Effects of Partial Replacement of Sand with Laterite on Compressive Strength of OPC-Activated Rice Husk Ash (ARHA) Concrete

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Abstract: The aim of this study was to evaluate the impact of partial replacement of sand with laterite on the compressive strength of Ordinary Portland Cement and Activated Rice husk Ash (OPC-ARHA) hybrid concrete. The ARHA binder was created by activating Rice husk Ash with a sodium hydroxide and sodium silicate alkaline solution mixture. This mixture was then utilized to replace OPC at 10%, 20%, and 30% levels. Moreover, 10%, 20%, and 30% of the sand was substituted with laterite. Additionally, control specimens consisting of 100% OPC and 0% laterite were cast. The binder to fine aggregate to coarse aggregate weight ratio employed in the mix was 1:2:4. After being cured in water for 7, 28, 56, and 91 days, the resulting concrete specimens' compressive strength was determined at the maturity ages. At 91 days, the control specimen's maximal compressive strength was 23.6 N/mm^2. At the same curing age of 91 days, laterized concrete (without ARHA) reached a maximum compressive strength of 22.5 N/mm^2, or 95.3% of the control, at a 30% replacement level of sand by laterite. The maximal strength of the OPC-ARHA hybrid concrete was 16.6 N/mm^2 and 15.6 N/mm^2 for laterized OPC-ARHA hybrid concrete. Based on the results, 30% of laterite content with 10% ARHA was ideal for use in concrete production. It was also discovered that addition of laterite can improve the compressive strength of OPC-ARha hybrid concrete.

Keywords: Laterized concrete, Compressive strength, Activated Rice husk Ash, Hybrid concrete

Introduction

Alkali activated material (AAM) and geopolymer are environmentally benign binders that is develop from the activation of a silica-rich precursor, like rice husk ash, by a potent alkaline solution, such as mixture of NaOH and NaSiO[3]. When compared to ordinary Portland cement (OPC) concrete, the manufacture of AAM/geopolymer concrete results in energy savings of at least 40% and a carbon emission reduction of almost 70% (Mclellan et al., 2011). Alkali-activated material and OPC are combined to generate an AAM/OPC hybrid, which aims to combine the benefits of OPC with the characteristics of alkali-activated material (Marczyk et al., 2021). The heat generated from the hydration of OPC can be utilized by AAM when hybridized with OPC (Rivera et al., 2014). Askarian et al. (2018) evaluated the characteristics of hybrid OPC-geopolymer concrete that was cured in ambient conditions and discovered that the combination of OPC and geopolymers leads to binders with higher early age strength and better compressive strength because of the OPC's quick reaction with alkali activators. The ability to hybridize 60% OPC and 40% geo-cement to produce concrete with a strength of up to 40 MPa was validated by Kumar et al. (2019) through an experimental investigation. Mortar and composite binder with almost the same compressive strength as plainly OPC mortar can be produced by combining OPC with 10% or 20% Diatomaceous earth powder (DEP), a very siliceous substance. There have been several attempts to substitute sharp sand, either entirely or in part, as the fine aggregate in concrete, particularly in areas where different types of soil or industrial materials are freely available and sand is not easily accessible. Some of the materials that have been utilized in place of sand as fine aggregate in concrete are sewage sludge ash (SSA), silica fume ash (SFA), biomass wastes (BW), fly ash (FA), incinerated bottom ash (IBA), recycled waste glass (RWG), mussel shell sand (MSS), coal bottom ash (CBA), and red soil (Dhir et al., 2018; Gonzalez et al., 2021; Alexander et al, 2016; Singh et al, 2018 and Siddique and Kunal, 2020).. Joy and Matthew (2015) discovered that 15% was the ideal replacement quantity when they substitute sharp sand in geopolymer concrete for foundry sand. Nevertheless, the use of many industrial materials is subject to a number of constraints. As an illustration, RWG, while a desirable choice for fine aggregate because of its pozzolanic qualities, has a low recovery rate (less than 10%) as a result of few recycling facilities (La and Poon; Harrison et al, 2006). Furthermore, a lot of the materials listed above have minimal practical application and have only been used on a laboratory basis (Gonzalez et al., 2021. Since laterite is a naturally occurring substance, it shows great promise when used in place of sand in concrete. Due to its natural qualities, quantity, and affordability as compared to sand, laterite is becoming more and more popular as fine aggregate. It has also long been used as a building material, particularly in tropical climates. Udoeyo et al. (2006) stated that laterite can substitute sand for up to 40% of the fine aggregate in concrete. They found that while compressive, split tensile, and flexural strength values decreased, workability increased with increasing laterite content. Saichand and Harshitha (2019) came to the conclusion that laterite may take the place of fine sand in concrete, with 10 percent being the ideal amount. When Rice husk Ash and laterite are used in place of Portland cement and fine aggregate respectively, fresh concrete becomes more workable and requires less superplasticizer (Manu and Srivathsa, 2017). When laterite is used in place of some of the sand in concrete, its compressive and split tensile strengths are equivalent to those of concrete without laterite (Ashwin et al., 2017 and Muthusamy et al., 2012). They discovered that concrete specimens' compressive strength will rise if laterite is limited to 20% replacement level. When 25% of sand is substituted with laterite as fine aggregate in GGBS-blended concrete, the resulting compressive strength ranges from 87 to 90% of that of the control mix.(Karra et al., 2016). 10% laterite added to the sandcrete block production process can reduce heat conductivity and enhance building insulation, according to Ewa et al., 2022 and Siddharth., 2016). Siddharth et al. (2016) experimental investigations on geopolymer mortar indicated that laterite replacement of sand as fine aggregate should ideally range from 25% to 50%. The relevance of this research, stems from the paucity of data about the impact of laterite on concrete's compressive strength when OPC is hybridized with alkali-activated rice husk ash as the primary binders. This research explored how the ranging of laterite from 10% through 30% as partial substitute of sand influenced the compressive strength of OPC-ARha concrete within 91 days of water curing.

Materials and methods

Materials

Cement

Tri-calcium silicate (C_3S), di-calcium silicate (C_2S), tri-calcium aluminate (C_3A), and tetra-calcium aluminoferrite (C_4AF) are the principal constituents of ordinary Portland cement. For this study, ordinary Portland cement that complies with EN 197-1:2000 (2000) and is produced by Dangote Cement Company was used. The cement had a grade of 32.5R. All the specimens were produced using this as the primary binder.

Rice husk Ash (Mk)

Rice husk ash obtained from Ekiti State, Nigeria was used as the precursor for the study. The calcination was done using furnace at Department of Mechanical Engineering, Federal University of Technology, Akure. A temperature of 600 °C was used for the calcination, The heat was maintained inside the furnace at a temperature of 600°C based on Zaffar *et al.* (2022). The ash was left inside the furnace to cool down before collecting and sieving it to the required fineness. The primary oxide composition in the RHA are given in Table 1.

Table 1 Oxides Composition of Rice Husk Ash

Oxide	RHA Oxide %
MgO	1.5292
Al_2O_3	5.3438
SiO_2	64.838
Fe_2O_3	2.7798
SnO_2	4.4262
P_2O_5	4.8697
SO_3	2.1507
K_2O	4.9286
CaO	3.7458

According to ASTM C618-12a (2014), the total SiO_2, Fe_2O_3, and Al_2O_3 content is 72.8%, confirming its applicability as a natural pozzolan.

Alkaline activator

For this study, an alkaline activator solution containing 16M of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was employed. The liquid forms of sodium hydroxide and sodium silicate were obtained from African Fertilizer and Chemicals located in Agbara, Ogun state, Nigeria. The two alkaline activators' technical specifications are displayed in Tables 2 and 3.

Table 2 Properties of Liquid Sodium Silicate Alkaline

Parameters	Result
Specific Gravity	1.56
% Soda Content (%Na_2O)	15.34
% Silica Content (%SiO_2)	30.70
Wt. Ratio (Na_2O:SiO_2)	1 : 2
% Total Solids	46.04
PH	11.9
Viscosity	1100CP

Table 3 Properties of Caustic Liquid Soda (NaOH)(16M)

Specification	Result
Specific Gravity	1.50
Appearance	Colourless
Sodium Hydroxide (%)	48.24
Sodium Oxide	37.38

Aggregates

Crushed granite from a quarry in Akure, Ondo State was used as coarse aggregate. It ranges in size from 4.75 to 19 mm. BS 12620:2002 (2002) was followed in the determination of the specific gravity and the sieve analysis. Natural fine sand that had been graded to a minimum particle size of 0.150 mm and had passed a 4.75 mm screen served as the primary fine aggregate. Sieved with a 5.0 mm sieve, laterite (Figure 1b) served as the second fine aggregate. The laterite used can be classified as coarse fine as per ASTM C136/C136M-19 (2019) because of its fineness modulus of 3.98. The used laterite falls into category A-2-6, which is silty or clayey gravel and sand, according to the AASHTO system of soil classification. Figures 2 and 3 showed the laterite and sand grading curves. The aggregates' specific gravity are displayed in Table 4, while Table 5 showed the laterite's oxide composition.

Figure 1a Rice husk Ash

Figure 1b Laterite

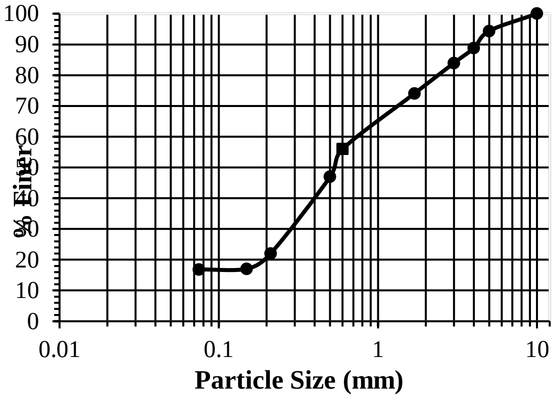

Figure 2 Particle Size Distribution Curve for Laterite

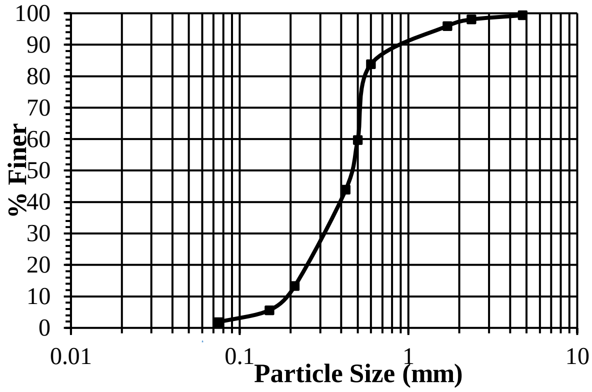

Figure 3: Particle Size Distribution Curve for Sand

Table 4 Specific gravity of the aggregates

Material	Specific gravity
Sand	2.61
Granite	2.73
Laterite	2.59

Table 5 Oxides Composition of laterite*

Oxides	Percentage chemical composition
SiO_2	42.64
Al_2O_3	28.59
Fe_2O_3	15.03
MgO	0.09
TiO_2	1.62
LOI	11.68

*Source: [27]

2.1.5 Water

It is recommended that water used in the production of concrete meet certain minimal standards, such as being potable or clean and devoid of contaminants that could damage the material (BS EN 1008:2002, 2016). This research employed potable water that complied with BS EN 1008:2002 (2016) and was obtained from the Federal University of Technology, Akure.

2.2 Methods

2.2.1 Mix Design

The laterized OPC-ARHA hybrid concrete specimens and the control group were mixed using a 1:2:4 (binder: fine aggregate: coarse aggregate) mix ratio in accordance with BS5328-2:1997 (2002). Table 6 illustrates this, with the control mix having neither ARHA nor laterite, and the other combinations having ARHA and laterite in varying amounts. Batching of materials was in kilogram (kg) weight. Sharp sand and OPC was replaced at10%,20%, and 30% with laterite and ARHA, respectively. 192 concrete cubes were cast in all.

Table 6 Mix proportions of OPC- ARHA concrete (kg/m^3)

Group*	Specimen Mark*	OPC	Rice husk Ash	Coarse Agg.	Sand	Laterite	Activator	Total Water
C	Control	326.0	0	1304	652.0	0	0	238
	C1	326.0	0	1304	586.8	65.2	0	238
	C2	326.0	0	1304	521.6	130.4	0	238
	C3	326.0	0	1304	456.4	195.6	0	238
R1	R1a	293.4	32.6	1304	652.0	0	14.67	239.4
	R1b	293.4	32.6	1304	586.8	65.2	14.67	239.4
	R1c	293.4	32.6	1304	521.6	130.4	14.67	239.4
	R1d	293.4	32.6	1304	456.4	195.6	14.67	239.4
R2	R2a	260.8	65.2	1304	652.0	0	29.34	248.7
	R2b	260.8	65.2	1304	586.8	65.2	29.34	248.7
	R2c	260.8	65.2	1304	521.6	130.4	29.34	248.7
	R2d	260.8	65.2	1304	456.4	195.6	29.34	248.7
R3	R3a	228.2	97.8	1304	652.0	0	44.01	251.1
	R3b	228.2	97.8	1304	586.8	65.2	44.01	251.1
	R3c	228.2	97.8	1304	521.6	130.4	44.01	251.1
	R3d	228.2	97.8	1304	456.4	195.6	44.01	251.1

* C = concrete with 100% OPC, R1 = concrete with 10% ARHA, R2 = concrete with 20% ARHA, R3 = concrete with 30%, ARHA, a = 0% laterite, b = 10% laterite, c = 20% laterite, d = 30% laterite,

Alkaline liquid preparation

A 16M solution of sodium hydroxide (NaOH) was ready-made in a factory. Displayed on Tables 2 and 3 are the percentage chemical composition of sodium silicate (SS) and sodium hydroxide (SH) respectively. Adding sodium silicate solution to the sodium hydroxide solution, the mixture was well mixed after about five minutes of stirring. Based of literature findings and suggestions (BS 5328-2, 19997; Sharma and Ahmad, 2017; Hardjito and Rangan, 2017) an SS/SH mix ratio of 2.5:1 (Na2SiO3): (NaOH) was used.

Mixing procedure

In a 1:2:4 ratio (binder: fine aggregate: coarse aggregate), the aggregates were combined with the binder (OPC and rice husk ash). A ratio of 0.45 was used to proportion the alkaline solution to rice husk ash. Water was added to the alkaline activator solution after determining the proper water to binder ratio. The fresh OPC/Activated Rice husk Ash hybrid concrete was then created by adding the alkaline activator solution to the dry mix (aggregate plus binder) and thoroughly mixing it to the necessary consistency. The freshly formed concrete was then transferred into the ready-made molds. This procedure was repeated for the different iterations of the mixtures.

Casting and curing

To find the compressive strength, 150 x 150 x 150 mm cube specimens were cast. Three layers of concrete were mixed, poured, and compacted. Tampering rods were used for compaction, and trowels were used to complete the specimens. After a day, the samples were demoulded and stored in curing tank for 7, 28, 56, and 91 days.

Compressive strength test

A compressive strength test was performed on concrete cube specimens measuring 150mm by 150mm by 150 mm in accordance with BS EN 196-1:2005. According to the applicable standards, the strength was calculated as the mean value across three specimens. The test machine seen in Figure 4 lowered its top plate on the cube specimen using a hydraulic ram to provide constant pressure until failure. Equation (1) is used to obtain the compressive strength.

$$\text{Compressive Strength (MPa)} = \frac{\text{Maximum Load (N)}}{\text{Cross-sectional Area (mm}^2\text{)}} \qquad (1)$$

Figure 4 Compression testing of concrete specimens

Results and Discussion

Effect of Laterite on the Compressive Strength of Concrete Without Activated Rha (C Group)

When the curing days rose from 7 through to 91 days, all of the concrete samples, with or without laterite, grew stronger. It is clear that laterized concrete does not lose strength due to the presence of laterite. As seen in Figures 5 and 6, the concrete specimens strengthened more quickly in the early days before slowing down at the 56th and 91st days, which is comparable to the occurence in the control. Figure 7 showed that when the laterite content increased from 0% to 30%, the compressive strength decreased somewhat between 10% and 20% of the laterite content before increasing again from 20% at 30% for the different curing days. The specimen with 0% laterite had the maximum compressive strength of 23.6 N/mm^2 at 91 days, while the specimen with 30% laterite closely trailed at 22.5 N/mm^2 at the same maturity age of 91 days; demonstrating a minor 4.7% drop in strength. . When compared to 0% laterite, the group's greatest strength reduction occurred at 20% laterite substitution, which led to an 8.9% loss in compressive strength. Consequently, it can be said that laterite can safely replace sharp sand up to 30% as the fine aggregate in concrete without risking any significant reduction in strength.

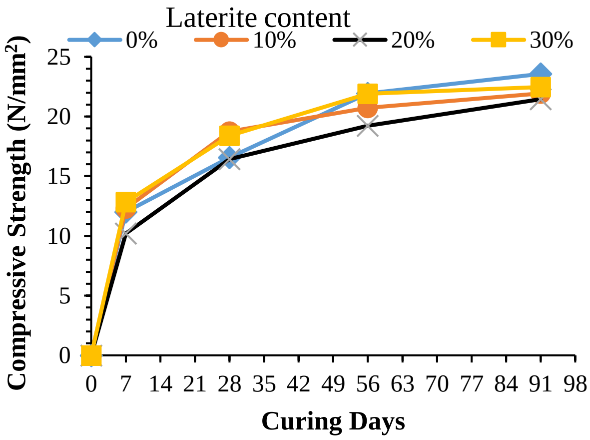

Figure 5 Compressive strength variation with progressing curing days of the C group

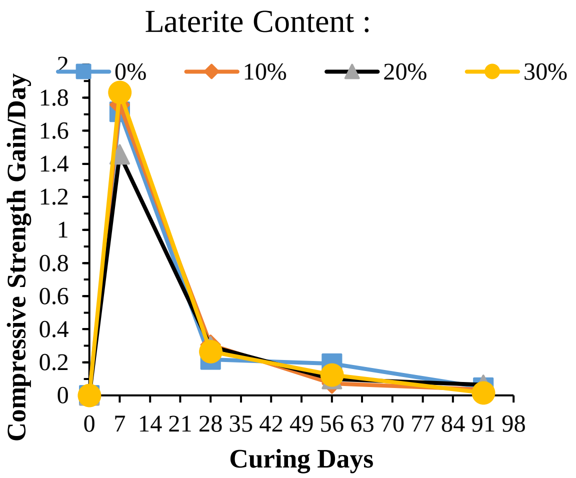

Figure 6 Compressive strength gain pattern for the C group

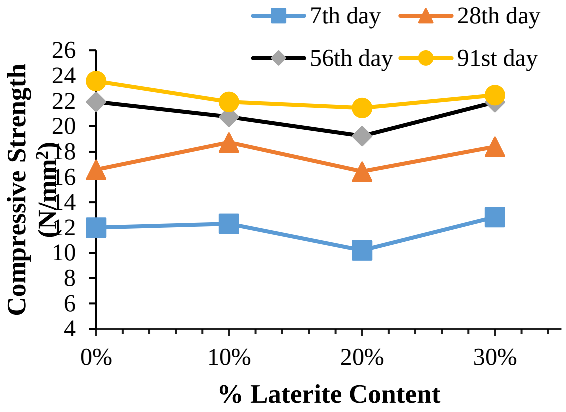

Figure 7 Effect of laterite variation on the compressive strength of C group (100% OPC, 0% ARHA)

Effect of laterite on OPC- activated Rice husk Ash hybrid concrete

It was discovered that laterite had a significant impact on the OPC-ARHA hybrid concrete's compressive strength. For every concrete sample analyzed, the compressive strength of OPC-ARHA hybrid concrete rose as the laterite content increased from 0% to 30% except in R1 group where there was observable fall in the compressive strength at 10% laterite inclusion before increasing again (Figures 8–10). On the other hand, as the laterite content grew from 10% to 30% after 91 days of curing, the compressive strength for the R2 and R3 groups increased from 10.7 N/ mm^2 to 14.1 N/ mm^2 and from 6.6 N/ mm^2 to 11.6 N/mm^2 respectively. A 1.13 N/mm^2 and 1.33N/mm^2 average strength gain with each 10% increase in laterite content respectively. This development can be attributed to the high fineness modulus of the laterite used and the hydraulic properties of lateritic soils. Even though laterite was intended to replace sand as the fine aggregate in the concrete, it complimented the OPC and ARHA because its amorphous silica reacted with the calcium hydroxide in the OPC to produce additional C-S-H formation, which increased the strength of the concrete as observed by Aldin *et al*. (2017). In general, laterite is beneficial to OPC-ARHA concrete.

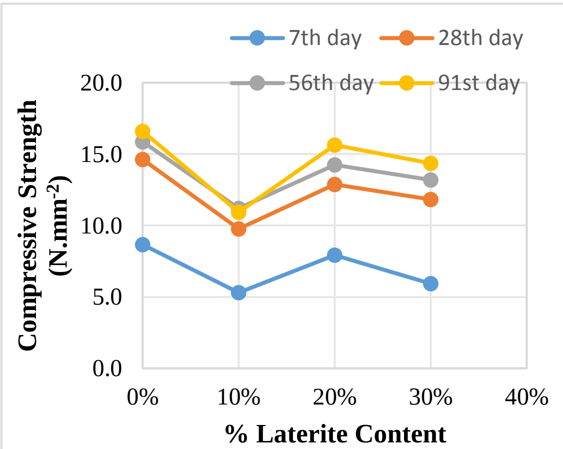

Figure 8 Effect of Laterite variation on the compressive strength of R1 group (90%OPC, 10% ARHA)

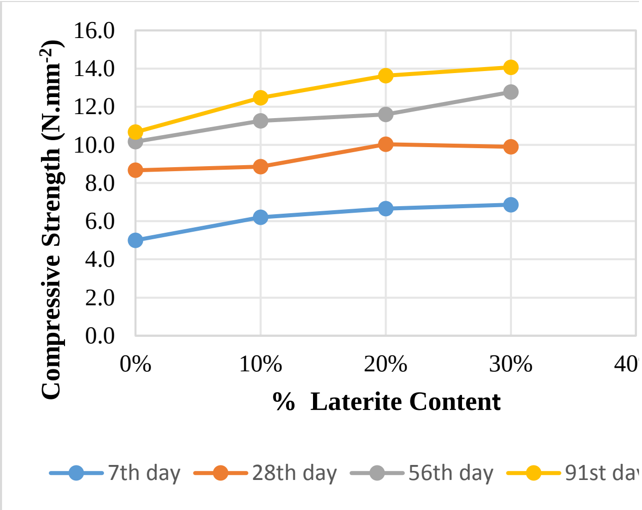

Figure 9 Effect of laterite variation on the compressive strength of R2 group (80%OPC, 20% ARHA)

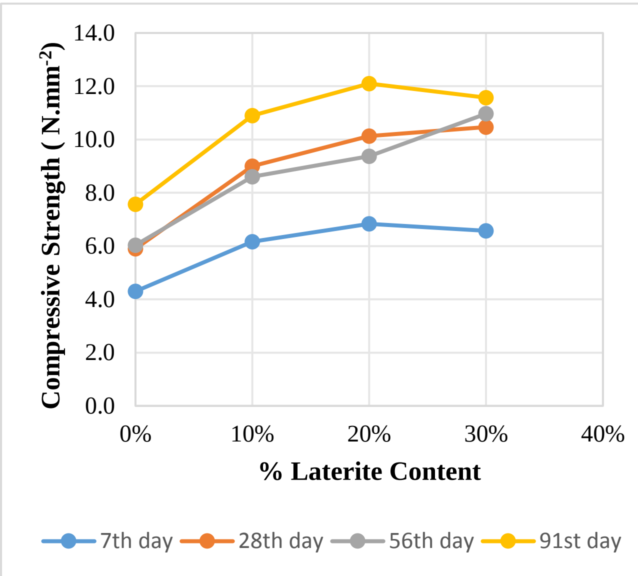

Figure 10 Effect of laterite variation on the compressive strength of R3 group (70%OPC, 30% ARHA)

The initial large difference in compressive strength between the specimens with 100% OPC and those with ARHA at different percentages when laterite was not utilized was a significant finding. This is an indication that water curing is not particularly beneficial for strength development in the ARHA part of the hybrid binder; supporting the findings of Hammat *et al*., (2021). However, from Figure 11 it could be observed that as laterite content increased, the gap between the compressive strength of the control and R2, R3 groups reduced. At 0% laterite, the difference between the control and R2 was 12.9N/mm^2, at 10% the difference reduced to 9.5 N/mm^2, at 20% it further reduced to 7.8 N/mm^2. Similarly, in R3 the difference between the compressive strength of the control and the group at 91 days reduced from 16 N/mm^2 to 9.4N/mm^2 as laterite increased from 0 to 20%. Using laterite as fine aggregate is more advantageous to the ARHA part of the binder than that of OPC. This is because laterite is a naturally occurring pozzolan, and it benefited from alkali activation of the rice husk ash to improve the strength of the resulting hybrid concrete as earlier postulated by Gorhan *et al.*, (2016).

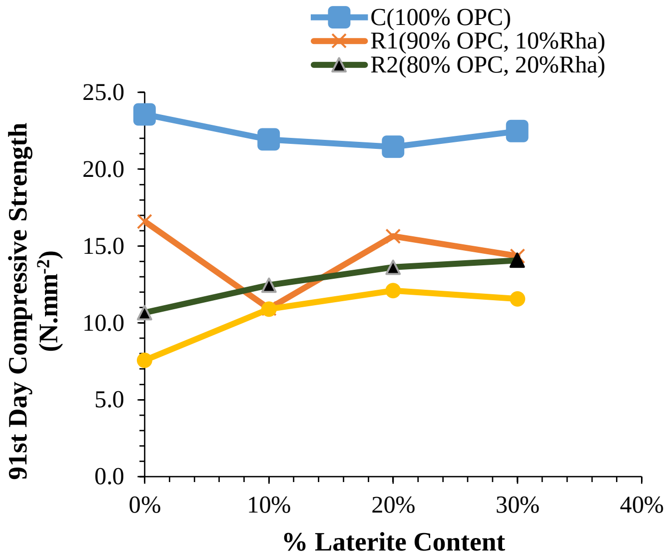

Figure 11 Effect of Laterite variation on the 91st day compressive strength of hybrid OPC-ARHA concrete

As seen in Figure 12, with increasing percentage (0-30%) of ARHA in the OPC-ARHA binder, the compressive strength of the concrete reduced. However, the inclusion of laterite was able to fairly mitigate the loss in compressive strength when compared to concrete without laterite.

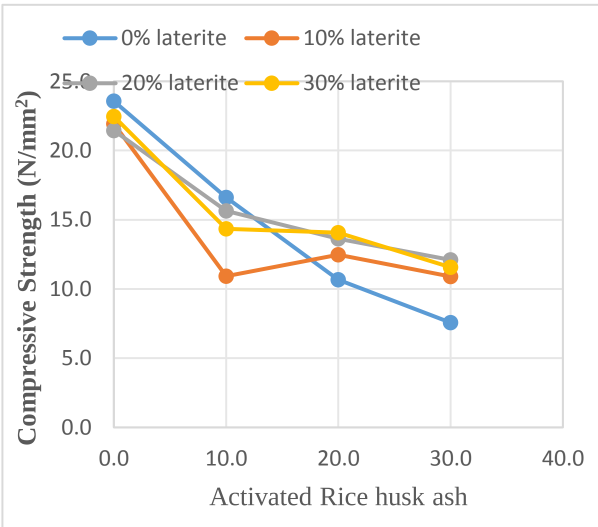

Figure 12 Effect of ARHA/ laterite on compressive strength of hybrid OPC-ARHA concrete

Conclusion

The strength gain of laterized concrete is not hindered by the partial substitution of fine aggregate with laterite. Laterized concrete shows a faster increase in strength in the early curing days compared to the later days, which is comparable to the strength development pattern in a concrete without laterite. Consequently, it is convenient to utilize laterite up to 30% in place of sharp sand as fine aggregate in concrete without worrying about the concrete's compressive strength being compromised. Specimen with 0% laterite was able to attain compressive strength of 23.6 N/mm^2 while the specimen with 30% laterite attained 22.5 N/mm^2 at 91 days of curing, a difference of 4.7% reduction in strength. With increasing laterite content, the compressive strength of activated OPC- ARHA hybrid concrete increased for all the concrete samples examined except R1. For R2 and R3 an average strength increase of 1.13 N/mm^2 and 1.33N/mm^2 respectively for every 10% increase in laterite was achieved.

Owing to the fact that laterite is a naturally occurring pozzolan and can be activated by alkali, it provides added strength to OPC-Activated RHA hybrid concrete, which is far more advantageous than OPC concrete alone. The compressive strength of laterized OPC-ARHA hybrid concrete increases with age more than that of laterized OPC concrete alone, indicating that pozzolan can improve concrete strength over an extended period of time. In OPC-ARHA hybrid concrete, 10% of OPC should be replaced with ARHA, while laterite can replace up to 30% of sand. This results in a compressive strength of 15.6 N/mm^2, the optimum for laterized OPC-ARHA hybrid concrete

Conflict of Interest

The authors state that there is no conflict of interest.

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