Comparative Study on Rice Husk Ash and Silica Fume as Supplementary Cementitious Material in High Performance Concrete Production

Okoh, B.O.[a], Olawuyi, B. J.[b] & Onogwu, C.M.[c]
Department of Building, Federal University of Technology, P.M.B 65, Minna, Nigeria
[a]oka2bless@gmail.com; [b]babatunde@futminna.edu.ng; [c]xtianpepsy@gmail.com
Corresponding email: oka2bless@gmail.com

Abstract

High-Performance Concrete (HPC) utilisation is gaining wide acceptance across the globe due to its high strength, elastic modulus, durability properties and economy. The production process however, requires incorporation of supplementary cementitious materials (SCMs) with Silica fume (SF) mentioned in literature as most adopted. Non-availability of silica fume in the sub-Sahara African countries has necessitated search for local alternative SCMs for HPC production of which Rice husk ash (RHA) has been found readily available with little or no attempt to benchmark its performance level with silica fume. This article thereby reports on a study conducted to establish the comparative effectiveness of Nigeria's RHA as an alternative to SF in HPC production for the development of a sustainable built environment in the era of pandemic. It further examines the effect of pre-soaked pumice in comparison to superabsorbent polymer (SAP) as internal curing (IC) agent on compressive strength of the HPCs. HPC mixes of varied RHA contents (5, 10 and 15% by weight of binder (b_{wob})) were studied and examined for compressive strength in comparison with HPC mix of 7.5% b_{wob} SF content. The IC-agents were kept constant (SAP at 0.2% b_{wob} and pre-soaked pumice at 5% by weight of coarse aggregate (b_{woca}) respectively) for this experiment. The HPC specimen were immersed in water bath for 28 days of curing before testing for compressive strength. The results reveal C_3 (i.e., 5%RHA based-HPC specimen with SAP as IC-agent at 0.2%b_{wob}) had compressive strength value slightly higher (i.e., 0.13%) than the control specimen – C_0 (7.5%SF based-HPC with similar SAP content)

Keywords: *Rice husk ash (RHA), Silica fume (SF), Superabsorbent polymers (SAP), Pre-soaked lightweight aggregate, and High-performance concrete (HPC).*

Introduction

Pandemic according to world health organization is defined as a disease outbreak that spread across countries. During pandemic, disease spread faster when people live in a clustered environment, sharing same item together resulting from inadequate housing due to high cost of building materials. A way out to tackle this problem is conversion and utilization of the locally available eco-friendly materials for the development of sustainable built environment.

Concrete is a composite material composed of aggregates bonded together with a fluid cement that hardens over time, and is one of the most frequently used building materials according to Mudashiru *et al*. (2021) and its usage worldwide, ton for ton, is twice that of steel, wood, plastic and aluminium combined. It is classified into different forms according to their properties such as normal concrete (NC) with maximum strength of 50 N/mm^2, but development of quality, deterioration and premature failure of the NC brought about the high strength / high-performance concrete (HSC/HPC) up to ultra-high strength concrete (UHSC), having minimum strength of 50 N/mm^2 (Mudashiru *et al*., 2021).

There is a growing acceptance of HSC/HPC in the construction industry across the globe within the past four decades. Although, there is a thin line of difference in these terms, there exists a shift from "high strength concrete property" to "high modulus of elasticity, "high density, "low permeability," and "resistance to attacking ions," which defined HPC (Neville & Aitcin, 2004). American Concrete Institute, ACI (1999) defined HPC "as concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using traditional constituents, normal mixing, placing, and curing practice. The applications of this type of concrete have majorly been witnessed in the construction of tunnels, precast pylons, bridges, shotcrete repairs, tall buildings, parking garages, and more (Aitcin, 2004; Orosz, 2017).

Nduka *et al.* (2020) reported that when HPC is used in the structures as mentioned above, thinner members are achieved, giving rise to the aesthetically appealing structure. The realisation of slender structural members amounts to less steel, reducing the entire structure's pressure and more functional spaces in buildings. Architects and designers can achieve greater architectural freedom, nearly unlimited structural shapes, form, and near-free reinforcement bars resulting in labour and cost lowering. Self-healing possibility in cracking situations can be produced by a considerable amount of unreacted cement in the finished product (Wang *et al.*, 2015). Furthermore, the utilisation of HPC in construction projects has been noted to account for the early removal of shuttering, culminating in early project completion. Many demonstrated construction projects had been accomplished using HPC in many countries (Aitcin, 2004; Abass *et al.*, 2016). Thus, the applicability of HPC in a developing country like Nigeria would improve infrastructure projects' future performances.

Previous studies (Persson, 1997; Kovler & Jensen, 2005; Bentz & Weiss, 2011; Di Bella *et al*., 2012; Di Bella *et al*., 2016; Mudashiru *et al*., 2021) empirically revealed that HPC is essentially a concrete with a low-water-to-binder ratio (W/B) ranging from 0.2 - 0.38. The substantial amount of cement and supplementary cementitious materials (SCMs) inherent in the mix results in increased temperature upon water addition and densification within the concrete area. Savva *et al*. (2018) inferred a direct relationship between ambient temperature and cementitious materials' pozzolanic activity. The study posits that cementitious grains are usually influenced by ambient temperature, hence a fast reaction that hinders the uniform distribution of hydration products leading to increased porosity of hydrated gel. In the same vein, SCM's inclusion furthers the propagation of autogenous shrinkage (AGS), chemical shrinkage, and self-desiccation due to combined effects of hydration and pozzolanic reaction necessitating higher moisture demand in the concrete (Wu *et al*., 2017). Additionally, Nduka *et al*. (2018) observed issues of concern like difficulty in curing vertical members, inaccessible locations in buildings, and poor craft when external curing methods are used in HPC structures. Consequently, to mitigate these challenges in concrete production, an innovative curing technique termed "internal curing (IC)" has gained tremendous attention in literature and practice in producing HPC and two notable materials (lightweight aggregates [LWA] and superabsorbent polymers [SAP]) have been used in past studies and practices in advancing the IC process.

Irrespective of the notable improved microstructural, mechanical, and durability properties of HPC, its usage has been limited in construction projects, especially in developing countries due to several reasons. These may be associated with the high cost of production, unavailability of SCMs, early age cracking potentials, and ultimately, lack of awareness by prominent professionals in the built environment (Nduka *et al*., 2018). Consequently, to drive the application of HPC in other regions of the world, extensive research has been conducted to reduce especially the cost components and early-age cracking of HPC. Rice husk ash (RHA) calcined in a controlled environment have been incorporated and investigated in HPC production (Olawuyi *et al*., 2021, Mudashiru *et al*., 2021). In contrast, IC, either with SAP or LWA, has been implemented to control early age cracking. Thus, to practically innovate the use of HPC with locally available material like Nigeria pre-soaked pumice as LWA and RHA as SCM in comparison with SAP and SF (already adjudged as effective IC agent and SCM) in the Nigerian built environment (Mudashiru *et al.*, 2021). HPC mixtures behaviour with this material needs to be examined for physical, chemical and compressive strength properties. Accordingly, this study is set out to investigate the influence of RHA as sustainable building materials in era of COVID19 on Class 1 (C55/67) HPC internally cured with Nigeria pre-soaked pumice in comparison with SF and SAP as a foreign SCM and IC agent respectively.

Materials and Methods

Materials

The materials that were used for this study are: the binders (PC, RHA and SF), aggregates (fine and coarse aggregates), internal curing agents (SAP and presoaked pumice), superplasticizer and water.

The PC used for this study was CEM II 42.5N (3X Dangote brand) whose properties conform to the Nigerian Standard --- and British Standard (BS EN 197-1: 2016) bought from a cement store in Gidan-Kwano, Minna, Niger State.

The RHA on the other hand which serve as (SCM) was obtained from the incineration of the husk using the locally available incinerator at the Concrete Laboratory of the Department of Building, Federal University of Technology, Minna, Niger State. The husk was burnt in an open air for about 24 hrs with a temperature about 700°C and then allow to cool before harvesting and milling with grinding machine. In accordance to ASTM C430- 2014, the milled RHA was sieved using 75 µm sieve and stored in an airtight polythene bag. The SF which serves as the second SCM was purchased from purechem Construction Chemical company in Lagos.

A natural sand with particle size not more than 300 µm according to (Shetty 2004, Neville, 1998, Nduka *et al*., 2020; Olawuyi *et al*., 2021 was used as the fine aggregate in this study for the production of HPC. To obtain values for the physical properties (fineness modulus (FM); coefficient of uniformity (Cu); coefficient of curvature (Cc); and dust content) of the natural sand, PSD was used using sieve analysis technique while the specific gravity was determined in accordance to EN 12390-7. The coarse aggregate used for the study was crushed granite stone which passed through 13.50 mm sieve size and retained on at least 9.50 mm sieve size. The coarse aggregate was washed to remove dust particle and to prevent more water absorption.

A Superabsorbent polymer (labelled FLOSET 27CS) of ≤ 600 µm grain size produced in France by SNF Floerger was added at 0.2% by weight of binder (b_{wob}) as detailed in Olawuyi *et al*., (2021) considering 12 g/g as the SAP absorption capacity conforming to the requirement of SAP specification for the production of HPC determined by tea-bag test (Olawuyi *et al*., 2021). The SAP type used is a thermoset polymer specifically the covalently cross-linked polymers of acrylamide and acrylic acid obtained from bulk solution polymerization and neutralized by alkali hydroxide.

The pre-soaked Pumice used for this study was a porous igneous rock formed as a result of explosives volcanic eruptions. It was crushed and 12.5 mm maximum size was used for this study. The pumice was soaked in water for 24hrs and before using it the water was (Olawuyi *et al*., 2021).

The water used for this study was portable clean water free from dirt and acid. It was gotten from the tap behind the convocation Square of Federal University of Technology, Minna, Niger State.

A Masterglenium polymer-based polycarboxylic ether (PCE) with label (sky 504) supplied by BASF Manufacturing was used as the superplasticizer in this study. It was administered at 1.5% concentration by weight of binder (b_{wob}) as recommended in the work of Olawuyi (2021).

Methods

Properties of Constituent Materials

The oxide content of binders (RHA, SF & PC) , X-ray Fluorescent (XRF) at the National Geoscience Research Laboratory, Kaduna State was used for data acquisition regarding their oxide composition. After calcination, milling and sieving of the binders, 100g for each of the binder was packaged in sealed polythene bags and sent to the Laboratory for the determination of the oxide compositions in accordance with BS EN 196-6: 2016. Wet sieving method was used to determine the particle size distribution of the aggregate's samples, while the specific gravity of the aggregate and binders were determined in the Building Laboratory of FUT, Minna in accordance with EN 12390-7.

Production of HPC Specimen

The production of the HPC specimen was carried out in accordance with the work of Nduka *et al*., 2020, and Olawuyi *et al*., 2021. Mean target strength of C55/67 at 28 days was adopted as the mix design procedure for material proportioning. Table 1 below gives the full details regarding mix proportions used for HPC specimen production. 0.2%b_{wob}) SAP was used for the SAP internally cured HPCs with 12.5g/g additional water provided for SAP absorption while 5% pre-soaked saturated pumice was measured and used for the pumice internally cured HPCs. De-moulding of the 100 mm cube HPC was done After 24 hours of casting. After de-moulding, the specimens were cured by full immersion in ordinary water and after 28days, HPC specimens were removed from the curing tank before subjecting it to compressive testing machine.

Table 61: Mix Proportioning of the HPC

	Materials (kg/m^3)								
Label	PC	SF	RHA	F/A	C/A	Pumice	SAP	SP	W/B
C_0	499.5	40.5	-	700	1050	-	1.08	8.1	0.3
C_1	499.5	40.5	-	700	997.5	52.5	-	8.1	0.3
C_2	513	-	27	700	997.5	52.5	-	8.1	0.3
C_3	513	-	27	700	1050	-	1.08	8.1	0.3
C_4	486	-	54	700	997.5	52.5	-	8.1	0.3
C_5	486	-	54	700	1050	-	1.08	8.1	0.3
C_6	459	-	81	700	997.5	52.5	-	8.1	0.3
C_7	459	-	81	700	1050	-	1.08	8.1	0.3

Fresh and Strength Properties

The fresh and compressive strength properties of HPC samples was carried out in accordance to BS EN standards (BS EN 12350 -1 & 5, 2000; 12390-1 & 2, 2000; 12390 - 3, 2002). In accordance with BS EN (12350 - 5 - part 1), for each of the mixtures with 5% pre-soaked pumice and 0.2% SAP, workability test was conducted using Slump Flow Table method to determine the followability of the HPC. Compressive strength test was then were performed on 36 samples after the 28 Days of curing in water at 0.5 N/mm^2 loading rate using 2000 kN loading capacity ELE Compressive Strength Testing Machine with a model number AT-120-1.1.

Results and Discussion

Physical and Chemical Properties

The XRF analysis of the binders (RHA, SF & PC) used for this study in powder form is presented in Table 2. The Table revealed main oxide of the RHA as SiO_2 at 95 % content and that the RHA belong to a Class N Pozzolan having a total useful oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$) content of 95.6 % which is above 70 % minimum as specified in ASTMC 618 (2012).

Table 62: Oxide Composition of Binder Constituents

Oxides	RHA (%)	SF (%)	CEM II (%)
SiO_2	95.0	96.35	25.64
Al_2O_3	0.45	0.47	5.24
Fe_2O_3	0.12	0.28	7.15
CaO	0.84	0.05	60.35
MgO	0.45	0.03	0.41
SO_3	0.10	0.10	0.11
K_2O	1.50	0.02	0.05
Na_2O	0.03	0.02	0.31
M_2O_5	0.05	0.50	0.04
P_2O_5	0.72	0.4	0.03
LOI	0.74	1.52	0.67
$SiO_2 + Al_2O_3 + Fe_2O_3$	95.57	97.10	37.43

The SF sample also has SiO_2 as its major oxide at having a 96.4 % content and a total useful oxide content of 97.1 % implying a very strong and reactive Class F Pozzolan in accordance to ASTM C618. The locally available Nigerian RHA can then be assessed as a strong reactive Pozzolan and good alternative to SF on basis of the oxide content. The PC (CEM II 42.5N) has Calcium Oxide (CaO) at 60.4 % content has the major oxide and conforms to oxides composition for CEM II Portland cement found in literature (Neville, 1998).

The physical properties of the aggregates used are presented in Figure 1 and Table 3. The result revealed that the fine aggregate is in conformity to the Shetty (2004) classification of medium sand with a Coefficient of Uniformity (C_u) of 2.39, Coefficient of Curvature (C_c) of 0.94 and Fineness Modulus

(FM) of 2.88. The coarse aggregates on the other hand, have a C_u of 1.32 and C_c of 0.92 and belong uniformly graded stone classification.

The specific gravity (SG) of the constituent materials (PC, RHA, SF and aggregates) used for this study is presented in Table 4 below. The Table gives the SG values as 3.14 for PC; 2.10 for RHA; 2.24 for SF; 2.62 for sand, 2.68 for granite; and 1.77 for Pumice. The results above conform well to values reported in Neville (1998).

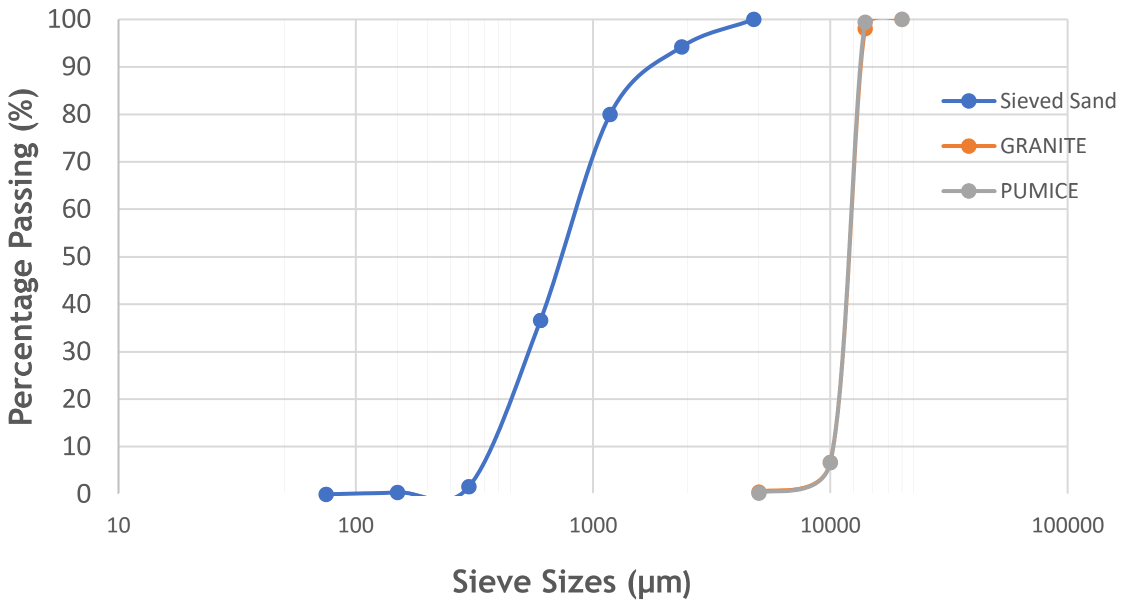

Figure 2: Particle Size Distribution of Aggregates

Table 63: Summary of Particle Size Distribution of Aggregates

Item	Sand	Granite	Pumice
D_{10}	360	10000	10000
D_{30}	540	11000	11000
D_{60}	860	13000	13000
C_u	2.39	1.3	1.3
C_c	0.94	0.93	0.93
FM	2.87		

Table 64: Specific Gravity of PC, MHA, CCW and aggregates

Test	PC	RHA	SF	Sand	Granite	Pumice
Empty cylinder (g) w_1	85	85	85	85	85	85
Empty cylinder + 1/3full of sample (g) w_2	107	96	100	119	119	112
Wt. of empty cylinder + 1/3full of sample + water full (g) w_3	169	160	162	176	176	165
Wt. of bottle + water only to full (g) w_4	154	154	154	154	154	154
SG $= w_2 - w_1 / (w_4 - w_1) - (w_3 - w_2)$	3.14	2.10	2.24	2.85	2.85	1.77

Fresh and strength properties

Results of the slump flow and compressive strength values for the HPC mixtures are presented in Table 5. The Table reveals that the slump flow values increased as the percentage of RHA increases for both HPC with 5% pre-soaked pumice and 0.2% SAP. It further shows that HPC with SAP as internal curing (IC) agent generally has higher slump flow values than the HPCs having pre-soaked pumice as the IC-agent. The higher slump flow of the SAP HPCs with SAP as IC-agent might be due to the additional water added to the mixing water meant to account for SAP absorption. The slump flow values for all HPCs irrespective of the IC-agent used were observed to be within 490 mm and 555 mm affirming that the workability of the HPCs are within the permissible limit of 460 - 600 mm as specified in Neville (1998) for the low W/B concrete.

Table 65: Slump flow and Compressive Strength Values of HPCs

Mix proportion	**C_0**	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**
Slump flow (mm)	510	490	515	525	530	545	550	555
fcu_{cube}	59.86	58.62	58.52	59.94	57.81	59.10	56.05	57.48
% of Control	100.00	97.93	97.76	100.13	96.58	98.73	93.64	96.02

The compressive strength of the internally cured HPCs at 28 days as seen in Table 5 is further presented in Figure 2. The results reveal C3 (i.e., 5%RHA based-HPC specimen with SAP as IC-agent at 0.2%b_{wob}) had compressive strength value slightly higher (i.e., 0.13% as shown in figure 2) than the control specimen – C0 (7.5%SF based-HPC with similar SAP content). The HPC specimen with values for C0, C1, C2, C3, C4, C5, C6 and C7 are 59.86, 58.62, 58.52, 59.93, 57.81, 59.10, 56.05 and 57.48 respectively. The result revealed that as the percentage of RHA increases, the compressive strength decease for both HPCs internally cured with pre-soaked pumice and SAP but the compressive strength of HPCs internally cured with SAP is higher than that internally cured with pre-soaked pumice.

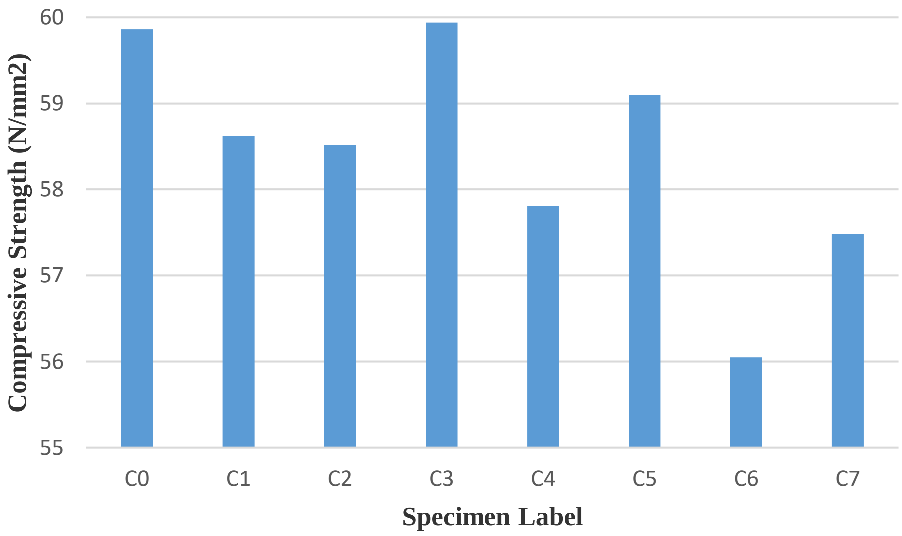

Figure 3: compressive strength of HPCs at 28 days

Conclusion and Recommendation

From the study, the following conclusion was deduced;

6. The RHA is a suitable alternative cementitious material and a good Class N Pozzolan.
7. The HPC with 5%RHA internally cured with 0.2% SAP has a higher value compressive strength when compared with the control (i.e. 7.5%SF internally cured with 0.2% SAP).
8. As the percentage of RHA increases, the compressive strength decreases for both presoaked pumice and SAP internally cured HPCs.
9. 5% content of RHA and 5% pre-soaked pumice are recommended for use as Nigeria local SCM and IC-agent in HPC.

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