized concrete, compressive strength, ordinary portland cements.

Introduction

Research trends globally in materials development has been that of sourcing for alternatives necessitated by the high cost of conventional materials, difficulty in accessing fund for construction/building development, the need to recycle agricultural waste materials for construction, the bio-degradability of the materials, the need to maintain ecological balance and population growth and the challenges of housing amongst the many other reasons [1,2,3,4]. The development of supplementary cementitious materials (SCMs) is said to be fundamental to advancing low-cost construction materials to be used in the production of self-sufficient means of shelter especially in developing countries. Apart from improving concrete properties, the main benefits of SCMs include saving natural resources and energy as well as protecting the environment through the use of these main admixtures [5].

Studies into utilisation of laterite as a partial substitute for fine aggregate in concrete production for building purposes has been carried out as attempts in direction of the need to use locally available materials disfiguring our construction sites as waste products.

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So also are efforts being made to substitute cement (wholly or partially) with locally available pozzolanic materials like volcanic ash, rice husk ash, sawdust ash, millet husk ash, pulverized fuel ash, bagasse ash and others in concrete [6,7]. Laterite has been identified as a possible material for partial replacement of sand in concrete to produce what has been called laterized concrete, while studies have been carried out on effects of laterite incorporation in strength and serviceability properties of fresh and hardened concrete [8–13]. This paper is a report of part of an ongoing research on the use of volcanic ash as a pozzolana in Laterized concrete with experimental design for up to 120 days of hydration in consonance with previous works such as Mattawal [6], Neville [18], and Neville & Brooks [19]. The 28-day strength can also be used as a trial assessment of pozzolanic activity in accordance to ASTM C618 [20]. This work investigates the effect of the incorporation of the locally available lateritic soils on strength characteristics of concrete with the addition of another locally available pozzolanic material (volcanic ash) as partial replacement of cement [4]. The introduction of volcanic ash (a seemingly waste and supposed potential hazardous material of volcanic eruption), into concrete and now laterized concrete can be viewed as an attempt to convert an ecological waste material to a purposeful use.

Literature Review

Research trends on sourcing, development and the use of alternative, non-conventional materials have been concentrated either on purely partial or total replacement of ordinary Portland cement (OPC) in concrete on one hand and the replacement of sand with laterite on the other. Job [14] reported the efforts made by researchers like Popovics [15], Smith [16], Talero [17] and Neville [18] to substitute cement with locally available materials called pozzolanas. "Pozzolana" is used to describe naturally occurring and artificially siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious value but will, in finely divided form and in presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compound possessing cementitious properties [19,21,22,23]. In the words of Mattawal [6], the application of use of various ashes as potential replacement of cement in mortar and concrete production has attracted the attention of researchers because of its potential to:

a. Reduce or totally eliminate the classification of ashes as waste materials polluting the environment, and
b. Reduce the quantity and consequently the cost of cement applied in concrete works.

Mattawal [6] further highlighted that recent researches in Nigeria and abroad have shown that pozzolanas can produce concrete with close characteristics as normal concrete at ages beyond 28 days. Experimental studies have thereby been carried out on variety of waste ashes and materials with pozzolanic potentials such as fly ash, rice husk ash, sawdust ash, acha (wheat) dust ash, sugarcane fibre (bagasse) ash, pulverized fuel ash, groundnut husk ash, blast furnace slag, mining tailings and volcanic ash [23].

Volcanic ash is a finely fragmented magma or pulverised volcanic rock, measuring less than 2 mm in diameter, that is emptied from the vent of a volcano in either a molten or solid state. The most common state of ash is vitric (glass like), which contains glassy particles formed by gas bubble busting through liquid magma [24].

Volcanic ash comprises small jagged piece of rock minerals and volcanic glass that was erupted by a volcano [25]. Volcanic ash is opined not to be a product of combustion like soft fluffy material created by burning wood, leaves or paper. It is hard, does not dissolve in water and is extremely abrasive, mildly corrosive and conducts electricity when wet. In their opinion, the average grain size of rock fragment and volcanic ash erupted from an exploding volcanic vent varies greatly among different eruption. Heavier and large size rock fragment typically fall back to the ground or close to the volcano while smaller and lighter fragments are blown farther from the volcano by wind.

It has been for millennia that the mixture of volcanic ash or pulverized tuff (siliceous), with lime produces hydraulic cement. An examination of ancient Greek and Roman structures provide sample evidence of the effectiveness and durability of this cement. The lining to a cistern in Kamiros, Rhodes (230 km east of Santorini) dating from the 6th or 7th century BC is still in existence. Pozzolanic natural cement was for millennia the only available material for lining cisterns and aqueducts and binding the brick and stone of water–front structure and monumental buildings.

Volcanic ash is still used in various countries like Greece, Italy, Germany, Mexico, and China, because it reduces cost and improves quality and durability of concrete. When volcanic ash develops internal cementation, it is transformed into a soft rock called Tuff. In spite of its inferior qualities when compared with other stones (lower strength and resistance to erosion), Tuff is often quarried and used as building stone.

Laterite or laterized concrete on the other hand has attracted the attention of many authors and researchers. Gidigasu [26] as cited in Olusola [13] defined laterite as a term used to describe all the reddish residual and non-residual tropically weathered soils, which generally form a chain of materials ranging from decomposed rock through clay to sesquioxide (Al_2O_3 + Fe_2O_3) - rich crusts, generally known as carapace. Laterite, either in raw form or improved form is commonly used both in rural and urban areas for housing construction in form of masonry units. The Federal low-cost housing scheme at satellite town, Ojo, Lagos, Nigeria is built of stabilized laterite blocks. So also are low-cost housing schemes in some States like Kebbi, Ekiti and others in Nigeria built with hydra-form (i.e. interlocking stabilized laterite) blocks. However, it has not been widely utilized to an equal level as sandcrete blocks and concrete, especially for structural works [2]. The reasons for this had been given as uncertainties as to their reliability, lack of knowledge of their physical properties and strength characteristics prior to use, inadequate knowledge of the actual performance of structures made from it under varying climatic condition and problems of quality control [2, 27]. The public believed that for laterite to be used on a wider scale, it should be improved at the technical level. Research investigations have thereby shown that stabilized laterite (laterite mixed with a certain quantity of cement $\leq 10\%$ by weight) can be advantageously used for the production of masonry units and that laterite holds promise as a partial replacement for sand in concrete constructions, both structural and non-structural.

Laterized concrete is defined as concrete in which stable laterite fines replace sand wholly or partially; whole replacement is also referred to as terracrete [13]. Neville [22] reported that laterite when used to wholly replace sand in concrete can rarely produce concrete stronger than 10 MPa (10 N/mm^2). Report of studies by Osunade [28], Ata [12] and Olusola [13] has proved this not true; they submitted that laterite can produce concrete of much higher grades.

Materials and Methods

Laterized concrete mixtures with four levels of volcanic ash (VA.) replacements ranging from 0 to 30% and four levels of laterite replacement also ranging from 0 to 30% (i.e. a total of 16 levels of samples produced in triplicates) were investigated. The control mixture was proportioned for a target concrete strength of 25 N/mm^2 and had a cementitious material content of 292 kg/m^3, fine aggregate content of 680 kg/m^3, coarse aggregate content of 1158 kg/m^3, and a water cementitious materials ratio of 0.65 giving a free water content of 190 kg/m^3. The cement and sand replacement by VA and laterite respectively was thereby computed for by weight as required.

The volcanic ash used was obtained from Kerang in Mangu Local Government Area of Plateau State in Nigeria as a solid mass. This was grinded and sieved with a 75 μm sieve at the Civil Engineering Laboratory of the Federal University of Technology, Minna, Nigeria. As shown in Table 1, the total content of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) can be said to range between 63.74% reported by Lar and Tsalha [29] and 67.14% by Hassan [23], which is slightly below the minimum of 70% specified in ASTM C618 [20].

Table 1. Chemical Analysis of Kerang's Volcanic Ash Sample

Elements	% Composition by weight	
	KG1	KG2
SiO_2	39.64	48.75
Al_2O_3	11.18	16.26
Fe_2O_3	12.92	2.13
CaO	10.43	11.67
MgO	18.79	4.24
K_2O	1.64	5.71
Na_2O	0.95	3.83
P_2O_5	0.48	0.81
TiO_2	2.52	
MnO	0.08	
SO_3	0.02	
Cr_2O	0.04	
L.O.I		2.71
Total SiO_2+Al_2O_3+Fe_2O_3	63.74	67.14

Source: KG1- Lar and Tsalha [29]
KG2- Hassan, [23].

Table 2 however shows the specific gravity of the VA sample as 3.04, which is similar to 3.05 as given by Hassan [23], a value less than that of cement (3.15) as provided by Neville [22]. The fine aggregate used were sand and laterite. The laterite was obtained from Julius Berger (Nigeria Public Limited Company) burrow pit at Maikunkele, Minna, Niger State, Nigeria. While sand used was river sand, free from deleterious substances obtained from Bosso area of Minna; the coarse aggregate used was granite obtained from Tri-Acta quarry in Minna with maximum size 19 mm (3/4 in) specified. Table 2, presents the results of the physical properties of the aggregates. The laterite sample has a specific gravity of 2.54, bulk density of 1375 kg/m^3, moisture content of 15.79%, fineness modulus of 2.91, coefficient of uniformity C_u of 8.68 and coefficient of curvature C_c of 1.20. The sand on the other hand has a specific gravity of 2.59, bulk density of 1458 kg/m^3, moisture content of 3.67%, fineness modulus value of 2.41, C_u of 8.00, and C_c of 1.57. These results reflect that both the laterite and sand samples are well graded. The granite sample has a specific gravity of 2.64, bulk density of 1792 kg/m^3, C_u of 1.42, and C_c of 0.92, reflecting a uniform sample. All the aggregates conformed to the British Standard Specification [30]. The cement used was Dangote Portland cement produced in Obajana factory, Kogi State, Nigeria and conformed to BS EN 197-2000 [31].

Table 2. Summary of Physical Properties of Constituent Materials

Parameter	VA	Sand	Laterite	Granite
Specific Gravity	3.04	2.59	2.54	2.64
Bulk Density(kg/m^3)				
Uncompacted	1394	1337	1267	1287
Compacted	1649	1458	1375	1792
Void (%)	18.29	9.05	7.85	28.18
Moisture Content (%)		3.67	15.79	
Sieve Analysis				
Fineness Modulus		2.41	2.91	
Coefficient of Uniformity, Cu		8.00	8.68	1.42
Coefficient of Curvature, Cc		1.02	1.20	0.92

Tests to determine slump, density and comprehensive strength were carried out in this study.

For the comprehensive strength tests, 150 mm cube specimens were used. A total of 192 specimens were cast and cured in water at room temperature in the laboratory for 7, 14, 21, and 28 days. At the end of each curing period three specimens of each mixture were tested for compressive strength and the average was recorded.

Results and Discussion

Workability of the laterized concrete decreases as the percentage of VA and laterite (lat) increases. The slump value ranges between 40-60 mm. The density of the laterized concrete mixtures decreases as the percentage VA replacement increases, so also as the lat content increases. At 0% VA / 0% lat, the density was 2390 kg/m^3; at 30% VA / 0% lat, the density was 2285 kg/m^3 representing decrease of about 4.4% (Tables 3 and 4).

Table 3. Summary of Density (kg/m^3) and Compressive Strength (CS.-N/mm^2) of VA/OPC Laterized Concrete

Lat. Cont. (%)	VA Cont. (%)	Curing Days							
		7		14		21		28	
		Density	CS	Density	CS	Density	CS	Density	CS
0	0	2422	10.17	2428	14.50	2430	21.11	2390	25.08
	10	2358	8.35	2369	12.42	2351	17.47	2351	21.88
	20	2307	7.44	2319	10.11	2321	15.42	2312	19.84
	30	2283	6.58	2290	8.05	2287	13.07	2285	17.98
10	0	2365	8.38	2363	11.71	2362	16.02	2374	19.90
	10	2329	7.08	2329	9.50	2322	13.26	2308	19.27
	20	2323	6.09	2297	8.10	2291	12.72	2291	18.11
	30	2296	4.56	2274	6.50	2258	11.40	2278	17.57
20	0	2356	8.28	2368	9.79	2342	13.76	2335	18.92
	10	2326	6.74	2336	8.13	2314	12.55	2289	17.33
	20	2297	5.75	2322	6.82	2280	11.67	2315	16.75
	30	2271	4.22	2276	5.87	2253	9.99	2274	16.07
30	0	2336	7.38	2355	9.53	2355	12.74	2329	18.26
	10	2304	6.36	2315	7.92	2326	11.75	2302	16.98
	20	2292	5.02	2297	6.60	2282	10.32	2283	14.68
	30	2268	3.98	2269	5.70	2249	8.95	2240	12.09

Table 4. Compressive Strength as Percentage of 28-Day Strength

%Lat.Cont	%VA.Cont	Curing Days			
		7	14	21	28
0	0	41	58	84	100
	10	33	50	70	87
	20	30	40	61	79
	30	26	32	52	72
10	0	33	47	64	79
	10	28	38	53	77
	20	24	32	51	72
	30	18	26	45	70
20	0	33	39	55	75
	10	27	32	50	69
	20	23	27	47	67
	30	17	23	40	64
30	0	29	38	51	73
	10	25	32	47	68
	20	20	26	41	59
	30	16	23	36	48

As shown in Fig. 1 to 4, the compressive strength of the VA / OPC laterized concrete decreases as the percentage VA content increases. Fig. 1 shows for the 0% lat/0% VA (i.e. the control) sample, the 28-day strength gave a value of 25.08 N/mm^2 while the 0% lat/30% VA sample has 28-day strength of 17.98 N/mm^2, representing a decrease of about 28%. The 30% lat/0% VA (Fig. 4) on the other hand has 28-day strength of 18.26 N/mm^2, representing a 27% decrease. The trend however shows a gradual strength development of the VA/OPC laterized concrete as the hydration period increases with the 0% lat./30% VA mix having values representing 26, 32, 52, and 72% of the target strength at the 7, 14, 21, and 28 days respectively (Table 4). The 20% lat/20%VA mix however was noticed as the limit to which both the cement and sand can be replaced for quality and economy in consonance with the requirements of ASTM C618 for 28-day strength. Table 3 and 4 shows this sample as having gathered a compressive strength value of 16.75 N/mm^2 (67% of the target strength) on the 28-day from the initial 7-day strength of 5.75 N/mm^2 (only 23% of the 28day target strength) while code ASTM C618 specifies 75%. Hence it is hoped that at a later date the sample will have attained strength value similar to the control mix sample. The laterized concrete in general was noticed to present strength values similar to the results of the previous researchers [8, 14, 28] with a 30% lat/30% VA sample having 28-day strength value of 12.09 N/mm^2 (about 50% of the target strength) as presented in Table 4 and Fig.4

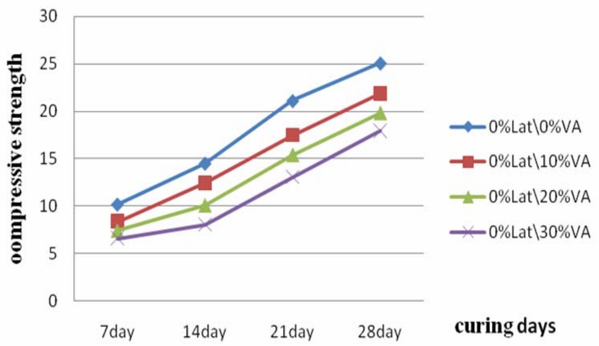

Figure 1. Plot of Compressive Strength for 0% lat/0%-30% VA.

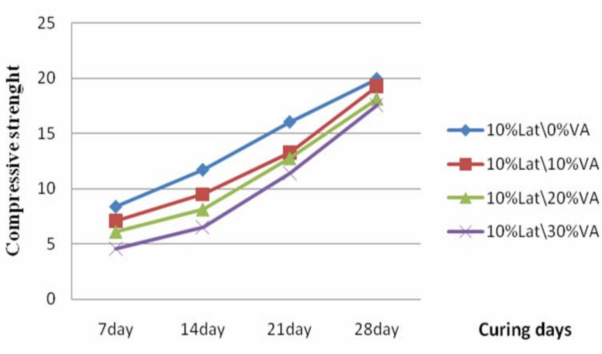

Figure 2. Plot of Compressive Strength for 10% lat/0%-30% VA.

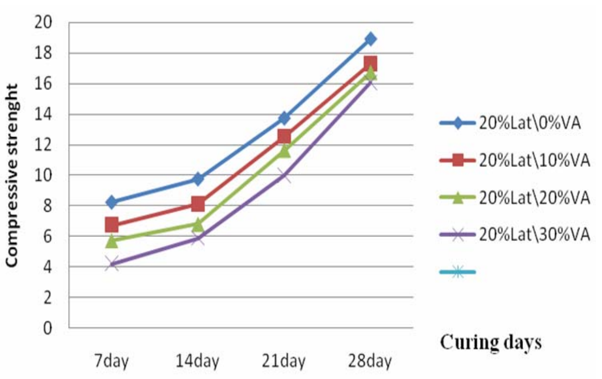

Figure 3. Plot of Compressive Strength for 20% lat/0%-30% VA.

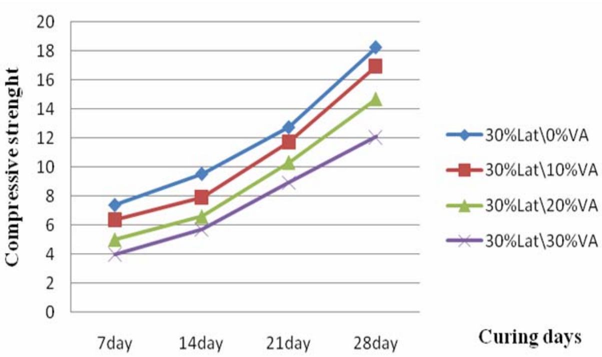

Figure 4. Plot of Compressive Strength for 30% lat/0%-30% VA.

Conclusion

The results presented demonstrate that although the VA/OPC laterized concrete only had compressive strength values ranging between 48% and 73% of the 28-day strength (for 30% lat / 30% to 0% VA), the introduction of volcanic ash (VA.) presents a good tendency of pozzolanic activity, while research studies towards boosting the property of the volcanic ash sample from the study area will be a welcome development in the continued search for alternatives. The VA/OPC laterized concrete can at the moment be adopted for construction of masonry walls and simple foundations. Further studies should be concentrated on boosting the total SiO_2 + Al_2O + Fe_2O_3 content of the VA. sample from Kerang while the laterized concrete sample can be investigated for longer hydration periods such as 56, 90, and 120 days to ascertain its pozzolanic tendencies.

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