Compressive Strength of Millet Husk Ash as Alternative to Silica Fume in Internally Cured High Performance Concrete

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Abstract

Challenges of deterioration and premature failure of concrete structures made with normal concrete (NC) has led to the development of high-performance concrete (HPC) which is a low water-binder and very dense concrete. However, lack of adequate internal water for proper curing in HPC are noted to result in autogenous shrinkage and micro-cracking for which existing literature showed are often addressed by incorporating internal curing (IC) agents such as superabsorbent polymers (SAP) and pre-saturated lightweight aggregate (LWA). Also of note is that HPC production requires additional supplementary cementitious materials (SCM) especially Silica fume – a material not readily available in Sub-Saharan Africa like Nigeria. This study thereby is a report of attempt at utilizing Millet husk ash (MHA) as SCM in HPC as an alternative to Silica fume for the development of a sustainable built environment in the era of COVID-19. The HPCs were internally cured with presoaked pumice as LWA and SAP respectively with the view to establish the effectiveness of Nigeria supplementary cementitious material (MHA) and IC-agent (presoaked pumice) for production of HPC. This article presents results of 28th day compressive of C55/67 HPC mixtures for 100 mm concrete cubes having 7.5% silica fume content in comparison with MHA based HPC of varied (2.5%, 5%, 7.5%, 10% and 15%) MHA contents. The SAP and Presoaked pumice contents were maintained as 0.2% by weight of binder (b_{wob}) and 5% by weight of coarse aggregate (b_{woca}) and the cubes were subjected to curing in water by immersion for 28 days before testing.HPC mix with 2.5%MHA internally cured with 5% pre-soaked pumice and 0.2% SAP content gave the best performance having 28th day compressive strength of 53.58N/mm^2 and 55.62N/mm^2 respectively.

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

1.0 INTRODUCTION

Concrete is a composite material made by mixing cement, water and aggregates (Neville, 2012; Mudashiru *et al*. 2021). The foundation of the material is cement which when mixed with water forms a paste that binds aggregates together thereby setting to form a hard material called concrete. The strength of concrete is commonly considered as the most valuable property because it usually gives an overall picture of the quality of concrete and it is the most vital element of structural design which is specified for compliance purpose (Olawuyi *et al*., 2020, Mudashiru *et al.*, 2021). Many materials are being added to concrete to improve its properties in both fresh and hardened state, but still serve the same purpose as cement and with good workability (Olawuyi *et al*., 2020).

Challenges associated with deterioration and premature failure of normal concrete (NC) structures has led to the development of high-performance concrete (HPC) which is a solution to normal concrete (NC) (Mudashiru *et al*. 2021).Nowadays, high performance concrete (HPC) is mostly used in the construction industries for constructing tunnels, bridges, tall buildings because of its high durability, high strength, low water: binder (W/B) ratio, high modulus of elasticity (Aïtcin, 2004 and Orosz, 2017).

With HPC, thinner structural members can be constructed thereby giving rise to an aesthetically appealing structure (Nduka *et al.* 2020). The construction of structural member using HPC will help to reduce the amount of steel to be used, reduce the entire structure pressure, and increase functional spaces in buildings. Hence, greater architectural freedom, nearly unlimited structural shapes, forms, and near free reinforcement bars which results to lower labour and cost can easily be achieved by architects and designers (Wang *et al*., 2015).

The amount of cement and supplementary cementitious materials (SCMs) added to the HPC mix usually cause an increase in temperature on addition of water and densification in the concrete area. The study of Savva *et al*. (2018) on direct relationship between ambient temperature and cementitious materials reveal that the grains of the cementitious materials are usually influenced by ambient temperature, hence fast reaction which obstruct uniform distribution of hydration products and makes the hydrated gel to be more porous. The incorporation of SCMs causes autogenous shrinkage, chemical shrinkage, and self-desiccation resulting from the combined effect of hydration and pozzolanic reaction and this has led to an increase in water demand in the concrete (Wu *et al.*, 2017).

One of the most effective and efficient way of providing solution to these challenges in concrete production is by using a curing method called internal curing (IC). IC method has been reported to be one of the most effective and efficient way of reducing risk associated with autogenous shrinkage since low permeability of HPC renders external curing not to be sufficient enough for water to penetrate into the concrete (Olawuyi *et al.*,2017, Mudashiru *et al*. 2021). Hence, the incorporation of IC agents which has the ability to absorb water and release it in to the system when the need arises.

Researches has been carried out on the use of different IC agents in HPC production with lightweight aggregate (LWA) and superabsorbent absorbent (SAP) being the most commonly used in literature (Mudashiru *et al*. 2021). Hence, this article will focus on performance assessment of MHA as alternative to SF in internally cured High performance concrete with the view to establish the effectiveness of Nigeria supplementary cementitious materials (MHA) and internal curing agent (pre-soaked pumice) in HPC production for the development of sustainable built environment in the era of COVID-19.

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials

The materials used for this research are binders (PC, SF and MHA), fine aggregates (sand), coarse aggregate, super plasticizer, pumice, superabsorbent polymer (SAP) and water.

The PC for this study was Dangote brand (3X) of Portland cement (CEM 42.5N) whose properties conform to the requirements of NIS 444-1:2014 and BS EN 197-1: 2016. It was purchased from a cement store in Gidan-Kwano; Minna, Niger State.

The MHA which was used as (SCM) was obtained from the incineration of the husk using the locally fabricated incinerator available at the Concrete Laboratory of the Department of Building, Federal University of Technology (FUT), Minna, Niger State. The burning took place in an open air for about 24 hrs with a temperature just below 700^{o}c and then allows to cool before harvesting and milling with grinding machine. The milled MHA was sieved with 75µm in accordance to ASTM C430- 2014 before storing in an airtight polythene bag.

The SF used as the second SCM for this study was purchased from Purechem chemical company in Lagos.

The fine aggregate used for this research is natural sand with minimum particle size of 300 μm which is the required specification for HPC production (Shetty 2004, Neville, 2012, Nduka *et al.*, 2020; Olawuyi *et al.*, 2020). The physical characteristics of the sand (i.e., specific gravity (SG); fineness modulus (FM); coefficient of uniformity (C_u); coefficient of curvature (C_c); and dust content) were analysed using the sieve analysis.

SAP (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 and Boshoff (2017) considering 12.5 g/g as the SAP absorption capacity conforming to the requirement of SAP specification for the production of HPC determined by tea-bag test result of 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 which was later crushed and 12.5 mm maximum size was incorporated. The pumice was soaked in water for 24 hrs after which it was drained before use (Olawuyi *et al.*, 2020).

Crushed granite stone which passed through 13.5 mm sieve size and retained on at least 9.5 mm sieve size was used as coarse aggregate in compliance with typical HPC mixes found in literature (Aitcin, 2004; Beushausen and Dehn, 2009; Neville, 2012; Olawuyi & Boshoff, 2018; Nduka *et al.*, 2020;

Olawuyi *et al.*, 2021). The coarse aggregate was washed to remove dust impurities for less water demand by the mixture.

The water for the study was portable water from the tap behind the convocation Square of Federal University of Technology, Minna, Niger State in accordance with the specification of BS EN 1008 (2002) and was used for the mixing at 0.3 W/B (Ogunbayo *et al*, 2018).

A Sky 504 Mastergleniumpolycarboxylic ether (PCE) superplasticizer supplied by Armorsil Manufacturing Incorporation was used as the chemical admixture (superplasticizer) and was administered at 1.5% concentration by weight of binder (b_{wob}) in the typical HPC mixtures in accordance with manufacturers specification with conformity with cement ascertained as recommended in the work of Aitcin (1998) reported in Olawuyi (2021).

2.2 Methods

2.2.1 Properties of constituent materials

The oxide compositions of binders (MHA, SF & OPC) were conducted using X-ray Fluorescent (XRF) at the Laboratory of the National Geoscience Research Laboratory, Kaduna State. About 100g of these binders were packaged in sealed polythene bags and sent after the calcination, grinding and sieving for the determination of the oxide compositions in accordance with BS EN 196-6: 2016. The particle size distribution of the aggregate's samples (i.e., the sieved sand and granite stone) was determined by wet sieving while the specific gravity of the aggregate and binders were also determined in the Building Laboratory of FUT, Minna in accordance with EN 12390-7.

2.2.2 Production of HPC Specimen

In accordance with the work of Olawuyi *et al.*, 2021, mean target strength of C55/67 at 28 dayswas adopted as the mix design procedure for material proportioning for HPC production. Table 1 shows mix proportioning of the HPCs with 5% of pre-soaked pumice by weight of coarse aggregate (b_{woca}), and 0.2% SAP by weight of the binder.

Table 1: Mix proportioning of the HPC mixtures

Mix proportion	Materials (Kg/m^3)								
	PC	SF	MHA	F/Agg.	C/Agg	pumice	SAP	SP	water
With 5% pre-soaked pumice									
M0a	499.5	40.5		700	997.5	52.5		8.1	156
M1a	526.5		13.5	700	997.5	52.5		8.1	156
M2a	513		27	700	997.5	52.5		8.1	156
M3a	499.5		40.5	700	997.5	52.5		8.1	156
M4a	486		54	700	997.5	52.5		8.1	156
M5a	459		81	700	997.5	52.5		8.1	156
With 0.2% SAP									
M0b	499.5	40.5		700	1050		1.08	8.1	156
M1b	526.5		13.5	700	1050		10.8	8.1	156
M2b	513		27	700	1050		1.08	8.1	156
M3b	499.5		40.5	700	1050		1.08	8.1	156
M4b	486		54	700	1050		1.08	8.1	156
M5b	459		81	700	1050		1.08	8.1	156

NB: F/Agg = Fine Aggregate; C/Agg = Coarse Aggregate; SP = Superplasticizer; **M0**=92.5%PC+7.5%SF; **M1**=97.5%PC+2.5%MHA; M2**=**95%PC+5%MHA; **M3**=92.5%PC+7.5%MHA; **M4**=90%PC+10%MHA; **M5**=85%PC+15%MHA; **a**=5% pre-soaked pumice; **b**=0.2% SAP

The SAP contents 0.2%b_{wob}) was used for the SAP internally cured HPCs with additional water of 12.5 g/g provided for SAP absorption while 5% by weight of the coarse aggregate of the saturated pre-soaked pumice was measured and used for the Pumice internally cured HPCs. After 24 hours, the cast 100 mm cubes HPCs were de-moulded and cured by full immersion in water for 28days before testing for compressive strength.

2.2.3 Fresh and strength properties

The preparation and curing of HPC samples were made in accordance to BS EN standards (BS EN 12350 -1 & 5, 2000; 12390-1 & 2, 2000; 12390 - 3, 2002) for compressive strength. The compressive strength tests were performed on 36 samplesat 0.5 N/mm^2 rate of loading using 2000kN loading capacity ELE Compressive Strength Testing Machine with a model number AT-120-1.1.

3.0 RESULTS AND DISCUSSION

3.1 Physical and Chemical Properties

Table 2 present the result of XRF analysis of the binders (MHA, SF & PC) powder. The result shows that The MHA is a Class N Pozzolan having total useful oxides (SiO_2 + Al_2O_3 + Fe_2O_3) content of87.2 %, which is above 70% minimum limit as specified in ASTMC 618 (2012). The SF major oxide is SiO_2 (96.2 %) implying that it is a very strong and reactive Class F Pozzolan in accordance to ASTM C618. The total SiO_2+Al_2O_3+Fe_2O_3 for the SF (96.91 %) is above the 70% specified for the Class of Pozzolan in ASTM C618. The PC on the other hands major oxide is calcium oxide (CaO – 64.35 %). This conformsto oxides composition for CEM II Portland cement found in literature (Neville, 2012; Mehta & Monteiro, 2014).

Table 2: Oxide Composition of Binder Constituents

Oxides	MHA (%)	SF (%)	CEM II (%)
SiO_2	71.05	96.20	25.64
Al_2O_3	14.66	0.45	5.24
Fe_2O_3	1.49	0.26	7.15
CaO	1.55	0.05	64.35
MgO	0.73	0.03	0.41
SO_3	0.67	0.10	0.11
K_2O	5.21	0.02	0.05
Na_2O	1.16	0.02	0.31
M_2O_5	2.06	0.50	0.04
P_2O_5	1.19	0.4	0.03
LOI	2.10	1.02	0.00
SiO_2 + Al_2O_3 + Fe_2O_3	87.20	96.91	38.03

Figure 1 and Table 3 show the physical properties of the aggregate used for the study. From the result it reveals that the fine aggregate is in conformity to the medium sand classification of Shetty (2004) having a uniformity coefficient (C_u) of 2.39, coefficient of curvature (C_c) of 0.94 and fineness modulus (FM) of 2.88.

Table 3: Summary of sieve analysis 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		

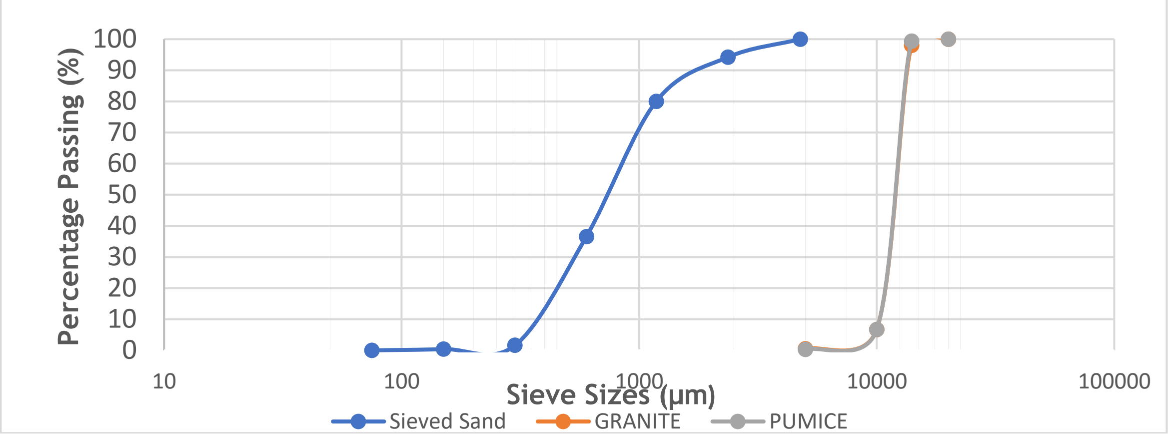

Figure 1: sieve analysis/particle size distribution of aggregates

Table 4 present the specific gravity of the constituent materials (PC, MHA, SF and aggregates). The results gave the values as 3.14, 2.63, 2.24, 2.85, 2.85 and 1.77 for PC, MHA, SF, sand, granite and pumice respectively. The values are inconformity with the previous reports found in literature (Neville, 2012).

Table 4: Specific Gravity of PC, MHA, CCW and aggregates

Materials	PC	MHA	SF	F/Agg.	Granite	Pumice
Specific gravity	3.14	2.63	2.24	2.85	2.85	1.77

3.2 Fresh and strength properties

Workability test for each of the HPC mixture with 5% pre-soaked pumice and 0.2% SAP was examined using slump flow test as described in BS EN (12350 - 5 - Part 1) before the production of the specimens. From figure 2 below, the slump flow value for the various HPCs with 5% of pre-soaked pumice are 490, 505, 520, 530, 545 and 560 mm while slump flow of HPCs with 0.2% of SAP are 510, 518, 525, 540, 555 and 570 mm. The slump flow increases as the percentage of MHA increase for both HPC containing 5% pre-soaked pumice and 0.2% of SAP. However, the slump flow values of the HPCs with 0.2% of SAP is higher when compared with that cured internally with 5% pre-soaked pumice. It was also observed that the slump flow values for all the HPC mixtures are within permissible value of 460-600 mm as the standard requirement for HPC production as specified by the code. This implies that irrespective of the IC-agents incorporated, the workability was within acceptable limit.

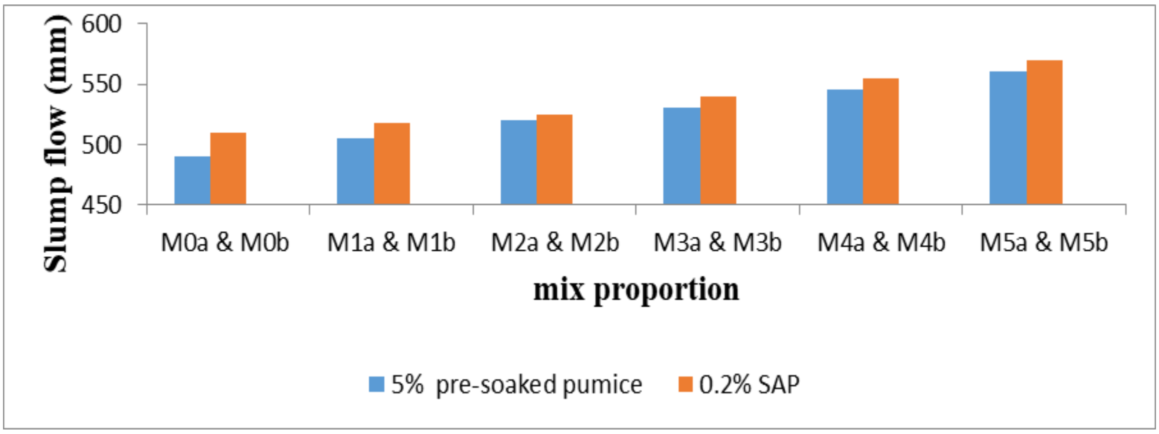

Figure 2: Workability of HPCs

M0=92.5%PC+7.5%SF; **M1**=97.5%PC+2.5%MHA; **M2**=95%PC+5%MHA; **M3**=92.5%PC+7.5%MHA; **M4**=90%PC+10%MHA; **M5**=85%PC+15%MHA**a**=5% pre-soaked pumice; **b**=0.2% SAP

Figure 3 present the compressive strength of the HPCs cured in water at 28days of age. The values obtained for all the HPCs with 5% pre-soaked pumice are; 58.62, 53.58, 52.04, 50.21, 47.73 and 45.90. While the HPCs with 0.2% SAP are 59.86, 55.62, 53.29, 52.70, 49.54 and 48.08. The result revealed that as the percentage of MHA increases, the value of compressive strength decease for both HPCs mix with 5% pre-soaked pumice and 0.2% SAP but HPCs mixes with 0.2% SAP was observed to have the highest value of compressive strength when compared with HPCs with 5% pre-soaked pumice at 28 days of curing. From the figure, it also shows that the HPC with 7.5%SF was the highest follow by 2.5%MHA, 5%MHA, 7.5%MHA, 10%MHA and 15%MHA as the least.

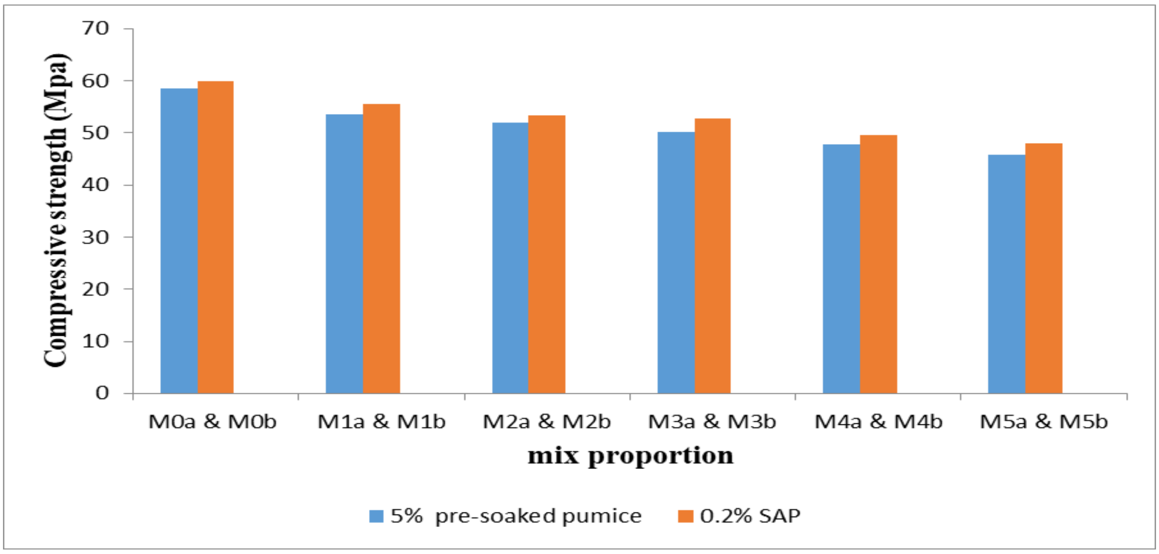

Figure 3: compressive strength of HPCs cured in water at 28 days
M0=92.5%PC+7.5%SF; **M1**=97.5%PC+2.5%MHA; **M2**=95%PC+5%MHA; **M3**=92.5%PC+7.5%MHA; **M4**=90%PC+10%MHA; **M5**=85%PC+15%MHA
a=5% pre-soaked pumice; **b**=0.2% SAP

4.0 CONCLUSION AND RECOMMENDATION

From the study, the following conclusion was deduced;

1. The SF and MHA used for the study were a good Class F and N Pozzolan with physical and chemical properties that conform to ASTM C618 specifications.
2. 2.5%MHA HPC has a closer value of compressive strength when compared with 7.5%SF HPC for both pre-soaked pumice and SAP internally cured HPC.
3. The compressive strength of HPCs internally cured with 0.2% SAP is more than the compressive strength of HPCs internally cured with 5% presoaked pumice.
4. The compressive strength of HPCs decrease as the MHA content increases for both 5% presoaked pumice and 0.2% SAP With 2.5%MHA having the highest value of compressive strength of 53.58 and 55.62 for 5% pre-soaked pumice and 0.2% SAP content respectively. Also, the compressive strength of HPC with 2.5%MHA internally cured with 0.2% SAP is higher than the strength of HPC with 2.5%MHA internally cured with 5% pre-soaked pumice.
5. MHA content of 2.5% and 5% pre-soaked pumice are recommended for use as Nigeria local SCM and IC-agent in HPC.

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