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Mechanical and Durability Properties of Engineered Cementitious Composite Containing High Volume of Pozzolanic admixture

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ABSTRACT: *This research was carried out to evaluate the effects of high amount of pozzolana admixture on strength and durability properties of concrete. Mechanical properties considered were compressive strength and tensile strength, the durability properties considered were: water permeability, sulphate permeability and corrosion of concrete. A reference concrete was proportioned to attain the 28-day compressive strength of 40 MPa. Locust bean pot ash, (a pozzolana material) was used at three levels as cement enhancer (40, 50, and 60% by volume) in producing concrete mixtures. The water to cementitious materials ratio was maintained at 0.50 ± 0.02 for all mixtures. In general strength and durability properties of concrete were considerably affected by the amount of Locust bean pot ash. Also, the strength and durability properties was increased for the 40%. Locust bean pot ash mixture were either comparable or superior to the no-Locust bean pot ash concrete. The corrosion resistance of Locust bean pot ash concrete was either comparable to or better than the non-Locust bean pot ash concrete, except for one source of Locust bean pot ash at 60% addition level. All the mixtures, with and without Locust bean pot ash, tested in this investigation conformed to the strength and durability requirements for excellent quality structural grade concretes.*

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I. INTRODUCTION

The rate of deterioration and the durability is directly relate to the permeability of concrete which depends on the w/c-ratio. This has been reported by [1] among others and in the BS guidelines for concrete in aggressive ground [2] which specifies w/c ratio for certain sulphate classes. Increasing the cement content could also have the effect of reducing the degree of deterioration but not eliminating it [3, 4]. Similarly, the incorporation of large amounts of inert filler material, for example limestone powder, into concrete may influence the microstructure the capillary pore size distribution and the permeability. The effect may be negligible, positive or negative depending on the coupling between w/c-ratio, cement powder ratio (c/p), filler cement ratio (f/c) and water powder ratio (w/p) [5, 6].

Various types of admixtures are used in concrete to enhance the performance of concrete. Concrete admixture is defined as the material other than the aggregate, water and cement added to the concrete. Pozzolanic admixtures are used to prepare dense concrete mix which is bets suitable for water retaining structures like dams, reservoirs etc. They also reduce the heat of hydration and thermal shrinkage. Best pozzolanic materials in optimum quantity gives best results and prevents or reduces many risks such as alkali aggregate reaction, leaching, sulphate attack etc. Pozzolanic materials used as admixtures are either natural or artificial. Naturally occurring Pozzolanic materials are clay, shale, volcanic tuffs, pumicite, etc. and artificial pozzolans available are fly ash, silica fume, blast furnace slag, rice husk ash, etc. A pozzolan is a material which, when combined with calcium hydroxide, exhibits cementitious properties. Pozzolans are commonly used as an addition (the technical term is "cement extender") to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete and in some cases reduce the material cost of concrete.

In recent years, the use of solid waste derived from agricultural products as pozzolans in the manufacture of blended mortars and concrete has been the focus of researchers in the construction materials sector. The addition of ashes from combustion of agricultural solid waste to concrete is at present, a frequent practice because of the pozzolanic activity of the ashes toward lime. As a result of increased industrial and agricultural processes across the globe, there has been significant increase in industrial and agricultural wastes which most often have negative impact on the environment. Much research efforts in recent times are geared towards possible ways of recycling these wastes for re-use to keep the environment clean and safe.

Locust bean pod which is a Waste Agricultural Biomass and obtained from the fruit of the African locust bean tree (Locust bean Pot) is the material resource required for the production of Locust Bean Pod Ash (LBPA). The harvested fruits are ripped open while the yellowish pulp and seeds are removed from the pods; the empty pods are the needed raw material. The pods make up 39% by weight of the fruits while the mealy yellowish pulp and seeds make up 61%. The locust bean tree is being cultivated over a wide area within the African sub region [7].

This paper presents the feasibility of the usage of Locust bean pot ash (LBPA) as admixure for Conventional Concrete. Tests were conducted on cubes and cylinders to study the strengths and Durability properties of concrete made of LBPA for three different proportions.

II. MATERIAL AND EXPERIMENTAL METHODS AND PROCEDURES

Materials

Locust Bean Pod Ash (LBPA

The Locust Bean Pods used in this research were sourced from Wa in the Upper West Region of Ghana. The material is usually available as a waste product of agricultural processing of the locust bean fruits during the harvest season.

Cement

Ordinary Portland Cement (43 Grade) with 28 percent normal consistency Conforming to BS [8] was used.

Cement aggregate (Natural river sand)

River sand having density of 1460 kg/m^3 and cementness Modulus (FM) of 2.51 was used. The specific gravity was found to be 2.6.

Coarse aggregate

Natural granite aggregate having density of 2700kg/m^3 and cementness modules (FM) of 6.80 was used. The specific gravity was found to be 2.60 and water absorption as 0.45%.

Admixture

Commercially available Super-plasticiser was used to enhance the workability of fresh concrete for selected proportions of ingredients.

Method and Procedure

Studies were done for concrete with LBPA and compared with the Conventional Concrete. A series of concrete mixtures with varying percentages of pozzolana was prepared aimed at increasing the e strengths and optimizing the pozzolana dosage. The pozzolan content in the mix was fixed at 40%, 50% and 60% by volume of cement.

Production of LBPA

The LBPA was prepared by burning large mass of the locust bean pod in the incinerator at temperatures of up to 500 C. The residue was then left to cool and sieved using BS Sieve 42.5µm to obtain a fine powdery form which is needed for chemical analysis. Temperature was control in the combustion process which allowed some degree of confinement of the biomass during combustion. The ratio of the LBPA residue to the pod produced from the combustion process was 1:20 by weight. Thus, every 10kg of the pod that was burned, the weight of the ash produced was 500g.

Mix Design

The method mix design proposed by BS 1881 [9] were employed to design the Conventional Concrete mixes and LBPA was added to concrete mixes as an enhancer. The purpose of mix proportioning is to produce the required properties in both plastic and hardened concrete by working out a combination of available materials, with various economic and practical standards.

Specimen preparation

The 150 mm size concrete cubes, concrete cylinder of diameter 150 mm and 300mm height were used as test specimens to determine the compressive strength and split tensile strength respectively. The specimens were cast for C40 grade and for coarse aggregates of size 10-12 mm was used. The workability of fresh concrete was measured in terms of slump values. To obtain the required slump value, superplasticiser (0.7 to 2.4 % of weight of cement) were added. The properties of fresh concrete were measured according to BS 1881 [9]. The ingredients of concrete were thoroughly mixed in mixer machine till uniform consistency was achieved and compacted on compacted table in three layers with each layer being compacted for about 30 seconds. The specimens were de-moulding after one day and cured under water until the age of 28 days.

Test Methods

Compressive strength

The compressive strength test was determined using by universal testing machine of capacity 1000kN. A universal testing machine can provide a consistent testing on a wide range of specimens through a hydraulic pump and a digital readout system.

Splitting tensile strength

Splitting tensile test was performed according to [9]. The determination of the splitting tensile strength was done by conducting the splitting tensile test on the cylindrical specimens of diameter 150mm and height of 450mm. The concrete specimens were placed horizontally between plates of the universal testing machine. In order to support the testing specimens, narrow strips of plywood were required to interpose between the specimens and the plates. The strips were usually a 3mm thick and a 25mm width as per [9]

Figure 1. compression and Split Tensile test set-up

III. DURABILITY STUDIES

The objective of this durability study was to investigate the drying and shrinkage studies, deterioration, and water absorption studies for both Conventional Concrete and LBPA concrete.

Water absorption

Water absorption tests were conducted on the control cement paste specimens and the cement paste modified with the ashes. The test was carried out in accordance to [10], ASTM C (642-1997). In the test procedure, the specimens were dried in an oven at (100-110°C) for 24 hours, and then their masses were measured. Next, the specimens were fully immersed in a water tank for 24 hours, then they were taken out. Their surfaces were dried with a cloth and finally their weights were measured again. The test was conducted on the specimens at a curing ages of 28 days, and the percentage of water absorption was calculated from the following equation:

Water absorption (%) = (W2-W1)/W1 × 100 (2)

Corrosion test

The concrete cubes of 150 × 150 × 150 mm were mad with 10 mm diameter and 300 mm length of steel rod inserted at the middle of the cubes. After 24 hours, the cubes were demoulded and placed in water tank for curing for 28 days. The cubes were removed from the tank after curing and allowed to dry for 7 days. After the cubes were dried, they were placed in a tank containing sea water. The cubes were then observed for corrosion that occurred on the surface of the concrete away from the steel rod position after one week, two weeks, three weeks and four weeks [11] (ASTM C876 - 15).

Deterioration of concrete test

The experimental samples were cubes of 150 mm in side length and were cured under standard conditions for 28 days. The concrete cubes were soaked in 10% sodium sulphate solution for 30 days at 25°C. The cubes were dried for 1 hour at room temperature and then placed in an oven for 1 hour at 40°C and then naturally cooled for another 1 hour. The samples were tested for compressive strength [12].

IV. RESULTS AND DISCUSSIONS

Particle Size Distribution of LBPA

The particle size distribution of LBPA is shown in Figure 2, it can be seen that the percentage mass retained on ASTM C136-06 (2006) sieve 425 µm is 30 %.

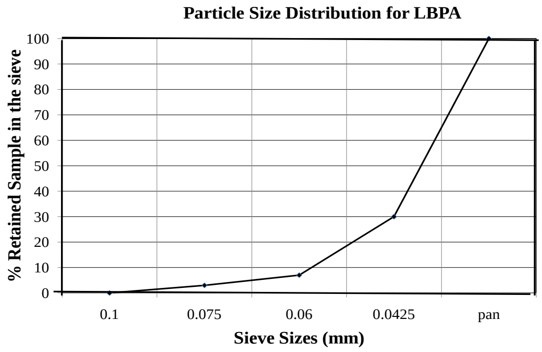

Figure 2. Particle size distribution for LBPA

Chemical Analysis

The LBPA was prepared and analyzed for its chemical composition at the facilities of Forest Research Centre of Centre for Scientific and Industrial Research (CSIR), Ghana. laboratory. The test results showing quantities of the respective constituents of the ash sample are presented in Table 1.

Table 1. Chemical composition of Locust bean pot ash

Chemical composition	Na_2O	K_2O	MgO	PbO	Fe_2O_3	Al_2O_3	CaO	SiO_2	L.O.I
%	1.2	4.65	2.0	5.64	12.51	14.40	15.71	40.07	3.82

From the result of the chemical analysis of LBPA as shown in Table1 it can be seen that while the sum total of the combination of the chemical compounds (Sio + Al O + FeO) was about 67%, which when compared with standard specifications (ASTM Specification 12 C618-92a) , LBPA will fall under the class C mineral admixture class and thus can be considered a pozzolana.

Workability

The variation of workability of fresh concrete is measured in terms of slump, with water/cement ratio and reported in Tables 2. For the given water/cement ratio, the highest slumps was recorded for the mixes designed by British method. The overall workability value of LBPA concrete is less compared to conventional concrete. The slump height decreased with increased in LBPA content.

Table 2 Slump height

Sample	Slump (mm)	Quantity of super-plasticiser added by weight of cement (%)	Adjusted slump (mm)
C0	60	0	60
C40	53	0.7	62
C50	48	1.0	62
C60	42	1.2	60

Compressive strength

The compressive strength increased with increasing the curing period for all concrete mixtures in Table 3. Concrete with LBPA gained higher early compressive strength than the concrete with no LBPA. The early effect of the ashes may be due to its influence on accelerating the pozzolanic transformation of C3S, C2S and CH into the C-S-H gel which were responsible for the strength improvements of the concretes [9]. The compressive strength of LBPA concrete were either comparable or superior to the no-Locust bean pot ash concrete. The concrete mixtures with 40% content ash had the highest compressive strength at all curing periods due to the adequate smaller particle size, which were superior in filling the concrete pores [13]. Studies reported here has shown that the compressive strength of 40% LBPA concrete is comparatively 5.0 percent more than that of similar mix of conventional concrete

Table 3. Compressive strength properties of samples

Specimens	**Curing Age (days)**			
	7	**14**	**21**	**28**
OPC/0	27	32	38	40.0
OPC/40	32	34	40	42.0
OPC/50	30	32	36	39.8
OPC/60	28	31	35	38.2

The regression analysis in Table 4, indicates that, curing age, LBPA had significant effects on the compressive strength of concrete and the equation generated is adequate for making predictions (F=390.775, P<0.001). The coefficient of multiple determination, R^2 shows that about 98% of the variations in the compressive strength could be explain by the curing age, amount of LBPA used for the concrete (R^2 = 0.977, Adjusted R^2 = 0.974). It can be found from regression equation (2) that, upon increasing curing age by one day, the compressive strength increased by 0.525N/mm^2 (t=18.024, P<0.001) Again, upon increasing LBPA as by one percent will result to an increase of the compressive strength by about 1.2N/mm^2 (t=7.553, P<0.001) when all other variables are kept constant. From the Beta values the variance in the compressive strength was mostly influenced by curing age and more influenced by the addition of LBPA.

Table 4. Statistical analysis of compressive strength

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
1	(Constant)	40.062	.822		12.243	.000
	CURING AGE	.525	.029	.520	18.024	.000
	LBPA	1.193	.158	.256	7.553	.000

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig.
1	.988[a]	.977	.974	1.28953	390.775	.000[a]

a. Dependent Variable: Compressive Strength b. Predictors: (Constant), Curing Age and LBPA

F_{cu} = 40.062 + 0.525CA +1.193LBPA ……………… (2)

Splitting tensile strength

The tensile strength results of the concretes and the concretes with different LBPA percentages are presented in Table 5. The tensile strength of the concrete prepared with different LBPA was higher than the tensile strength of the control concretes samples except when replaced with 60% LBPA. The reason for this may be related to the large surface area of LBPA which promote the pozzolanic reaction to form C-S-H gel which in turn gives the mixture its strength [13]. The tensile strength consistently increased with the increase in the curing age for all concrete mixtures. It can also be observed that the highest tensile strength was gained for concrete mixture with 40% LBPA at the curing age of 28 days.

Table 5. The tensile strength

Specimens	**Curing Age (days)**			
	7	**14**	**21**	**28**
OPC/0	2.8	3.0	3.3	3.8
OPC/40	3.3	3.6	3.8	4.5
OPC/50	3.0	3.2	3.5	4.2
OPC/60	2.0	2.6	2.8	3.1

Table 6 for regression equation indicate that, curing age, LBPA had significant effects on the split tensile strength of concrete and the equation generated is adequate for making predictions (F=312.513, P<0.001). The coefficient of multiple determination, R^2 shows that about 99% of the variations in the tensile strength could be explain by the curing age, amount of LBPA used for the concrete (R^2 = 0.985, Adjusted R^2 = 0.971). It can be found from regression equation (3) that, upon increasing curing age by one day, the split tensile strength increased by $0.51N/mm^2$ (t=15.387, P<0.001). While, upon LBPA increased by one percent will result to an increase of the split tensile strength by $0.153N/mm^2$ (t=-8.584, P<0.001) when all other variables are kept constant. From the Beta values the variance in the split tensile strength was much influenced by the addition of LBPA but mostly by the curing age.

Table 6. Statistical analysis of tensile strength

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	.916	.093		9.880	.000
	Curing Age	.051	.003	.495	15.387	.000
	LBPA	.153	.018	.324	8.584	.000
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig.
1	.985[a]	.971	.968	.14540	312.593	.000[a]

F_{ten} = 4.916 + 0.51CA +0.153LBPA ……………… (3)

Corrosion test

The areas of corrosion that occurred as observed on weekly basis and the areas of corrosion coverage were subsequently calculated as shown the Table 7.

Table 7. Area of corrosion

Sample	Area of corrosion (mm^2)			
	1st Week	2nd Week	3rd Week	4th Week
OPC/0	12.57	16.24	22.18	24.37
OPC/40	7.07	12.91	14.91	19.53
OPC/50	7.14	11.71	14.57	19.01
OPC/60	6.77	11.14	14.22	18.74

The area of coverage of corrosion stains was reduced as the LBPA content increased. There was significant increased in the corrosion resistance when LBPA was added. At the end of week four there was a decreased of coverage stains from $24.37mm^{2,}$ when no LBPA was added to the concrete sample, to 18.74 mm^2 when 60% of cement was replaced by LBPA. There was no significant effect when the LBPA was increased beyond 40%.

Water absorption

Water absorption was measured by the increase in weight for a specimen stored for 28 days in a laboratory environment and then immersed in water for 24 hours. The increase in weight is summarised in Table 8. LBPA concrete composite reduced substantially the absorptivity from 10.4% for 0% LBPA content to 7.2% ,8.5%, and 8.8% when LBPA contents were 40%, 50% and 60% respectively. The presence of LBPA content thus resulted in lower migration of water into the block (i e. lower permeability). The LBPA content makes the sample less porous and more impermeable than the control sample, probably by infilling the voids thereby reducing paths for water ingression.

Table 8. Water absorption of samples

Samples	Water Absorption (%)
OPC/0	10.4
OPC/40	7.2
0PC/50	8.5
OPC/60	8,8

Deterioration of concrete test

The Durability of LBPA concrete under sulphate action is higher than Conventional Concrete (Fig 3). The compressive strength decreased by 43%, 28%, 32% and 38% for OPC/0, OPC/40, OPC/50 and OPC/60 respectively. The Concrete with LBPA performed better than the control specimen. This may be due to the fact that the silicate gel produced during hydration processes, proceeds immediately to coat and bind matrix together and to block off the sulphate action in the concrete structure. In time this gel gradually crystallizes into well defined calcium silicate hydrates and the micro crystals also interlocking preventing damage by the sulphate [8].

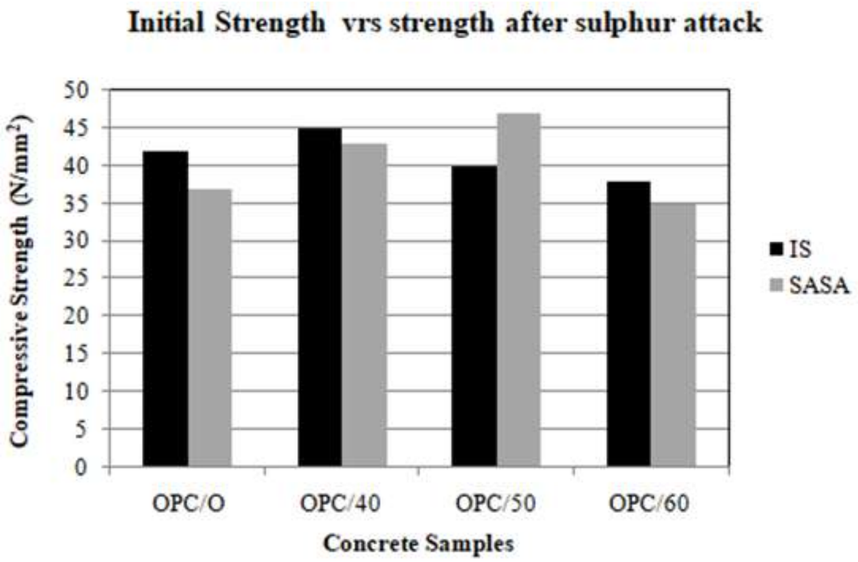

Figure 3. Mechanical properties of samples

V. CONCLUSIONS

Based on the above discussions, the following conclusions are drawn: chemical properties of LBPA is satisfied the requirements of pozzolana. Studies reported here and elsewhere have shown that the strength of LBPA concrete is comparatively 712 percent more than that of similar mix of Conventional Concrete. The Durability of LBPA concrete under sulphate action is higher to the Conventional Concrete. The water absorption of LBPA concrete is slightly lower than Conventional Concrete. Therefore, the results of this study provide a strong support for the use of LBPA as cement aggregate in Concrete Manufacturing. Thus, it can be concluded that the replacement of cement with LBPA partial replacement in concrete is possible. However, it is advisable to carry out trial casting with LBPA proposed to be used, in order to arrive at the water content and mix proportion to suit the required workability levels and strength requirement. However, more research studies are being made on LBPA concrete necessary for the practical application of LBPA as Cement Aggregate.

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