# Shrinkage Characteristics of Cassava Peel Ash Concrete

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## ABSTRACT

This study investigated the effect of cassava peel ash (CPA) on the shrinkage property of concrete. Cement replaced with CPA at replacement levels of 0, 5, 10, 15, 20 and 25% by weight of cement was used as binder to produce concrete specimens, while water-binder ratios (w/b) were varied between 0.5 and 0.8. Slumps were measured for different w/b. Concrete cubes and short columns were cast and cured in water for 210 days before they were tested for compressive strength and shrinkage.

The results showed that an optimum w/b of 0.7 was adequate to produce workable cement-CPA concrete and compressive strength of concrete containing up to 15% CPA had strength activity index above 75%.Shrinkage strains of concrete with up to 15% CPA had about 24% lower than that of the normal concrete at ages 90 days and above. The rate of shrinkage deformation study showed that concrete mixes containing up to 15% CPA content had lower rate than normal concrete. The average temperature and relative humidity recorded during the testing period were 24 ℃ and 64.28% respectively. It was concluded from the study that CPA has potential to limit shrinkage of concrete.

(Keywords: shrinkage strain, cassava peel ash concentrate, CPAC, pozzolanic reaction, shrinkage deformation rate)

## INTRODUCTION

Cassava, *manihot esculenta,* is a plant originating from South America. It is known under various names: yucca and tapioca. The tubers (part of the root system) are usually processed and used as food source which is high in carbohydrate. It is an important staple food in many developing countries of Africa, South and Central America, India and Southeast Asia. Cassava peels are by-products of cassava processing. Nigeria, being the largest producer of cassava in the world, produces more than 34 million tonnes of cassava annually which produced about 25% of peels by weight (Adesina, 2012, Adesanya et al., 2008). Underutilization and lack of appropriate technology to recycle these peels make them a threat to the environment.

Recently, the mechanical properties of concrete and mortar produced with partial replacement of cement with cassava peel ash (CPA) have been studied with positive results (Salau and Olonode 2011, Salau et al., 2012). However, there is no reported work on the time-dependent properties of cement-cassava peel ash concrete (CCPAC) such as shrinkage. This study will ascertain the effect of CPA on long-time deformation of concrete. Shrinkage of concrete due to drying is important and frequent parameter that negatively affects cracking of concrete. This can aggravate the vulnerability of the concrete structures by the environmental aggressive agents and in particular increases the risk of corrosion of the metallic reinforcements due to chloride and carbon dioxide penetration.

Drying shrinkage of concrete has been given a great deal of attention, driven by the need to quantify the long-term deformation and behavior of nuclear reactor containments (Acker, 2001). Babaei and Purvis (1996), studied the effect of drying shrinkage on a bridge deck within one year after construction. They observed that cement content, type, source, and fly ash replacement can impact drying shrinkage. It was suggested that reducing the water content, through reduction in cement content (at a constant water-cement ratio) or using a water reducing admixture, can reduce drying shrinkage. This observation agrees with the findings of Lindquist et al. (2005).

AppaRao (2001), investigated the influence of different aggregate sizes on shrinkage. He observed that at 28 days of drying, the mortar shrinkage values were 110 and 75.7$\mu s$ for mortar containing sand of maximum size of 1.18 mm and 2.36 mm, respectively, while at 730 days of drying, the shrinkage values increased to 6300 and 1900 $\mu$ respectively. Comparable observations were also obtained when comparing mortars for each series with 10, 15, and 20 percent silica fume replacements at 730 days. He concluded that, at 730 days of drying, the mortars with the smaller aggregate size experienced shrinkage values from 1.5 to 3 times higher than what were observed from bigger sizes. Shah et al., (1992) studied three types of shrinkage reducing admixtures (SRA) to determine their effectiveness in reducing drying shrinkage. Studies on the use of agricultural wastes to limit drying shrinkage were equally reported with positive results.

According to ACI Committee 233 (2003), there are conflicting results on how the use of slag in concrete affects the drying shrinkage. Li, et al. (2002), evaluated concrete mixtures with a constant water cementitious material ratio of 0.30 to determine the effect of slag on concrete shrinkage. They found that concrete containing silica fume had noticeably lower early-age and long-term (greater than 60 days) shrinkage than the control mix without silica fume. Since the silica replacement was made by weight, the silica fume mix had slightly higher paste content (32 percent) than the control mix (31 percent). Lately, agricultural wastes are found to have potential to inhibit drying shrinkage of concrete containing them (Purna and Varun, 2015, Manju et al., 2015, Whiting et al., 2000). Hence, the thrust of this study is to document the drying shrinkage properties of cassava peel ash concrete

## MATERIALS AND METHODS

This section presents the materials used and methodology adopted in the study.

### Materials and Preparation of Specimens

In this study, natural granite of igneous origin was used as coarse aggregate. The maximum and minimum sizes of the aggregate were 19 and 3.18 mm respectively. River sand of maximum size of 3.18 mm was used as fine aggregate. The coefficients of curvature for coarse and fine aggregates were 1.36 and 1.0, respectively, while those of uniformity were 5.0 and 5.4 respectively, as determined from particle size distribution analysis conducted. The values show that the aggregates were well graded. Binder used was Portland cement blended with varying percentages of cassava peel ash (CPA) at 5 to 25% (5% interval) replacement levels by weight of cement while binder (0% CPA) was taken as control. The chemical compositions of cement and CPA used are summarized in Table 1. Potable water was used as mixing water. The cassava peel ash use was produced by burning cassava peels at 700℃ for 90 minutes and sieved through sieve size of 150 $\mu m$. The surface area of the ash was 330 kg/m$^2$.

Concrete of mix ratio of 1: 2: 4 (binder: sand: granite) was prepared with a constant water-binder ratio (w/b) of 0.7. Concrete cubes of sizes 150 mm were cast for compressive strength test. For shrinkage test, concrete short columns of sizes 100 × 100 × 500 mm were cast and de-molded after 24 hours.

**Table 1:** Chemical Composition of CPA and OPC.

| Material | Oxide of Metals (%) | | | | | | | | Sp. Gravity | LOI |
|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | | |
| [a]CPA | 58.02 | 12.80 | 1.41 | 8.53 | 5.02 | 2.18 | 7.67 | 0.03 | 0.32 | 4.18 |
| OPC | 18.33 | 5.00 | 2.75 | 60.11 | 1.15 | 3.21 | 0.08 | 0.04 | 3.09 | 7.22 |

a: Source (Salau and Olonode, 2011)

## Testing Program

### Determination of Slump, Density and Compressive Strength

The workability of the fresh concrete mixes was studied by measuring the slump height in accordance with BS 1881-102. Concrete cubes of sizes 150 mm were cast tested for compressive strength after curing in water for 7, 28, 56, and 90 days. The procedure prescribed in BS 1881-107 was followed. The concrete cubes were weighed before testing for compressive strength to determine their bulk densities as prescribed by BS 1881-103.

### Shrinkage Test

The experimental set-up for testing drying shrinkage is shown in Figure 1. Concrete beam specimen was placed vertically between a base and the tip of dial gauge with accuracy of 0.01 mm. A comparator reading was taken as the reference point, corresponding to 'zero' strains for the measurement. Since the shrinkage of beam specimen started after 24 hours, the strains attributed to the fresh and setting of concrete such as autogenous, plastic and thermal shrinkage were not considered in the deformations measured. Shrinkage reading was taken every day for one week, weekly for 7 weeks and once in two weeks up to a period of five months, totaling seven months (210 days). Since the environment condition is one of the main parameters that have influence on the shrinkage study, polymeter was installed to monitor the temperature as well as relative humidity of the testing room, throughout the testing period. The shrinkage strains at different ages were calculated on the basis of the Equation (1) of the ASTM C 157/C 157M- 99.

## RESULTS AND DISCUSSION

### Effect of Cassava Peel Ash on Workability

The workability of fresh concrete has traditionally been evaluated with the slump test which measure the ease with which concrete flows. Slump values depend upon number factors in which water-binder ratio is a major one. Results of slump conducted on concrete with varying percentage of cassava peel ash (CPA) as replacement for cement at various water-binder ratios are presented in Table 2. Test results show that as w/b ratio increases, the slump increases for all mixes while slump reduces as the content of CPA increases for each mix. It is equally seen that, at w/b ratios of 0.55 and 0.60, there were zero slumps for concrete containing 15% CPA while stiff mixes were obtained with 20 and 25% CPA content. But, at w/b ratios of 0.65 to 0.75, all the mixes produced varying slump values with very low slump obtained when above 15% CPA was used for w/b of 0.65.


**Figure 1:** Experimental Set-up for Shrinkage of Cassava Peel Ash Concrete at Different Content of CPA.

**Table 2:** Effect of Water-Binder Ratio (w/b) on Slump of Fresh Cassava Peel Ash Concrete.

| CPA (%) | Slump (mm) | | | | | |
|---|---|---|---|---|---|---|
| | Water-binder ratio (w/b) | | | | | |
| | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| 0 | 31[a] | 35[b] | 51[b] | 100[b] | 150[c] | 220[c] |
| 5 | 24 [a] | 30[a] | 42[b] | 70[b] | 120[b] | 210[c] |
| 10 | 15[a] | 21[a] | 30[a] | 65[b] | 100[b] | 180[c] |
| 15 | 0 | 0 | 26[a] | 63[b] | 95[b] | 130[b] |
| 20 | ** | ** | 20[a] | 58[b] | 80[b] | 100[b] |
| 25 | ** | ** | 10[a] | 51[b] | 71[b] | 90[b] |

*a – Shear Slump; b- True Slump; c – Collapse Slump*
*** Mix was not workable, too stiff.*

Also, at w/b ratio of 0.8, there were collapse slump in case of normal concrete, 5 and 10% CPA concrete. The reason for this behaviour could be credited to the fact that CPA absorbed moisture than cement of equal quantity. This indicates that more water is required to maintain the same consistency as the CPA content increases.

The recent European standard, as reported by Domone (2003), states that the slump test is sensitive to changes in consistency corresponding to slumps between 10 and 200 mm and the test is not considered suitable beyond these extremes. Also, mix having slump between 60-130 mm is considered being plastic and required either mechanical or hand compaction. This suggests that 0.65 and 0.70 water binder ratios (w/b) could be considered.

In order to avoid being on the lower extreme of 10 mm (slump value for 25% CPA at 0.65 water-binder ratio), water binder ratio of 0.70 should be considered optimum. The w/b ratio above 0.70 could lead to segregation and excessive bleeding of concrete in which water or water-rich grout rises to the surface of the concrete to produce laitance, a weak surface layer, or becomes trapped under the aggregate particles thus enhancing interface transition zone effects.

**Density and Compressive Strength of Cement-Cassava Peel Ash Blended Concrete**

The densities of concrete made with 0 to 25% at interval of 5% replacement of cement with CPA are presented in Table 3. The results show that the densities ranged between 2429 and 2498$kg/m^3$, indicating that they can be categorized as normal dense concrete. The density of normal dense concrete is between 2300 and 2500$kg/m^3$.

It is observed the results do not follow any pattern as showing that percentage replacement levels of cement with CPA did not have any appreciable influence on the densities of the test specimens of the concrete mixes. This may be attributed to the lower specific gravity of the CPA which was much lower than that of cement (Table 1). The variations observed in the values may be due to mixing and handling.

The compressive strength of cement-CPA blended concrete, irrespective of the amount of CPA in the mixture, increases as the age of curing increases. However, the compressive strength decreases as CPA content increases. This is more pronounced at the early age especially at age 7 days (Table 3).

For normal concrete, 0% CPA, the compressive strength at 28-day is 21.44$MPa$ while that of 5, 10, and 15% are 18.72, 18.36 and 17.64$MPa$ respectively, representing 87.3, 85.6 and 82.3% of 28-day strength of normal concrete.

These values are greater than the minimum of 75% recommended for pozzolanic materials (ASTM C 311). At the same day (28-day), strength of concrete containing 20 and 25% CPA were 71.2 and 70%of that of normal concrete respectively. But at later ages of 56 and 90 days, the strength development is observed to be on the increase with concrete containing CPA compared to the normal concrete.

With the exception of 20 and 25% CPA replacement of cement, it can be observed that the difference in strength between the normal concrete and CPA blended concrete reduces progressively with age with 5, 10, and 15% CPA replacement levels at 90 days (Table 3). This also indicates that CPA has potential to contribute to late strength development when not more than 15% by weight of cement is used. This behavior suggests that CPA possesses pozzolanic characteristics.

**Table 3:** Density and Compressive Strength of Cassava Peel Ash Concrete.

| % CPA | Density ($Kg/m^3$) | | | | Compressive Strength ($N/mm^2$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Curing Age (Days) | | | | Curing Age (Days) | | | |
| | 7 | 28 | 56 | 90 | 7 | 28 | 56 | 90 |
| **0** | 2438 | 2438 | 2451 | 2508 | 16.26 | 21.44 | 24.36 | 25.19 |
| **5** | 2481 | 2429 | 2447 | 2445 | 13.09 | 18.72 | 22.32 | 24.15 |
| **10** | 2451 | 2477 | 2498 | 2441 | 12.54 | 18.36 | 21.48 | 22.77 |
| **15** | 2444 | 2481 | 2465 | 2475 | 11.66 | 17.64 | 20.64 | 21.51 |
| **20** | 2449 | 2461 | 2455 | 2463 | 10.56 | 15.36 | 17.16 | 18.75 |
| **25** | 2462 | 2452 | 2445 | 2491 | 10.12 | 15.00 | 16.68 | 17.94 |

## Temperature and Relative Humidity of Test Environment

The temperature and relative humidity (RH) distribution of the testing room for shrinkage study for the period are shown in Figure 2. The RH of the room throughout the experiment was between 62 and 66% with standard deviation of$\pm 1.49$. This deviation is within the allowable range of ±4%, prescribed by ASTM C 157/C 157M - 99. As for the temperature, it varies between 23℃ and 25℃ with a standard deviation of $\pm 0.65$which is less than ±2℃(ASTM C 157/C 157M - 99). This indicates that environmental conditions of the room were relatively stable. Hence, the variations in the test results between normal concrete (0% CPA) and concrete with different amounts of CPA were primarily due to the composition of the binder (i.e., the presence of cassava peel ash).

## Effect of Cassava Peel Ash on Shrinkage of Concrete

In view of the effect of size on shrinkage, the deformation (shrinkage strain) is determined in relation to the height of specimen. Since this is a comparative study of the effect of cassava peel ash, the total shrinkage strain is considered. Autogenous shrinkage was not considered in this study because the initial shrinkage reading was taken after specimen was left for 24 hours and most of the hydration processes which causes autogenous shrinkage would have already occurred.

The results of the shrinkage strain are shown in Table 2 and expressed graphically in Figure 3. It is observed, as expected, that the shrinkage strain increased with time in all concrete specimens as moisture content of the concrete reduces on drying, which consequently causes volume change. The shrinkage development shows that at age 7 days (early age), the shrinkage strains were 390, 445 and 470$\times 10^{-6}$(micro strain) for concrete specimens with 5, 10 and 15% content of CPA respectively, representing139.2, 158.9 and 167.8% of the shrinkage strain of normal concrete (280$\times 10^{-6}$). However, at the same age, the shrinkage strain of concrete with more than 15% CPA (20 and 25%) were lower than that of normal concrete by 7% and 10.7%, respectively (Figure 3a).

This behavior could be attributed to the presence of CPA in the mix. When CPA replaces cement, it changes the composition of cement and thus its performance. Although, it is generally concluded that the composition of cement can affect drying shrinkage but the effect is not completely determined (Data Sheet, 2002). It is observed that CPA is rich in alumina and alkali content (Table 1). So, when it replaces cement in a mix, the blended cement could cause increase in alumina and alkalis which consequently increases the tri-calcium aluminate ($C_3A$) and alkalis content. According to Lawrence (2004), the components of cements which most likely influence shrinkage are the alkalis, $C_3A$ and sulphate; these compounds interact with the fineness of cement. In addition, an increase in $C_3A$ or alkalis increases the first-drying shrinkage.

Similarly, the replacement of cement with cassava peel ash leads to reduction in the dicalcium silicate ($C_2S$) of the blended cement and hence causes delay in hydration reaction to occur, leaving more moisture in the pore of the concrete matrix.

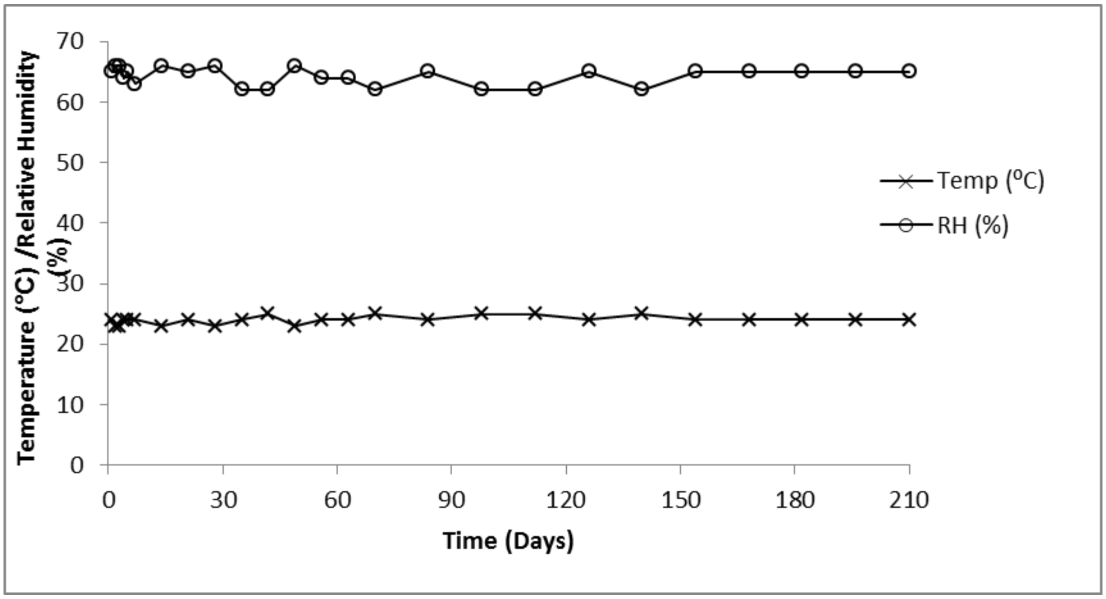



**Figure 2:** Temperature and Relative Humidity Variations during the Testing Period.

Also, at early age, pozzolanic reaction would not have started, so as to make use of the *excess* moisture. This could be responsible for the shrinkage behavior of concrete containing up to 15% CPA. Since, moisture is needed during pozzolanic reaction; more moisture will be available in the concrete to evaporate from the mixture.

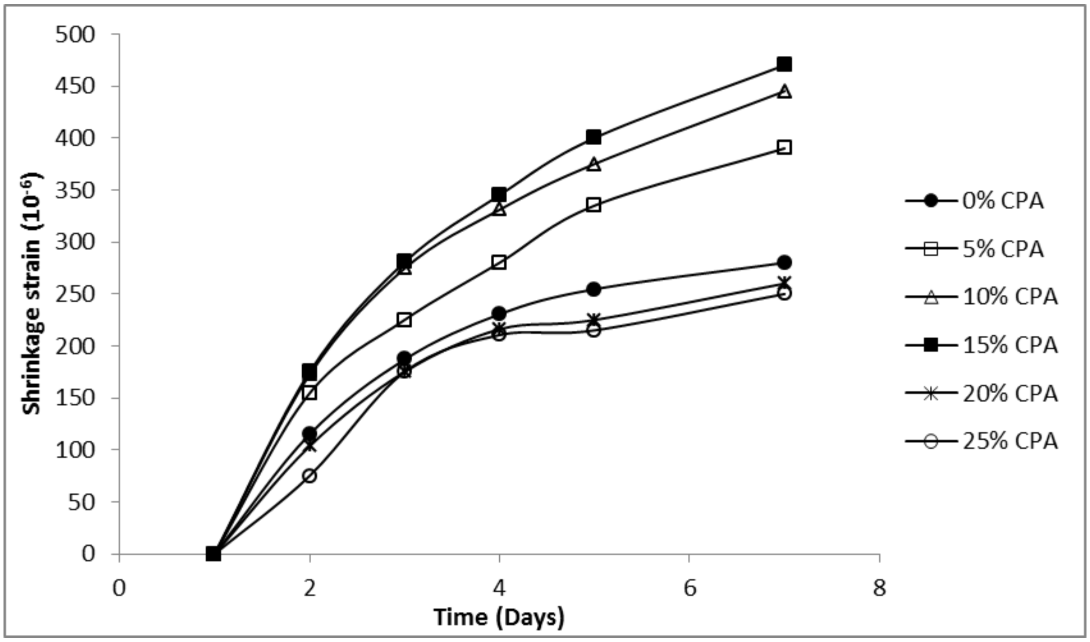
A major factor that influences the high shrinkage of concrete is the absorption ability of the aggregates as well as water in the cement paste. Shrinkage happens mainly because of reduction of water in the capillary pores of the hardened concrete by evaporation. The higher the amount of water in the fresh concrete the greater the shrinkage effect. However, the low shrinkage strain observed at higher content of CPA (above 15%) in the mix could be due to low slump [4] as less water is available in the concrete.

At constant water-cement ratio of 0.7, less water will be in the mix. So, the loss of water from the network of capillary pores within the hardened concrete to the environment is reduced; hence, low shrinkage.

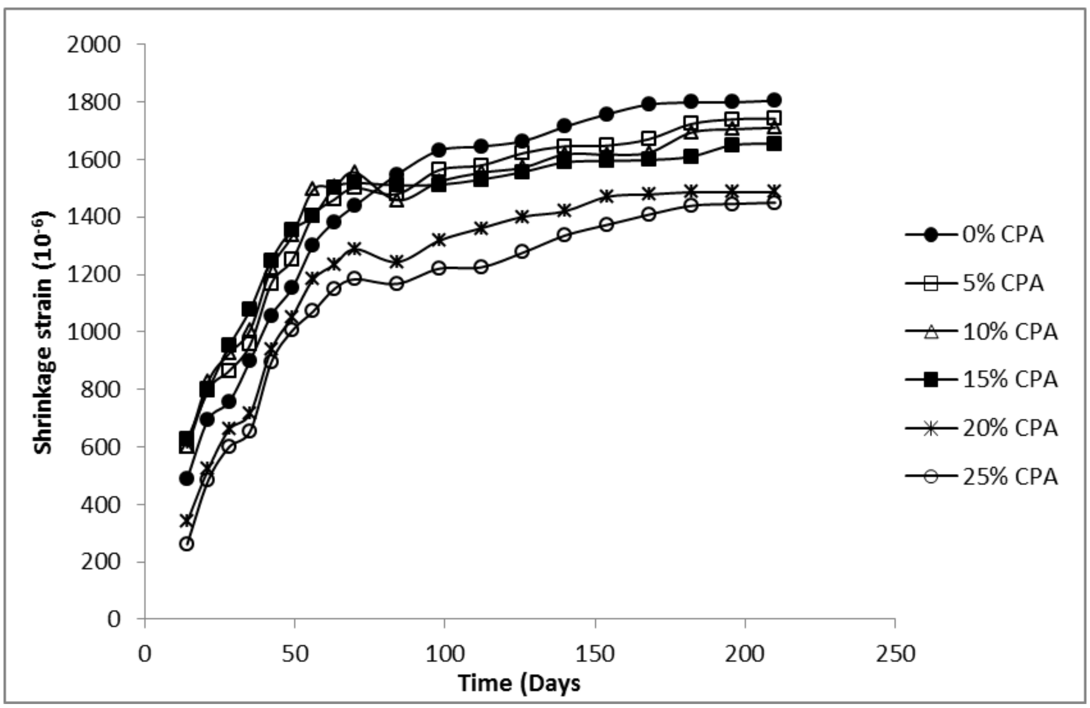
It is observed that the shrinkage rate is reducing gradually with elapsed time for all specimens with most critical shrinkage value falling within the first 28 days. At 28 days, 42% of the total shrinkage strain had occurred for normal concrete while 50, 54 and 63% of total shrinkage strains for the 5, 10 and 15% CPA concrete were observed (Figure 3b).

After about 90 days and up to 210 days, the shrinkage of normal concrete was higher than all other mixes (Table 2 and Figure 3b). At the age of 210 days of exposure of specimens to the ambient conditions, the shrinkage strain of 1805.0, 1741.5, 1710.5 and 1668.7$\times 10^{-6}$were observed for normal concrete, 5, 10 and 15% CPA blended concrete respectively. While concrete containing 20% and 25% CPA concrete had shrinkage strain of 1486.7 and 1450$\times 10^{-6}$, respectively.

At these later periods, pozzolanic reaction would have started which also required consumption of more moisture. The inclusion of CPA helps to promote late hydration of cement and increases the density of hardened cement paste. This strengthens the pore structure of concrete, thus producing concrete that is more resistant to deformation. The effect of cassava peel ash on shrinkage properties of concrete is comparable to the performance of metakaolin (Megat Johari et al., 2001). Li and Yao (2001), reported similar effect when 30% replacement of ground granulated blast furnace slag (GGBS) is used. However, Mokarem *et al*.(2005), stated that the addition of pozzolans generally increases pore refinement; thus creating smaller pores.




(a) Shrinkage pattern for the first 7 days




(b) Shrinkage pattern for the between 14 and 210 days.

**Figure 3:** Shrinkage strain of Cassava Peel Ash Concrete over Period of Time.

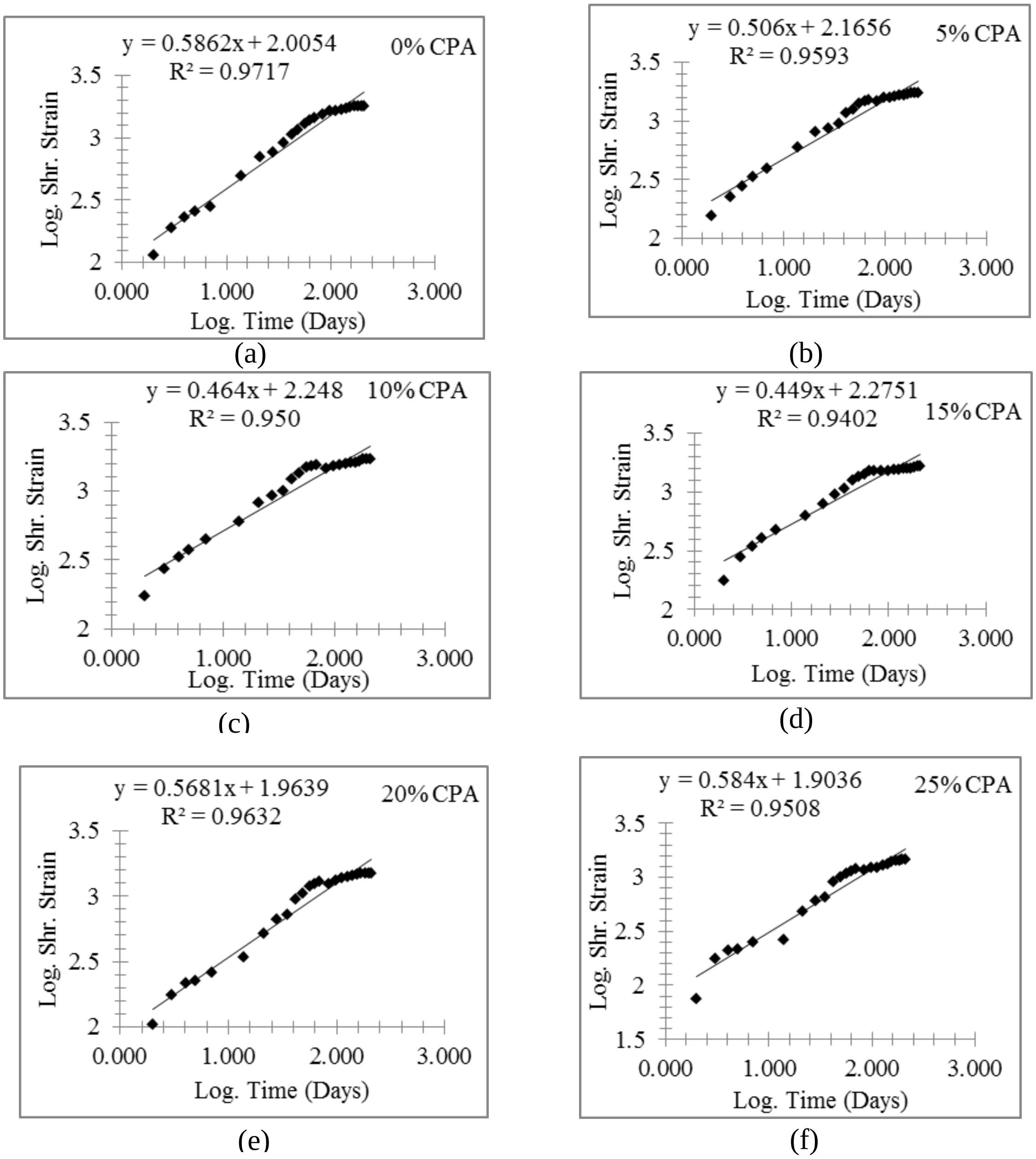



**Figure 4:** Log of Shrinkage Strain with Log Time for Concrete with Varied Amount of CPA

## Rate of Shrinkage Deformation of Cassava Peel Ash Concrete

The effects of logarithm of shrinkage strain with logarithm time for all the mixes are shown in Figure 4 (a-f) in order to observe the divergence in the results of shrinkage deformation. The translation into logarithmic graph provides a clearer comparison and analysis of the shrinkage results, as the gradient of the logarithmic graph indicates the rate of shrinkage deformation. The intercept of log shrinkage strain (Y-axis) represents the deformation constant which controls the magnitude of the deformation (Neville, 2005).

Generally, the consistency of the graph plotting to the equations is within a consistent range, having the Pearson residuals squared, $R^2$, between 0.94 and 0.99.

It is observed that the deformation constant for normal concrete (Figure 4a) and those of 5, 10 and 15% CPA [Figure 4(b-d)] were all greater than 2 with highest value being for concrete containing 15%. However, the rate of shrinkage deformation reduces as the content of CPA increases up to 15%. For normal concrete rate of shrinkage deformation is 0.586 representing 115.8, 126.3 and 130.5% of rates of deformation for CPA concrete having 5, 10 and 15% CPA, respectively.

## CONCLUSION

In this study, the total shrinkage of concrete containing different percentages of cassava peel ash was studied for a period of 210 days at ambient temperature and relative humidity. The results obtained can be summarized as follows:

1. The shrinkage strain increased with time in all concrete specimens as moisture content of the concrete escapes to the environment on drying which consequently causes volume change. The rate of shrinkage deformation reduces as the content of CPA increases up to 15% but increases above 15% CPA content.

2. At early age of 7 days, the shrinkage strains of concrete containing 5, 10 and 15% content of CPA were 390, 445 and 470 $\times 10^{-6}$representing 139.2, 158.9 and 167.8% of the shrinkage strain for normal concrete (280$\times 10^{-6}$). However, at the same age, the shrinkage strain of concrete with more than 15% CPA (20 and 25%) were lower than that of normal concrete by 7% and 10.7%, respectively.

3. At later age (above 90 days) when pozzolanic reaction would have started, the drying shrinkage of normal concrete was higher than all other mixes by a maximum of 24%. Thus, Cassava peel ash reduces shrinkage of concrete especially at later age.

## RECOMMENDATION

It is recommended that effect of long-term static loading (Creep) as well as shrinkage due to creep on the cassava peel ash concrete should be investigated. Also, effect of dynamic loading on the concrete is still a subject of future research.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