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The Influence of Partial Replacement of Some Selected Pozzolans on the Drying Shrinkage of Concrete

Ikumapayi C. M.*
Department of Civil Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

Akingbonmire S. L.
Department of Civil Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

Oni O.
Department of Civil Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

Abstract

Concrete is prone to cracking and one of the major causes of cracking is drying shrinkage of the hardened concrete. This research work was carried out to study the influence of partial replacement of some selected pozzolans on the drying shrinkage of concrete. Four pozzolans used in this study, were made to replace cement at various percentages resulting in various concrete mixes. Setting time test was conducted for the various cement mixes using Vicat's apparatus and drying shrinkage test was done for the concrete test specimens. The results of the setting time indicate that partial replacement of pozzolans with ordinary Portland cement increases both the initial and final setting time of cement as the percentage replacement increases. Similarly, drying shrinkage results show that concrete made with Groundnut Shell Ash (GSA) and Locust Bean Pod Ash (LBA) at 12% replacement will have a stable and better shrinkage resistance than the control at both 56 days and 90 days. Meanwhile, the control concrete gives a better drying shrinkage at 28 days curing. In conclusion, the results show that pozzolanas [Bamboo Leaves Ash (BLA), Locust Bean Pod Ash (LBA), Sugarcane Bagasse Ash (SBA) and Groundnut Shell Ash (GSA)] can successfully replace cement up to 12% without necessarily affecting the shrinkage ability of the produced concrete. It also shows that Groundnut Shell Ash (GSA), Locust Bean Pod Ash (LBA) and Bamboo Leaves Ash (BLA) are more resistance to drying shrinkage than the control.

Keywords: Pozzolans; Concrete; Drying shrinkage; Partial replacement; Vicat's apparatus.

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1. Introduction

Due to the versatility of the use of concrete as constructional materials [1], there is the need to study its constituents. Basically, concrete is composed of cement (binding agent), water and aggregates (fine and coarsed). Sometimes, admixtures are added to improve the quality of the concrete. Among these constituents, in term of cost, cement is the most expensive and also contributes more to environmental pollution. Globally, it is believed that cement industries emit about 5% of carbon dioxide (CO_2) into the environment [2]. One of the ways to reduce the quantity of cement used globally is to use a low cost material that has pozzolanic properties which can partially substitute Portland cement clinker. They are mostly industrial and agricultural waste products. Some of those materials that had been used to replace cement are periwinkle shell ash, clam shell ash, rice husk ash, egg shell ash, groundnut shell ash, palm kernel shell ash, coconut shell ash, etc. Afolayan [3]; Ikumapayi [4]; Oke, *et al.* [5];Oyedepo, *et al.* [6], Whiting, *et al.* [7], Mahmoud, *et al.* [8].

Pozzolans are siliceous materials that do not possess cementing properties alone but the presence of calcium hydroxide and water will show cementing property and other durability properties Ikumapayi and Akingbonmire [9], Oluremi [10]. When Portland cement and pozzolanic material are mixed together, they are termed pozzolanic cements. Such cements have the following advantages: good resistance to chemical attack, low evolution of heat of hydration, improvement of workability, reduction of bleeding and greater impermeability if well proportioned. The only disadvantage is that it brings about slower rate of strength development and also increased shrinkage [11].

Drying shrinkage is the reduction in volume of the hardened concrete as a result of loss of water in its matrix. This might leads to cracking [12]. It does cause water penetration into the concrete and hence weaken its durability. There are several factors that lead to drying shrinkage. The factors can be classified into external factors (ambient conditions and member geometry) and internal factors (concrete constituents) [13]. Since drying shrinkage has a significant effect on the properties and performance of concrete and the fact that pozzolanas have been reported to reduce the drying shrinkage of concrete when used , it is therefore very important to study the effect of some pozzolanas on the concrete when it partially replaces cement in its production. Even though so many researchers had worked on partial replacement of cement with various pozzolans in concrete production as highlighted above but most of these researchers concentrate on the compressive strength properties. There is need to study alongside other important properties of concrete like the drying shrinkage. This research work has been able to bridge this important gap by studying the effect of groundnut shell ash, bamboo leaf ash, locust bean pod ash and sugarcane bagasse ash

*Corresponding Author

(all as pozzolans) on the drying shrinkage of the resulting blended concrete. These in conjunction with the existing data on compressive strength of these selected pozzolans will bring out their better features for effective performance and use in the construction industries.

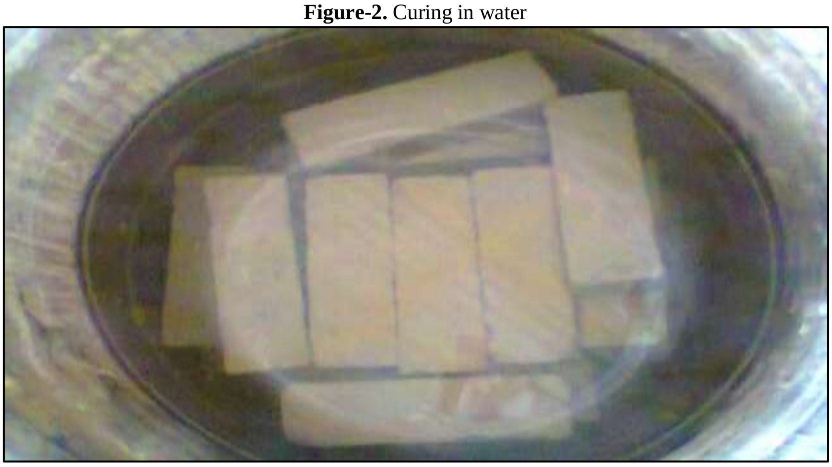
2. Materials and Method

The materials used are locally available. The coarse aggregates are hard, inert and well graded and of particles size 12 mm to 20 mm while the fine aggregate used are particle size of about 0.2 mm. Various tests were performed on the aggregates such as particle size distribution, moisture content and specific gravity. The cement used for the study was Ordinary Portland Cement (Elephant cement brand) which was locally obtained in Akure, Ondo State, Nigeria. Tests such as initial setting time, final setting time, consistency and soundness were performed on the cements used. The four types of pozzolanas used were bamboo leaves ash (BLA), Groundnut shell ash (GSA), Locust bean pod ash and (LBA) and Sugarcane bagasse ash (SBA). GSA were obtained from burning of dried groundnut shell or husk, at a temperature of 600°C to 700°C, after which the burnt husk/shell was grinded into very fine powder and made to pass through 212 microns BS sieve. BLA were obtained by drying bamboo leaves in sun, burnt in an open air and then heated in a laboratory electric furnace at 600°C calcinating temperature for 2 hours of retention, which represents a 5% of total mass of leaves. Once calcined, the ashes were grinded and sieved below 45µm. However, LBA is a solid/powder residue prepared by burning large mass of the locust bean pod in the incinerator at temperatures of up to 500o C. The residue is then left to cool and sieved. Bagasse is a residue obtained from the burning of bagasse in sugar producing factories. When this bagasse is burnt, the resultant ash is bagasse ash. Sugarcane bagasse was gotten from Ibadan in Oyo State.

The setting time for the cement paste was found by using Vicat's apparatus following ASTMC 191 standard [14] (Figure 1). Pozzolans were used to replace cement at 0% (control), 4%, 8%, and 12%. These pozzolans composite cements were mixed with sand and granite using mix ratio 1:2:4 by weight of concrete and 0.45 water/cement ratio. The mixtures were placed in wooden moulds of 75 mm × 75 mm × 250 mm dimension followed by compaction with steel rod. These concrete beams were demoulded after 24 hours and stored in water for curing at room temperature for 24 hours (Figure 2). The concrete beams were carried out from the curing tank and were allowed to soak in lime water basin for 30 minutes after which the initial measurement was taken, length of each beams was measured by using a length comparator. The beams were then soaked in lime water for additional three (3) days, after which they were removed from the lime water basin and placed in a normal temperature room for the remaining duration of the test. The length of the beams was measured for their change in length to calculate drying shrinkage at different ages. The drying shrinkage of concrete is the contraction in length of concrete expressed as percentage. The drying shrinkage of concrete was measured at different ages of 3, 7, 14, 28, 56, and 90 days after their removal from lime water.

Figure-1. Vicat's Apparatus

Figure-2. Curing in water



3. Results and Discussion

The results of the various tests performed in this research are presented.

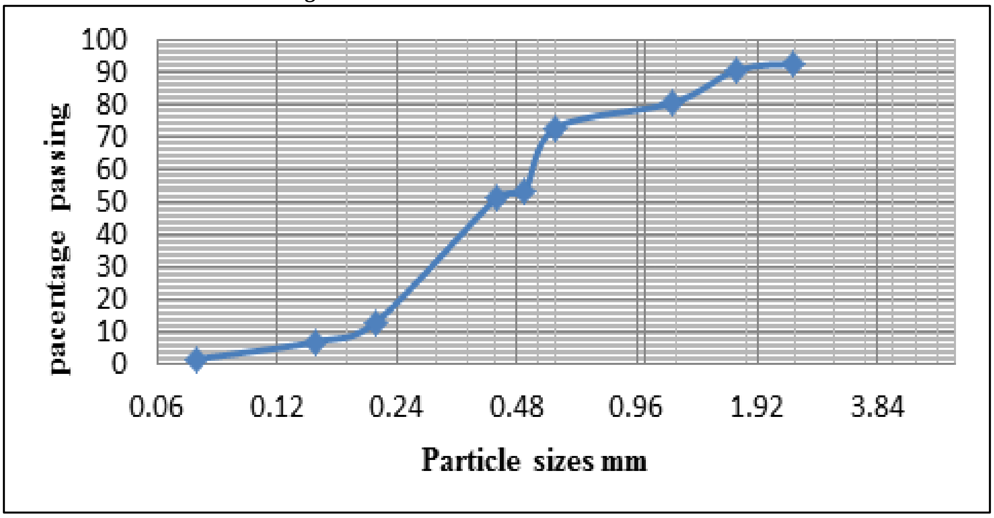
3.1. Sieve Analysis

The graph of the sieve analysis for the fine aggregate which was carried out according to BS 882 (1978) is presented in Figure 3. The percentage of the sand particles that passed through 7.5µm sieve size is 1.37%, which shows that the sand contains a negligible amount of clay and silt particles. Also, the sieve size 212µm has the highest percentage of soil retained hence, the sand is well graded and suitable for the intended purpose.

3.2. Specific Gravity

The specific gravity of fine aggregate is 2.65 which still lie within the range of 2.65 to 2.85 specified by BS 1377, 1991. Therefore, the result shows that the sand used was free from organic matters and porous particles which is suitable for the intended purpose. Also, the specific gravity of granite is 2.62 which is within the range of 2.6 to 2.7 BS 1377, 1991. Therefore, the granite is suitable for the concrete production.

Figure-3. Particle size distribution curve for sand



3.3. Setting Time of Cement and the Pozzolans

The results of setting time of cement and of different percentages of pozzolans that replaced cement are shown in the Table 1. The results of setting time tests indicate that the addition of pozzolans increase the setting time of the paste. Ajay, *et al.* [15], reported that the reduction in the amount of calcium hydroxide and also the development of films of silica gel around cement grains, and a mutual coagulation of components within the paste may have caused the retardation of setting time. Therefore, the reduction in these setting times is an indication that the reaction of the pozzolanic blended cement with calcium hydroxide (one of the end products of cement) continues even after ordinary Portland cement has completed its hydration. This same trend is also more visible in the results because the more the quantity of the pozzolan replacement, the higher the initial and the final setting times of the blended cements indicating the availability of more pozzolans reacting with the calcium hydroxide. Furthermore, the exothermic reaction involved in the hydration of cement generates heat which contributes to the faster setting.

Table-1. Setting time of cement and of different percentages of pozzolans

Cement							
Initial setting time (minutes)	60			Penetration = 5mm			
Final setting time (minutes)	480			Consistency time = 9min			
Locust bean pod ash replacement of cement							
	4%	8%	12%		4%	8%	12%
Initial setting time (minutes)	67	95	105	Penetration (mm)	6	8	6
Final setting time (minutes)	537	570	615	Consistency time (minutes)	7	10	6
Bamboo leaves ash replacement of cement							
Initial setting time (minutes)	70	80	100	Penetration (mm)	10	5	6
Final setting time (minutes)	605	740	832	Consistency time (minutes)	7	7	10
Groundnut shell ash replacement of cement							
Initial setting time (minutes)	67	71	72	Penetration (mm)	5	7	7
Final setting time (minutes)	553	751	740	Consistency time (minutes)	7	8	7
Sugarcane bagasse ash replacement of cement							
Initial setting time (minutes)	76	95	103	Penetration (mm)	6	5	7
Final setting time (minutes)	560	632	648	Consistency time (minutes)	7	7	8

For BLA at 12%, the initial and final setting times was high as 100 and 832 minutes respectively indicating 40 minutes in the former and 352 minutes in the latter delay in setting. For GSA at 12%, the initial and final setting times was 72 and 740 minutes respectively which was not as high as that of BLA and LBA indicating 12 minutes in the former and 260 minutes in the latter delay in setting. For SBA at 12%, the initial and final setting times was high as 103 and 648 minutes respectively indicating 43 minutes in the former and 168 minutes in the latter delays in setting. The rate at which the delay occurred was irregular and the setting time delay was increasing as those ashes were added.

3.4. Drying Shrinkage

The results of the drying shrinkage of different percentages replacement of cement are shown in Figure 3b for 3 days, Figure 4 for 7 days, Figure 5 for 14 days, Figure 6 for 28 days, Figure 7 for 56 days, Figure 8 for 90 days. Figure 9 to Figure 11 show the drying shrinkage at different days for different percentages.

Figure-3b. Drying shrinkage at 3 days

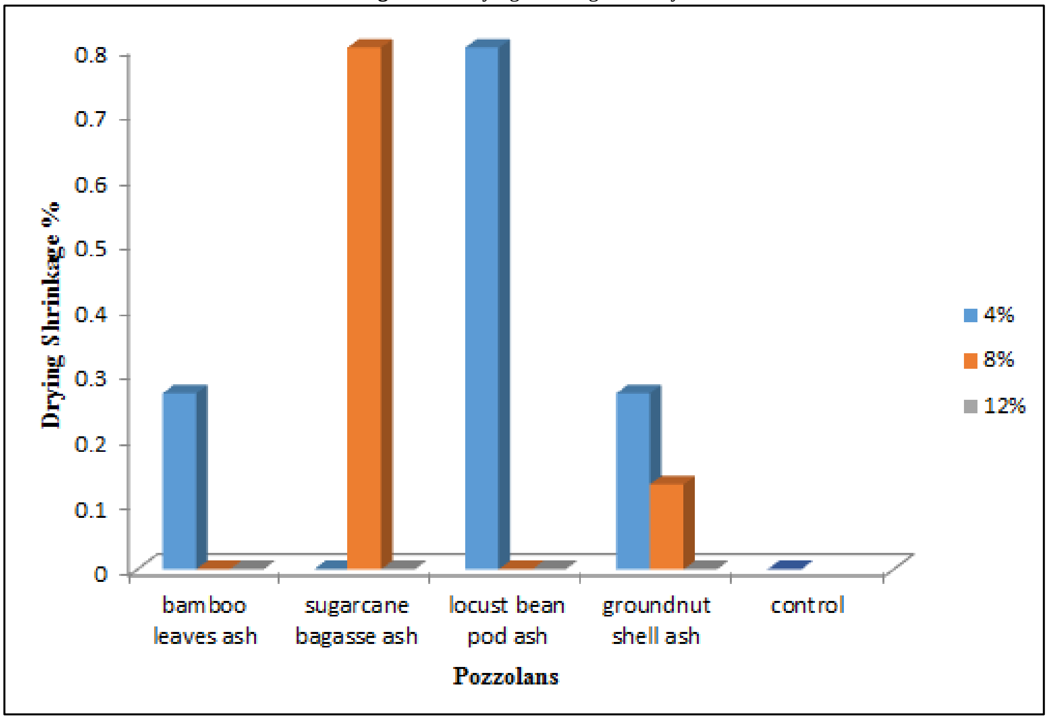


Figure-4. Drying shrinkage at 7 days

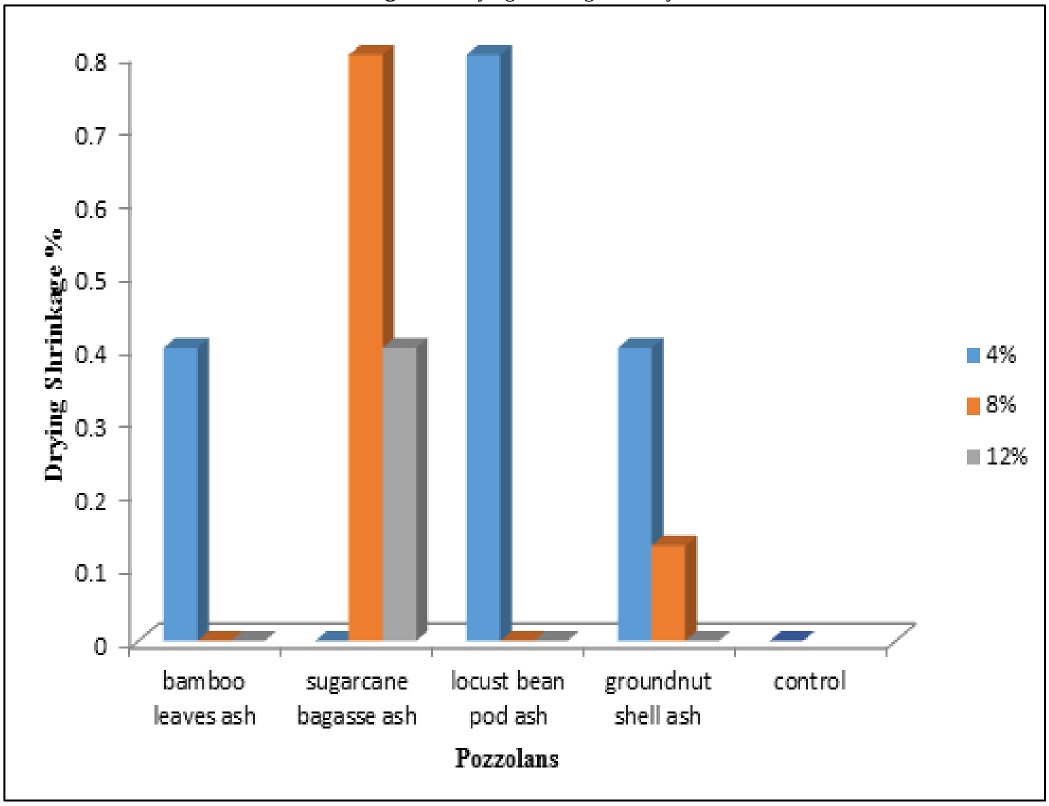


Figure-5. Drying shrinkage at 14 days

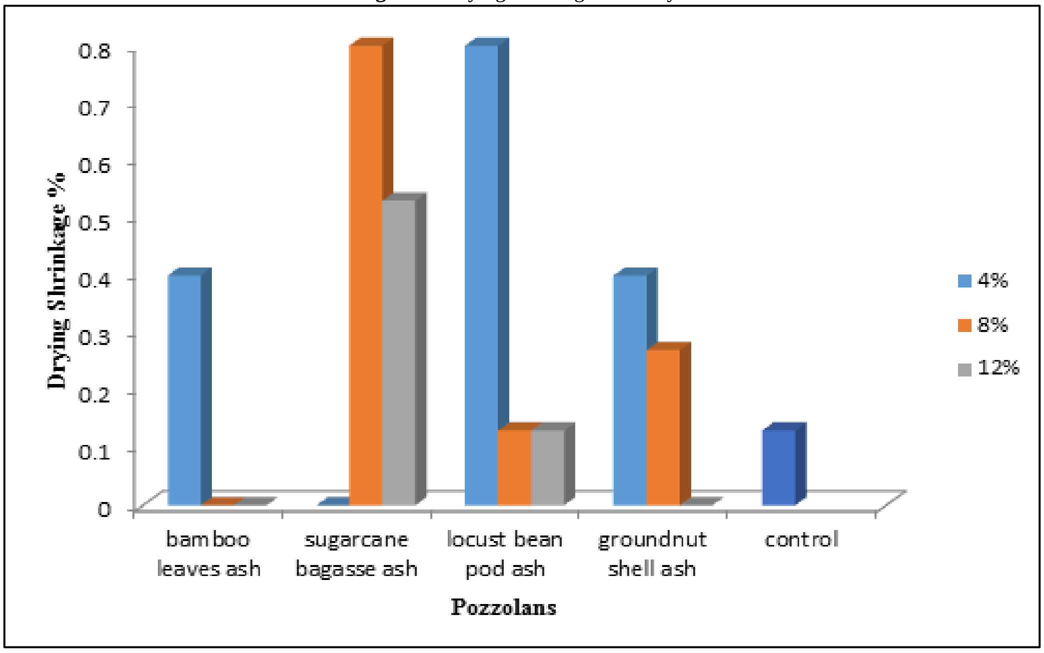


Figure-6. Drying shrinkage at 28 days

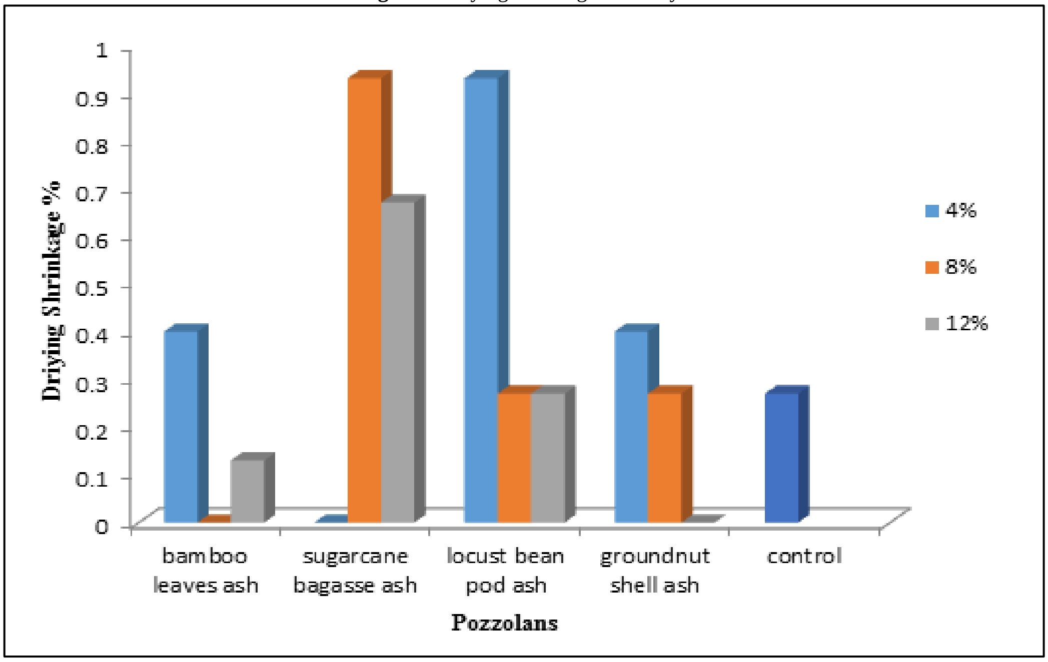


Figure-7. Drying shrinkage at 56 days

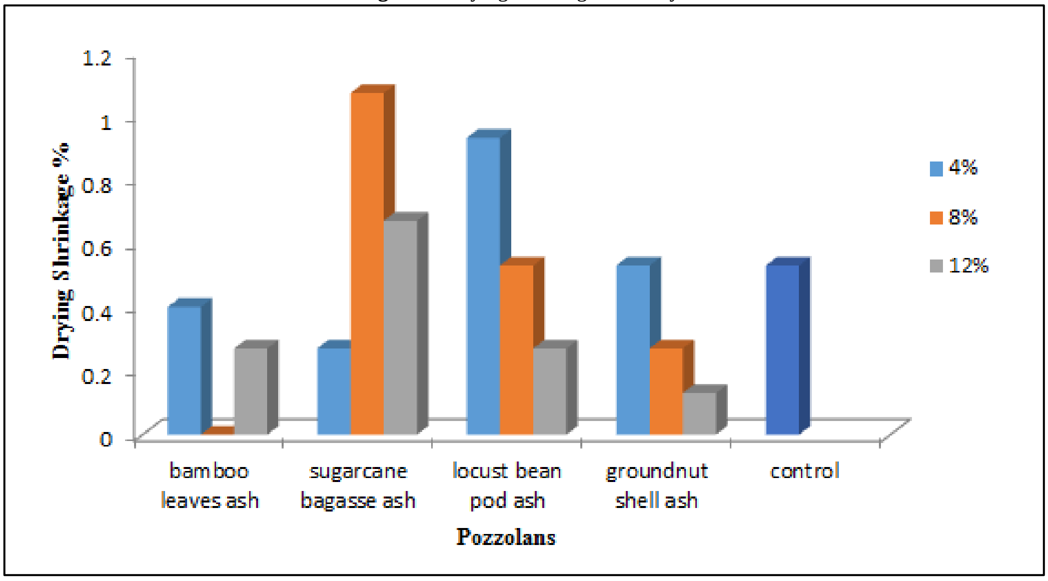


Figure-8. Drying shrinkage at 90 days

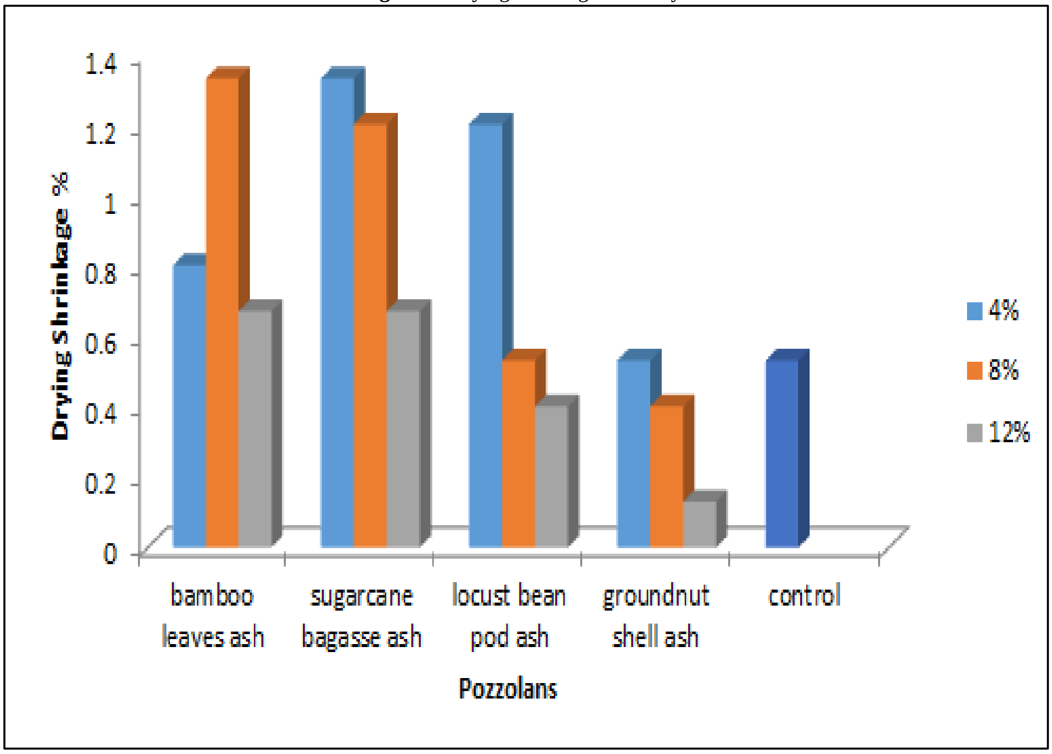


Figure-9. Drying shrinkage at different days for 4%

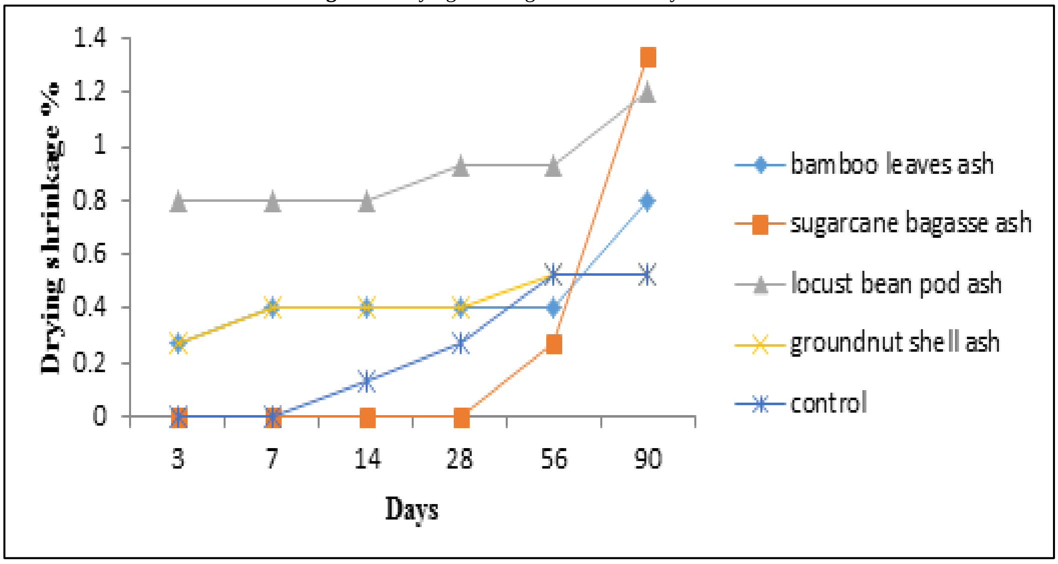


Figure-10. Drying shrinkage at different days for 8%

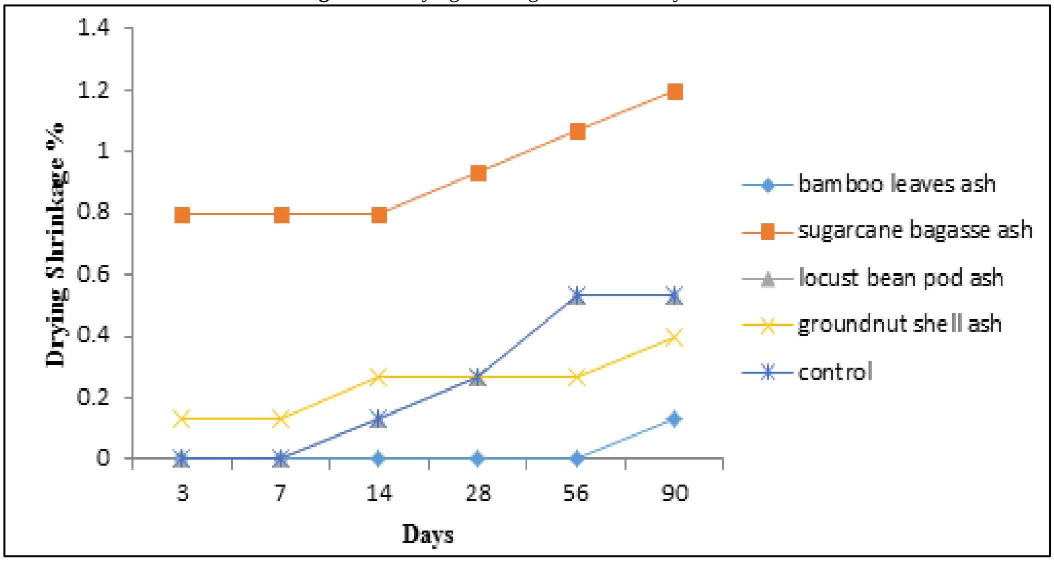
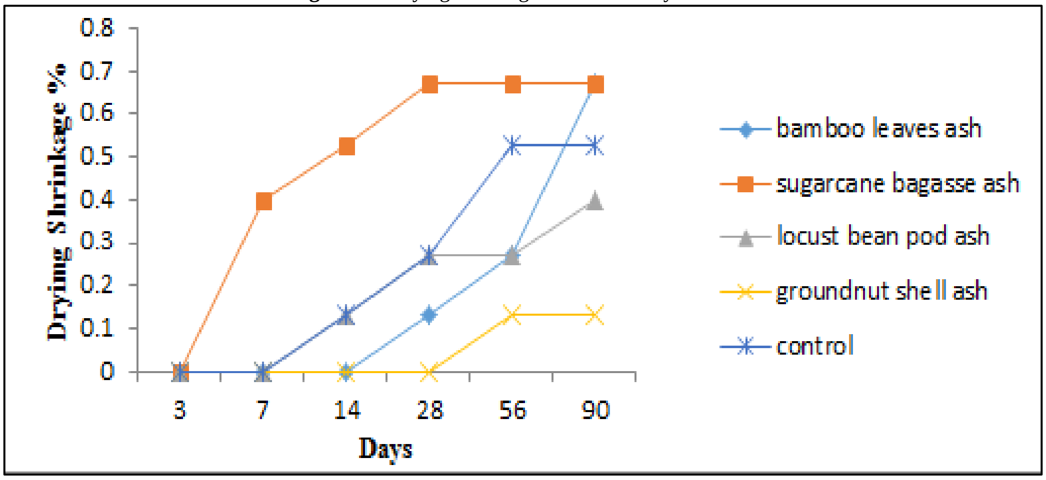


Figure-11. Drying shrinkage at different days for 12%



The result in Figure 3 for 3 days shows that there was no considerable change in length for the concrete made from all the pozzolans with the highest being 0.8% at 3 days even at 12% no change was observed in the shrinkage. Therefore, in respect of shrinkage all the four pozzolans can successfully be used to partially replace cement up to 12% replacement without altering the shrinkage ability of the concrete. Likewise, Figure 4 presented the result for 7 days which shows that there was no considerable change in length for the concrete made from all the pozzolans with the highest still being 0.8% at 7 days even at 12%, there was no considerable change of 0.4% in the shrinkage. Therefore in respect of shrinkage, all the four pozzolans can successfully be used to partially replace cement up to 12% replacement without altering the shrinkage ability of the concrete. Same trend was observed in the results for 14days and 28 days (Figure 5-6). At 56 days and 90 days shown in Figures 7 and 8 the control and GSA has 0.53% and 0.13% shrinkage which indicates that after 56 days there is likely to be no change in length for concrete made with control and GSA at 12%. The results also show that concrete made with GSA 12% and LBA 12% will have a stable and better shrinking ability than the control at both 56 days and 90 days i.e. as the concrete gets older. Whereas the control shows better shrinkage ability of 0.53% than BLA and SBA which both have 0.67%.

Studying each pozzolans at different percentage replacement and at different days (Figure 9 to figure 11), it can be observed that as the days of observation takes longer, there is increase in the drying shrinkage but later there was stability in the drying shrinkage.

D. Statistical Analysis of Drying Shrinkage of the Pozzolans at Different Percentage Replacement at 90 days

The effect of drying shrinkage of the pozzolanas at 90 days was analysed using analysis of variance test (ANOVA) as shown in Tables 2-4.

Table-2. LSD test for drying shrinkage of the pozzolanas at 4% for 90 days curing. 1- Control, 2 - BLA, 3 - SBA, 4 - LPA, 5 - GSA

I	J	M D (I-J)	p	Remarks
1	2	0.66667	0.576	NS
	3	-1.00000	0.407	NS
	4	1.66667	0.18	NS
	5	0.00000	1.000	NS
2	3	-1.66667	0.180	NS
	4	1.00000	0.407	NS
	5	-0.66667	0.576	NS
3	4	2.66667*	0.044	*
	5	1.00000	0.407	NS
4	5	-1.66667	0.180	NS

*Mean Difference (MD) is significant at $\propto_{0.05}$, NS= Not Significant

Table-3. LSD test for drying shrinkage of the pozzolanas at 8% for 90 days curing. 1- Control, 2 - BLA, 3 - SBA, 4 - LPA, 5 - GSA

I	J	M D (I-J)	p	Remarks
1	2	-1.00000	.356	NS
	3	1.66667	.138	NS
	4	0.00000	1.000	NS
	5	-.33333	.754	NS
2	3	2.66667*	.027	*
	4	1.00000	.356	NS
	5	.66667	.533	NS
3	4	-1.66667	.138	NS
	5	-2.00000	.082	NS
4	5	-.33333	.754	NS

*Mean Difference (MD) is significant at $\propto_{0.05}$, NS= Not Significant

Table-4. LSD test for drying shrinkage of the pozzolanas at 12% for 90 days curing. 1- Control, 2 - BLA, 3 - SBA, 4 - LPA, 5 - GSA

I	J	M D (I-J)	p	Remarks
1	2	.33333	.850	NS
	3	.33333	.850	NS
	4	-.33333	.850	NS
	5	-1.33333	.454	NS
2	3	0.00000	1.000	NS
	4	-.66667	.705	NS
	5	-1.66667	.353	NS
3	4	-.66667	.705	NS
	5	-1.66667	.353	NS
4	5	-1.00000	.572	NS

*Mean Difference (MD) is significant at $\propto_{0.05}$, NS= Not Significant

The result of the LSD post hoc test shown in Tables 2 - 4 showed that there was no significant difference in the drying shrinkage of the pozzolanic concrete and that of the ordinary Portland cement concrete at 90 days. This means that at any percentage replacement (4%, 8% and 12%) of these pozzolans, the concrete behaviour in term of drying shrinkage is the same.

4. Conclusion and Recommendations

The research investigates the influence of partial replacement of some selected pozzolans on the drying shrinkage of concrete. The results indicated that all the four pozzolanas (BLA, LBA, SBA and GSA) used can successfully replace cement up to 12% replacement without necessarily affecting the shrinkage ability of the produced concrete significantly. This will limit the quantity of cement used in the production of concrete. Also, it can be seen from the results that partial replacement of ordinary Portland cement with concrete will affect its initial and final setting time though higher replacement of cement by these ashes resulted in normal consistency. The study shows that GSA and LBA will give a better shrinkage durability of the concrete made from them at 12% partial replacement with cement. In summary, drying shrinkage ability of pozzolanic cement should be considered alongside with the compressive strength when determining the optimum percentage of pozzolans replacement with cement. From these, it is recommended that more than 12% replacement of cement with these pozzolans should be investigated so as to know the drying shrinkage effect of the resulting concrete.

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