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Effect of additives on the mechanical properties of some cement products

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ABSTRACT

In this work the effect of additives on the mechanical properties of some cement products were studied. After a 14day curing period, it was observed that, at 20% replacement level, PBA gave a compressive strength of 10.204 N/mm^2 whereas SDA concrete gave a compressive strength of 8.163N/mm^2. Similarly, compressive strengths of 5.405N/mm^2 and 14.80N/mm^2 were obtained for PBA and SDA respectively at 40% replacement level. These fell within the standard compressive strength for classes A, B and C blocks which are 4.0N/mm^2 (min.), 3.0N/mm^2 (min) and 2.5N/mm ^{2}(min), respectively. With the 20% and 40% replacement with PBA and SDA showing these compressive strengths, a larger amount of cements meant for mortar preparation would be saved and the wastes disposal problems would be avoided. Similarly, the sanitation problem created from the palm oil production as well as the furniture industries would be reduced.

INTRODUCTION

Waste disposal in every society has been a problem. From households through industries to institutions, waste generation and disposal have being a major concern. In view of this, several solutions of handling this problem have been developed. The utilization of residue from agriculture has primary and secondary energy source. For example, coconut shell, corncob, saw dust may be used as fuel without any suitable processing since they have low energy content [13]. Wastes from some agricultural produce are receiving attention now since they generally improve the properties of blended cement concrete [1]. In such a situation, the environmental problems associated with their disposal would be reduced [2,3] and also the mechanical properties affecting the cement-construction industries would be improved. Some additives may play an important role in further improvement of the soundness of cement by way of nullifying the harmful effects of the impurities present in the matrix [15]. Recently, the use of agriculture solid waste materials as additives in the manufacture of blended mortars and concrete has been the focus of research [4, 5, 6]. Rice is a seasonal crop which contains much starch and its husk is also abundant in many parts of the world. The amount of woody fiber or cellulose is considerable for rice with husk, but only slight for samples without husk. The excessive amount of ash in husk is very remarkable and the ash contains up to about 90 percent of silica (which is responsible for the flexural and compressive strength property of the cement). Sugarcane bagasse ash obtained by combustion consists of a high amount of silica (SiO_2) and unburned carbon which is used as an adsorbent and admixture of concrete and cement [12]. When rice husk is properly burnt at temperatures lower than 700^{o}C, Silica is obtained in amorphous form and with proper grinding (milling) becomes suitable for in Pozzolan cement. Similarly, when it is acetylated with NBS-catalyst it can be used as oil spill sorbent [11]. The reactive rice husk ash is used to produce good quality concrete with reduced $Ca(OH)_2$ and higher resistance to Sulphate attack. Similarly, there has been an innovative use of maize husk ash (MHA) as filler in concrete [7]. For example, MHA in the range of (0–30) % has been used in recent years as a partial replacement for ordinary Portland cement. In different mix ratios, it gives varying but improved concrete properties such as compressive, split tensile strengths, and modulus of rupture. Concrete is a composite that consists of cement, sand and steel rods to reinforce it [14]. Various studies have shown that the setting time of MHA concrete always increases with higher ash content, while the compressive, split tensile strengths and modulus of rupture shows a reverse trend. Saw dust ash and palm bunch ash are wastes from the wood and soap and palm oil industries respectively whose disposal has become a problem. Most of our furniture makers produce huge amounts of saw dust daily and its disposal have been a problem. Some have been deposited and have turned into heaps and people living nearby have taken advantage of this situation by turning the place into a refuse dump. Most of these piles up in our communities and when the wind blows, it is carried up into the atmosphere thereby polluting it. Sometimes it is burnt and the smoke fills the air for some time. In other for this to be avoided, another means should be employed where these wastes would be reused. Similarly, the palm bunch disposal has been a problem. A few is used as source of fire and the rest dumped in nearby bush. The most likely industrial section that could use for these materials is the cement block industries [8]. Cement block are manufactured from a mixture of Portland cement, sand and water in various proportions.

However, some properties of cement blocks with Saw Dust Ash (SDA) and Palm Bunch Ashes (PBA) as a replacement for Ordinary Portland Cement (OPC) have been investigated. If the amount of cement could be reduced and replaced with either of these wastes, the cost of production and prices of cement blocks could reduce. This would encourage more buildings to be put up to cater for the housing deficit that the country faces. Similarly, most of the pavement blocks would be produced to help in the city beautification project.

MATERIALS AND METHODS

Equipment/ Apparatus

(a) Mixer and mixing bowl
(b) Measuring balance (CYO J.K. 200)
(c) Straight-edged knife
(d) Vibrating machine
(e) Water-Resistant ink
(f) Cubic moulds(70mmx70mmx70mm)
(g) Damp cloth (wet)
(h) Impervious plastic plate
(i) Rubber scraper
(j) Spreader
(k) Oven

Operational Conditions

Curing temperature is at190^{o}C,
Temperature in preparation room is at 19^{0}C,
Humidity level not less than 60%,
Temperature for testing area is 19^{0}C

Raw materials

PLC class 32.5R (Portland Limestone Cement class 32.5 Rapid), Sand and Water

Additives
Palm-bunch Ash (PBA) and Saw-dust Ash (SDA)

Proportion of Mixing of Materials
Table 1 summarizes the variation of mixing proportions of mortar used. In table 1 the various ratio of the additives (PBA and SDA) are shown.

Table 1: Mixture of PBA and SDA in various proportions

Material	PLC (%)	PBA (%)	SDA (%)
PLC	100	-	-
20PBA	80	20	-
20SDA	80	-	20
40PBA	60	40	-
40SDA	60	-	40
60PBA	40	60	-
60SDA	40	-	60

Table 2 shows the details on the mixture of cement mixture with different proportions of additives added.

Table 2: Mixture of cement mixture with various proportions of additives

		Replacement levels of additives in percentages (%)		
Materials used	**No additive (g)**	**20%**	**40%**	**60%**
Mass of cement(g)	360	288	216	144
Mass of additive (g)	NIL	72	144	216
Mass of water (g)	108	180	180	180
Mass of sand (g)	1080	1080	1080	1080

(A) PREPARATION OF MORTAR WITHOUT ADDITIVE
Composition of the mortar
Each of the 2 (two) tests for a batch is made up of Cement, Water and Sand.

Batching of mortar
The Cement, Sand, Water and apparatus were kept at a laboratory temperature of 19^0C and the weighing was carried out using a balance with determination of ± 1.0g

Mixing of mortar
Each batch of mortar was mixed mechanically using the mixer. Measured quantities of cement and sand were poured into the mixer bowl and were stirred initially at low speed. Water was then added steadily after every 30seconds. The mixers speed was then switched to high for an additional 30seconds. After 90 seconds, mixing was stopped and the mortar adhering to the wall and bottom part of the bowl was removed using a rubber scraper and placed in the middle of the bowl. Finally, mixing was continued at high speed for 60 seconds.

(B) Preparation of the mortar (with additive)
Composition of the mortar
Each batch of 2(two) test specimens consist of cement, sand, water and additive of varying proportions (ref. to table 2)
Batching of mortar (with additive)

The cement, sand, additive (PBA or SDA) and apparatus were kept at a temperature range of (17-19)^{0}C and the weighing was carried out using a measuring balance.

Mixing of mortar (with additive)
Each batch of mortar containing either PBA or SDA was mixed mechanically using the mixer. A measured quantity of cement, sand and additive were poured into the mixer bowl and was turned on at low speed. After 30 seconds, water was steadily added and for an additional 30 seconds mixing was done at high speed. The mixer was stopped after 90seconds for the mortar adhering to the walls and bottom part of the bowl to be removed and placed in the middle of the bowl. Finally mixing was continued at high speed for 60seconds.

Preparation of test specimens
Size of the block specimen mold = (70x70x70) mm

Molding of test specimens
The specimens were molded immediately after preparation of the mortar. A (70mmx70mmx70mm) mould was filled with the paste using a spreader and was compacted using a vibrating machine. The excess mortar was stroked-off with a metal straight edge held horizontally and moved slowly with a transverse sawing motion once in each direction. The surface of the mould containing the paste was smoothened using the same straight-edged knife held almost flat. The mould was then labeled to identity the specimens.

Curing of test specimens
Handling and storage before demolding
A 75mmx75mm glass plate sheet of 6mm thickness was placed on the labeled placed in a moist place without delay. The moist air was made to have access to all sides of the mould. After 24hours, the mould was removed from storage and demoulded by dismantling to remove the specimen and cured in water at 19^{o}C.

Density of cured specimens
The density of the cured specimen after 7 days was determined using the mass and the volume of the cured specimen was also calculated as:

V, Volume of specimen = (70mmx70mmx70mm)

Volume of specimen = $(3.43\text{x}10^5)\ \text{mm}^3 = (3.43\text{x}10^{-4})\ \text{m}^3$

The measured mass of specimen divided by the volume of the specimen would give the density of the specimen.

Testing the specimen for compressive strength
The cubic specimens were centred laterally to the platens of the machine and the load was increased smoothly at the rate of about 2600N/Sec. over the entire load application until fracture.

Thus compressive strength, Cs in N/mm^2 was calculated as:

$$Cs = \frac{Fc}{A} \quad (1)$$

where *Fc* is the maximum load at fracture (N) and 4900mm^2 = 70mm x 70mm is the area (A) of one side of the cube.

Water absorption of specimens

The water absorption, (W_A) of a cured specimen was calculated as:

$$W_A = \frac{(W_F - W_i)}{W_i} \times 100 \quad (2)$$

Where W_F is the final weight after curing and W_i is the initial weight before curing.

RESULTS AND DISCUSSION

The results of the final densities of mortars after 7 days curing are given in table 3 above. It was observed that the final average densities of all the mortars (PLC, PBA and SDA) were almost the same. The reason is that, for each mortar preparation, a total initial mass of 1640g (equivalent to 1.64Kg) was used and was made to occupy a cubic mould of constant volume,

V= (3.43x10^{-4}) m^3. Table 3 summarizes the details on densities of cured specimen.

Table 3: DENSITIES OF CURED SPECIMENS

Cubic specimen type	Final Mass after curing (Kg)	Final Density after curing (Kg/m^3)	
		Density, P=M/V (Kg/m^3)	Average Density ,(Kg/m^3) (P1+P2)/2
PLC1	0.745	2.172 X 10^{-3}	2.1865 X 10^3
PLC2	0.755	2.201 X 10^3	
20PBA1	0.725	2.114 X 10^3	2.1065 X 10^3
20PBA2	0.720	2.099 X 10^3	
20SDA1	0.755	2.201 X 10^3	2.179 X 10^3
20SDA2	0.740	2.157 X 10^3	
40PBA1	0.690	2.012 X 10^3	2.019 X 10^3
40PBA2	0.695	2.026 X 10^3	
40SDA1	0.650	1.895 X 10^3	1.946 X 10^3
40SDA2	0.685	1.997 X 10^3	
60PBA1	0.685	1.997 X 10^3	2.012 X 10^3
60PBA2	0.695	2.026 X 10^3	
60SDA1	0.725	2.114 X 10^3	2.114 X 10^3
60SDA2	0.725	2.114 X 10^3	

Considering table 4 and figure 1, PLC (control) gave an average compressive strength of 22.45N/mm^2. At 20% replacement level, PBA gave an average compressive strength of 10.204 N/mm^2 whereas SDA concrete gave an average compressive strength of 8.163N/mm^2.

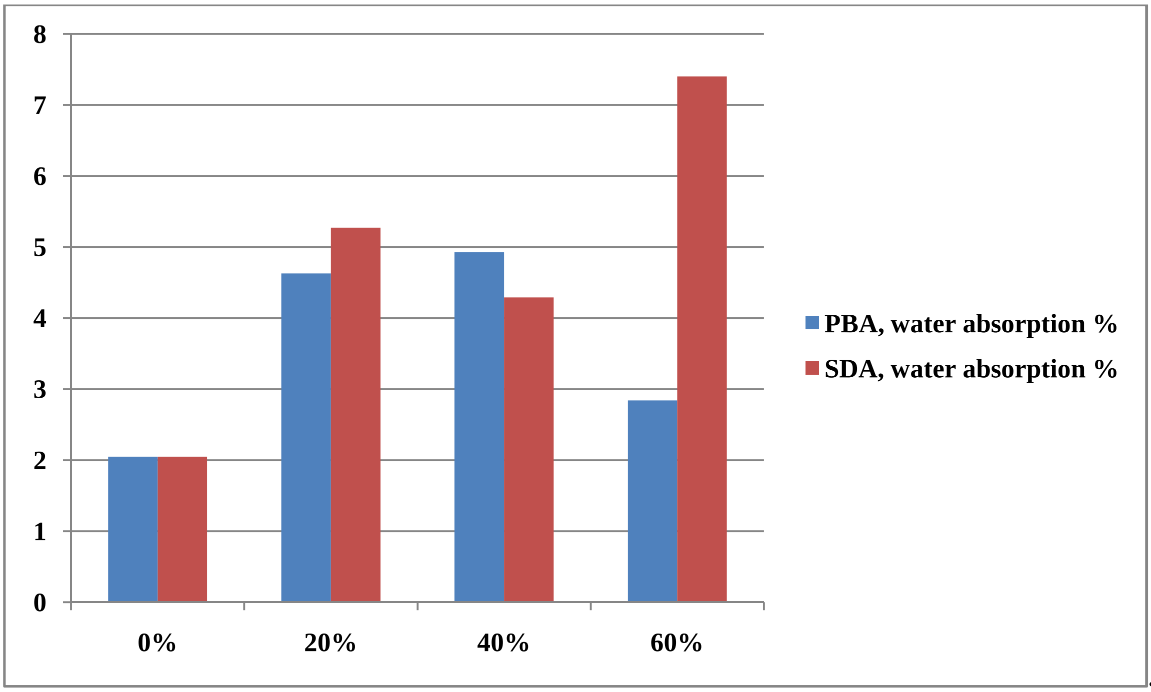

Figure 1: COMPRESSIVE STRENGTH VERSUS REPLACEMENT LEVEL

Table 4: COMPRESSIVE STRENGTHS OF CURED SPECIMENS

Cubic specimen type	Maximum load, L at fracture (KN) after curing	Compressive strength, Cs. Cs = Fc/A, (N/mm^2)	Average compressive strength, Cs, (N/mm^2)
PLC1	120.0	24.49	22.45
PLC2	100.0	24.41	
20PBA1	50.0	20.204	15.204
20PBA2	50.0	10.204	
20SDA1	40.0	8.163	8.163
20SDA2	40.0	8.163	
40PBA1	28.0	5.71	5.40
40PBA2	25.0	5.10	
40SDA1	75.0	15.31	14.80
40SDA2	70.0	14.29	
60PBA1	4.0	0.82	0.87
60PBA2	4.5	0.92	
60SDA1	0.5	0.10	0.14
60SDA2	0.2	0.04	

On the other hand, compressive strengths of 5.405N/mm^2 and 14.80N/mm^2 were obtained for PBA and SDA respectively at 40% replacement level. Interestingly, for 60% replacement level, reductions in strength after 7days were apparent for mixtures containing PBA and SDA. The reason could be that, cementitious materials such as Dicalcium silicate ($2CaO.SiO_2$) and Tricalcium silicate ($3CaO.SiO_2$) which are dominant in PLC contributed greatly to the compressive strength of the cement concrete whereas Tricalcium aluminates ($3CaO.Al_2O_3$) and Tetra Calcium alumino ferrites sped up the setting time of the cement. PBA on the other hand may contain Chlorides and other salts [9]. Generally, when ordinary Portland Limestone Cement is partially replaced with PBA, the compound which contributes to the compressive strength is reduced significantly and it is not enough to bind other materials together. The chlorides and other salts which may be introduced into the cement concrete induce the formation of cracks, thus reducing the compressive strength of the PBA concrete. Hence, PBA is only good for use as an additive at 20% replacement level of PLC. SDA contains mainly silica thus giving the concrete appreciable compressive strengths at 20% and 40% replacement levels respectively. At 60% replacement level, a lot of CaO is not available in the Portland Limestone Cement to form either $3CaO.SiO_2$ or $2CaO.SiO_2$ hence the hydration reaction produced would be very minimal leaving a significant number of regions unhydrated [10]. This means that the porosity in such SDA concrete is increased.

Table 5: WATER ABSORPTION OF MORTARS

Cubic Specimen Type	Initial Mass, M_I (Kg) before curing	Final Mass, M_f (Kg) after curing	Mass Difference, M_D (Kg)	Water absorption (%)	Average water absorption (%)
PLC1	0.74	0.75	0.01	1.40	2.05
PLC2	0.74	0.75	0.02	2.70	
20PBA1	0.69	0.73	0.032	4.61	4.63
20PBA2	0.69	0.72	0.04	4.65	
20SDA1	0.72	0.76	0.035	5.59	5.27
20SDA2	0.71	0.74	0.03	4.96	
40PBA1	0.66	0.69	0.035	4.55	4.93
40PBA2	0.66	0.70	0.025	5.30	
40SDA1	0.63	0.65	0.025	4.00	4.29
40SDA2	0.66	0.69	0.03	4.58	
60SDA1	0.64	0.69	0.05	7.87	7.40
60SDA2	0.65	0.70	0.045	6.92	
60PBA1	0.71	0.73	0.02	2.84	2.84
60PBA2	0.71	0.73	0.02	2.84	

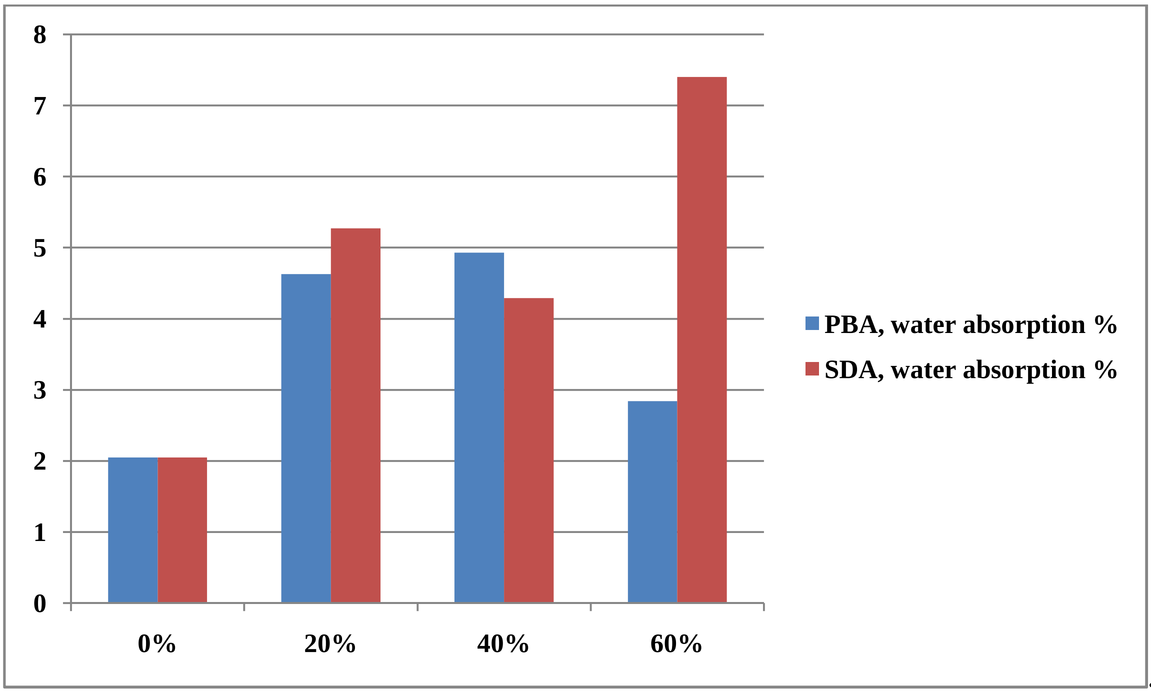

Figure 2: WATER ABSORPTION VERSUS REPLACEMENT LEVEL

Similarly, table 5 and figure 2 describe the trends in the water absorption of both PBA and SDA concrete at increasing replacement levels. The water absorption for PBA concrete increased as replacement level was increased from 20% to 40% and then gradually decreased as the replacement level reached 60% .Unlike PBA, SDA showed a decrease in water absorption as replacement levels of PLC were increased from 20% to 40%. Again, at 60% replacement level, there was a sharp increase in water absorption which corresponds to a decrease in the compressive strength of the SDA concrete. When the water absorption is high, it implies the pores within the concrete are high, the particles of materials are held loosely and the binding of other materials is poor. If the water absorption is low, it implies that the pores are minimal and the arrangement of the materials is compact (that is, the particles are held together strongly).

CHEMICAL REACTIONS INVOLVED IN THE SETTING OF CEMENT

During hydration, silicates and aluminates of calcium get converted to their respective hydrated colloidal gels.

$$\underset{\text{tricalcium aluminate}}{3CaO.Al_2O_3} + 6H_2O \longrightarrow \underset{\text{hydrated colloidal gel of tricalcium aluminate}}{3CaO.Al_2O_3.6H_2O}$$

$$2CaO.SiO_2 + xH_2O \longrightarrow \underset{\text{hydrated colloidal gel of dicalcium silicate}}{2CaO.SiO_2.xH_2O}$$

At the same time, hydrolysis precipitates calcium hydroxide and aluminium hydroxide.

$$\underset{\text{tricalcium silicate}}{3CaO.SiO_2} + H_2O \longrightarrow Ca(OH)_2 + \underset{\text{dicalcium silicate}}{2CaO.SiO_2}$$

Calcium hydroxide binds calcium silicate particles together. Aluminium hydroxide fills the interstices (intervening space) rendering the mass impervious

$$\underset{\text{tricalcium aluminate}}{3CaO.Al_2O_3} + 6H_2O \longrightarrow 3Ca(OH)_2 + \underset{\text{aluminium hydroxide}}{2Al(OH)_3}$$

Gypsum reacts with Tricalcium aluminates.

$$3CaO.Al_2O_3 + 3CaSO_4 + 2H_2O \longrightarrow \underset{\text{calcium sulpho aluminate}}{3CaO.Al_2O_3.3CaSO_4.2H_2O}$$

The fast-setting Tricalcium aluminates are removed to slow down the setting process. A quick setting will give rise to crystalline hydrated calcium aluminates. A slower setting yields the colloidal gel that imparts greater strength to the set mass. Thus gypsum helps in regulating the setting time of cement.

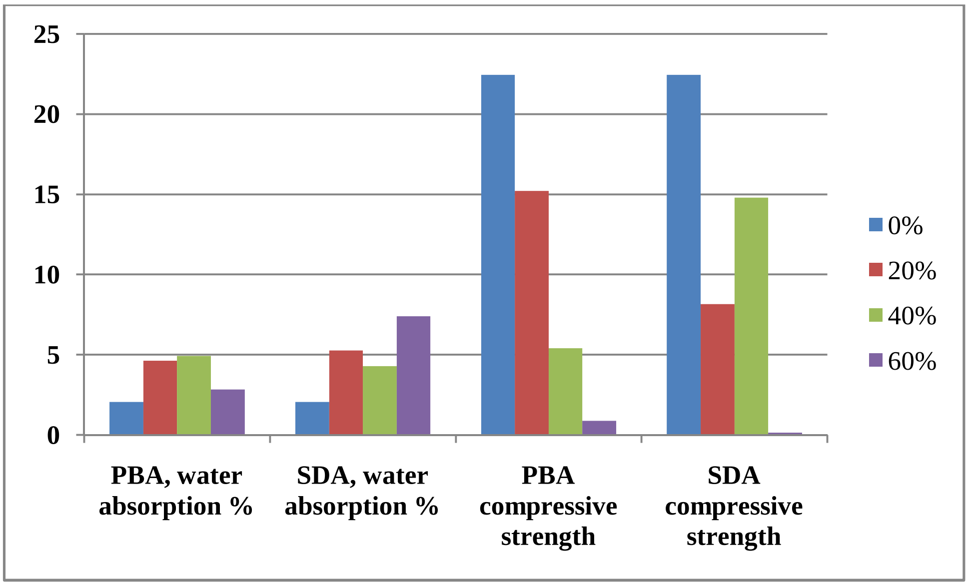

Figure 3: COMPRESSIVE STRENGTH VERSUS WATER ABSORPTION

Finally, it was observed that, as water absorption increases for both PBA and SDA, the compressive strengths decreased for both. Therefore, high compressive strength is always obtained at lower water absorption.

CONCLUSION

In conclusion, the use of Saw Dust Ash (SDA) is good at 40% replacement level of Portland Limestone Cement (PLC) whereas the use of Palm Bunch Ash (PBA) is also good at 20% replacement level of Portland Limestone Cement (PLC). Similarly, the SDA additive in the concrete gave a better compressive strength than the PBA additive.

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