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Effect of Sulphate Attack on the Strength of Cement Brands Blended with Cassava Peel Ash

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Research Article

Abstract

The Effect of four sulphate solutions on the strength of mortar made from four common brands of cement blended with cassava peel ash was investigated in this study. This is to determine the level of resistance of such mortar to an aggressive sulphate environment. Cassava peel ash (CPA) produced through controlled incineration was washed and used to replace each brand of the Portland cement at a replacement level of 20% by weight, while the control had no CPA (0%). Mortar of mix proportion of 1:3 (binder: sand) was prepared and a total of 300 mortar beams (160 x 40 x 40 mm) were cast and cured in fresh water for 28 days then in 50g/l concentration of sulphate solution of Calcium, Potassium, Magnesium and Sodium separately for 7, 14, 28, 56 and 90 days but the control samples were cured in fresh water. It was observed that the strength of the mortar specimens with CPA blended cement increased with increase in curing ages up till 28 days then decreased with the curing ages. Sokoto cement blended with CPA showed the highest resistance with an average of 39% loss in compressive strength in the sulphate solutions, while Sodium sulphate was the harshest environment for the mortar samples. It was concluded that presence of CPA reduced loss of strength in all the sulphate solutions used in this study.

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Keywords
Cassava peel ash; concentration; sulphate solution; curing ages.

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1. Introduction

Concrete and mortar are important construction materials. While concrete is used as a bulk building material, mortar is used to bind together bricks, stone, or other blocks in masonry-type construction. Concrete and most mortars rely on hydraulic cement binders for their strength and durability (Oss and Padovani, 2003).

Over the years, durability issues due to chemical attack on cement-based construction materials has been a growing concern. Sulphate attack – a form of chemical attack - is one of the primary causes of deterioration in concrete. Sulphates from sewage water, industrial effluent, sea water, groundwater to mention a few, penetrate into the concrete and react with the hydrated cement paste phases leading to the production of secondary phases like gypsum, ettringite or thaumasite, which may lead to cracking, spalling or loss of strength (Van Tittelboom and De Belie, 2009). Sulphate attack could be said to be of two types: External Sulphate Attack (ESA) and Internal Sulphate Attack (Nicolas, 2016). In the case of ESA, the sulphate ions present in the environment percolates into the material through the porous structure. The reaction proceeds from the surface and progresses till it gets to the inner layers. In the case of Internal Sulphate Attack (ISA), the reaction takes place without preliminary external diffusion process since the sulphate ions are already present in the material. According to Nicolas (2016) and Classie (2016), in both cases, expansion process is possible only in the presence of water. This was also supported by Panesar (2019) who opines that sulphate attack of concrete is a complex process, which includes physical salt attack due to salt crystallization and chemical sulphate attack by sulphates from soil, groundwater or seawater. El-Hachem *et al*. (2012) added that wastewater is a source of sulphate attack for concrete. It can be said then that the sources of sulphate attack are, not limited to sulphate rich soil, ground water, sea water and wastewater.

Due to damaging effect of sulphate and the substantial amount of resources being deployed for maintenance and/or repair of sulphate damaged concrete, efforts are geared towards finding ways to prevent sulphate attack. One of such approaches is the use of supplementary cementitious materials (SCM). Pozzolans were used to improve the properties of lime, and many structures are still extant as a testament to the durability of lime – pozzolan mortars and concrete (Salau and Olonade, 2012; Raheem *et al*., 2015). Many of these pozzolans are industrial by-products and considered as waste, so that the resulting benefits in terms of energy savings, economy, environmental protection and conservation of resources are substantial.

Industrial waste pozzolans such as Fly Ash (FA) and Silica Fume (SF) are already widely used in many countries (Cisse and Laquerbe, 2000), while attempts are being made to produce and use pozzolanic agricultural by-product ashes such as Rice Husk Ash (RHA) and Saw Dust Ash (SDA) commercially in some countries. Mehta and Pirtz (2000) investigated the use of RHA to

limit thermal cracking high strength mass concrete and found that RHA is very effective in producing dense concrete that do not crack easily due to thermal effect; hence present ingress of sulphate from the environment. In the same vein, Malhotra & Mehta (2004) reported that ground RHA with finer particle size than OPC improves concrete properties. It was also mentioned that higher amount of RHA substitution (up to 40%) results in lower water absorption values and thus causes increase in the compressive strength. Cordeiro *et. al*. (2009) carried out an elaborate study of Brazilian RHA, Rice Straw Ash (RSA). It was shown that grinding increases the effectiveness of RHA as a pozzolan and consequently increase the strength and compactness of concrete produced from the ash.

Cassava peel ash is another emerging pozzolanic materials and it has been used substantially in producing concrete with comparable strength (Salau & Olonade, 2021, Salau *et. al*., 2014). Adesanya *et al*. (2008) reported that cassava peel constitutes between 20-35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, they stated that about 6.8 million tons of cassava, peel is being generated annually and 12 million tons as at 2020.

Cassava peels are disposed carelessly due to lack of alternative uses. This caused environmental pollution as obnoxious odour ooze out from the dump site of cassava peels..

Olonade *et. al.* (2014) reported that concrete made from blended cement-cassava peel ash possesses relatively low compressive strength, when cured in sulphuric acid and that the sulphuric acid solution inhibits pozzolanic reaction between Cassava Peel Ash (CPA) and calcium hydroxide to take place. They recommended that more studies be carried out on the effect of sulphuric acid solution on cement-CPA concrete cured in fresh water for longer period to allow pozzolanic reaction to take place. Similar gaps in terms of durability of CPA concrete still exist. To what extent can blended CPA-cement products (mortar and concrete) resist sulphate rich environment is still a grey area.

This study, therefore, assessed the resistance of four common brands of cement in Nigeria blended with CPA, when exposed to four types of Sulphate salt solutions.

2. Materials and Method

2.1 Materials

Cassava peels were collected from a Gari processing centre at Ketu Ejinrin, Lagos State and burnt to ashes as recommended by Salau and Olonade (2011). River sand was used as fine aggregates, while different cement brands studied were Dangote (D), Lafarge (L), Purchem (P) and Sokoto (S) cements. Calcium sulphate, Magnesium sulphate, Potassium sulphate and sodium sulphate solution of concentration 50g/l were used as sulphate exposure medium, while water medium was used as control. The choice of the relatively high concentration of the sulphate solutions was deliberate. This was to ensure accelerated deterioration compared to natural sulphate attack, which take years before effect manifest.

2.2 Method

2.2.1 Aggregate characterization

Specific gravity and water absorption of the sand were determined. Sieve analysis was also carried out and the particle size distribution curve for the aggregate was plotted and their corresponding grading properties: coefficients of uniformity, coefficient of curvature and fineness modulus were determined. The characterization of the aggregate was conducted in accordance with the standard procedure of BS 13771(1990).

2.2.2 Determination of the physical and chemical properties of the cement

The chemical compositions of the different brands of cement studied were determined using X-ray florescence technique (XRF). The test was conducted in the Chemical Laboratory of Lafarge/WAPCO Ewekoro, Ogun State, Nigeria. The surface area of the cement brands was determined with Blain meter cell. The densities and the specific gravities of the cements were equally determined in accordance with the BS4550 (1987).

2.2.3 Mortar preparation

Mortar of mix ratio 1: 3 (binder: sand) with water/cement ratio of 0.5 was batched by weight. Binder contained 20% CPA of volume weight of cement, as earlier determined in previous studies (Salau and Olonade, 2011). Normal mortar (0% CPA) was used as reference. Mortar prism of 160 x 40 x 40 mm samples were cast with the cement brands one after the order. The samples were first cured in water for 28 days to allow for hydration to take place as well as pozzolanic reaction before they were exposed to sulphate attack for a period of 7, 14, 28, 56 and 90 days.

2.2.4 Flexural and Compressive Strength Test

At the end of each curing period, each of the prism was removed from the solution, surface-dried and weighed. The flexural strength of the mortar prism was first determined by loading the middle of the prism until failure. The load that broke the sample into two halves was recorded as the flexural force. The resulting halve from flexural strength tests were used as samples to determine the compressive strength, as recommended by BS EN 196 -1 (2016). Then, flexural strength was determined. The samples were placed in between two (2) metal cubes of sides 40 mm and the sample was loaded compressive load till failure. The failure load was then recorded as the compressive force. Thereafter, flexural strength was determined. This was in conformity with the provisions of BS EN 196 -1 (2016).

3. Results and Discussion

3.1 Aggregate Characterization

The properties of the aggregates were determined for proper classification. The results are summarized in Table 1

Table 1: Physical grading properties of the aggregate

Properties	Sand
Specific Gravity	2.66
Water Absorption (%)	4.10
Fineness Modulus	2.55
Coefficient of Curvature, Cc	1.25
Coefficient of Uniformity, Cu	4.60

The fineness modulus, an index number that represents the mean size of the particles in sand, is within the recommended standard in accordance with ASTM C125, while the water absorption was found to meet the recommended values given by standard of ASTM C70.

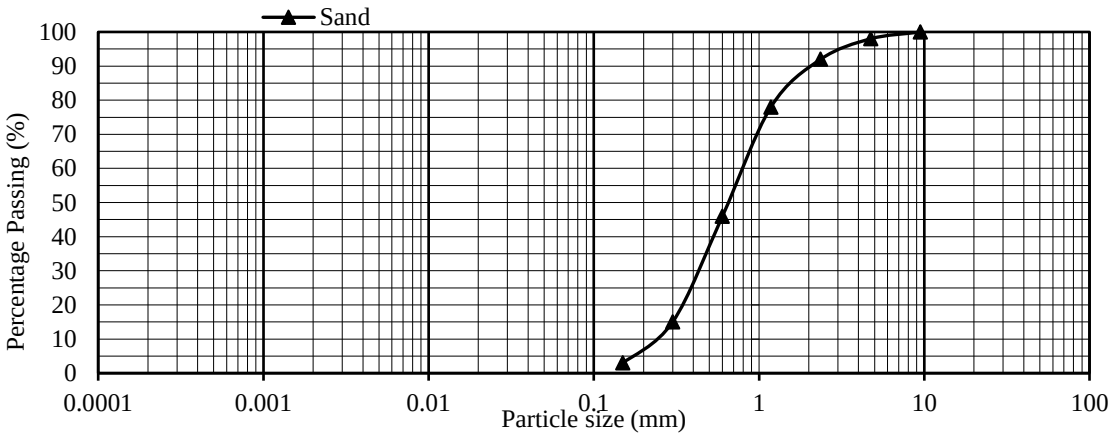


Figure 1: Particle size distribution curve of the sand

From Figure 1, uniformity coefficients (C_u) was calculated to be 4.6, while coefficient of curvature was 1.25. As C_u is greater than 4 and C_c is greater than 1 (according to Unified Soil Classification), the aggregate could be classified as well graded based on Unified Soil Classification; hence it could be used for mortar production.

3.2 Chemical Analysis of the Cements and CPA

The performance of any Portland cement or pozzolanic material is highly influenced by its chemical composition. In Table 2, the chemical compounds as well as their percentage chemical composition are shown. The chemical compositions were analyzed with X-Ray Fluorescence spectrometer. The dominant oxides were CaO, SiO_2, Al_2O_3 and Fe_2O_3, while other oxides present in the cement included MgO, SO_3, other visible alkali oxides such as K_2O and Na_2O as well as oxides of phosphorus, titanium and manganese. Each of these oxides play specific role during cement hydration. The specification for the aluminium-oxide according to the British code BS EN 196-2(1995) falls within 2.6-8.0%. All the cement brands were observed to be within the specification. The presence of the aluminium-oxide contributes to early strength development. From the analysis, Sokoto cement had the highest aluminium-oxide content.

The chemical compositions of the ashes showed that cassava peel ash satisfy the ASTM C618 (2006) requirements, where the sum of SiO_2, Al $_2O_3$, and Fe_2O_3 was found to be 72.34% higher 70% recommended. This result is comparable to what Salau and Olonade (2011) obtained in their study.

Table 2: Chemical composition of the Ordinary Portland Cements and CPA

% Oxides /LOI	Purechem (P)	Dangote (D)	Lafarge (L)	Sokoto (S)	CPA
SiO_2	19.08	15.77	16.77	19.06	59.72
Na_2O	0.00	0.03	0.02	0.00	0.05
K_2O	0.06	0.34	0.27	0.24	6.82
CaO	60.44	60.53	60.56	60.24	8.42
MgO	1.03	2.25	1.71	2.34	5.22
TiO	0.27	0.22	0.23	0.28	-
P_2O5	0.19	0.45	0.31	0.58	-
Al_2O_3	4.57	4.04	4.40	5.30	11.10
Fe_2O_3	3.13	3.11	2.85	3.35	1.52
SO_3	2.69	1.90	2.00	1.91	2.08
Mn_2O_3	0.05	0.05	0.06	0.13	-
LOI	7.04	11.15	10.24	6.20	5.07

Based on the concentrations of the chemical oxides in Table 2 and using the Bogue's calculation, the percentage proportions of C_3S, C_2S, C_3A and C_4AF in the cement brands; Dangote, Lafarge, Purechem and Sokoto were calculated. The results are presented in Table 3. The percentage of C_3S in the cement brands was higher than 50 % range as recommended by the European standard specification (EN 197-1). Dangote and Lafarge cement were observed to be 89.56% and 79.75%. The two calcium silicate minerals, C_3S and C_2S, are largely responsible for the early strength development and enhance long-term structural and durability properties of hydrated cement (Greame, 2003).

Table 3: The Bogue's Compounds

COMPOUNDS	DANGOTE	LAFARGE	PURECHEM	SOKOTO
Tricalcium silicate (C_3S)	89.56	79.75	58.19	54.54
Dicalcium silicate (C_2S)	22.35	12.08	10.80	13.50
Tricalcium-aluminate (C_3A)	5.44	6.84	6.81	8.38
Tetracalciumaluminoferrite (C_4AF)	9.46	8.67	9.53	10.19

3.3 Effect of Sulphate Attack on Compressive Strength of Cement Mortar

3.3.1 Effect of calcium sulphate

Compressive strengths of the mortar samples cured in water and calcium sulphate solution are presented in Table 4, while Figure 2 shows the loss in compressive strength of the four brands of cement blended with CPA as the curing ages increased. There was increase in compressive strength across

all the brands of cement as can be observed from Table 4 with ages until 28 days of curing when the strength begins to decrease except for Sokoto cement, which increased up till 56 days. This later strength increase may be related to the higher content of Alumina in Sokoto cement compared to other cement brands (Table 2). However, Dangote cement maintained a consistent increase in strength with the ages (Table 4). There was also gradual loss in strength in concrete cured in $CaSO_4$ solution across the ages and for all the cement, but at different values. For instance, Dangote cement had a strength loss of about 5.7 N/mm^2 at 90 days representing 35%, while a loss of about of 69% was observed in the case of Lafarge cement for the same period.

Lafarge cement, like Purechem cement, was observed to show an initial decrease in loss of strength from 3.18 N/mm^2 at age 7 through age 28 but exhibited a strength gain as compared to the mortal prism in water by 4.25 N/mm^2 rather than losing strength. Nevertheless, an increase in loss of strength through age 56 days at 3.72 N/mm^2 and a very sharp increase in loss of strength through the age 90 of 13.92 N/mm^2, which may be attributed to the effect of the sulphate attack. The loss of strength was observed in Sokoto cement, as its strength increased progressively across the ages. It was observed from the results that Dangote cement blended with CPA possessed the highest resistance to calcium Sulphate than Sokoto cement blended with CPA.

Table 4: Compressive Strength (N/mm^2) of Portland Cement Brands in water and $CaSO_4$

Cement	**Strength(N/mm^2)**					**Strength(N/mm^2)**				
Brands	**Ages of Curing (days) in water**					**Ages of Curing (days) in $CaSO_4$**				
	7	14	28	56	90	7	14	28	56	90
Purechem	7.18	9.25	9.93	13.65	14.84	6.46	9.10	9.73	9.07	6.12
Dangote	9.86	13.25	13.67	15.58	16.15	7.25	9.10	9.73	10.19	10.37
Lafarge	9.64	9.81	10.1	17.41	20.04	6.46	7.14	14.35	13.69	6.12
Sokoto	11.65	16.58	17.65	19.59	20.76	7.25	9.10	12.93	12.99	12.45

From these results, it could be deduced that the initial increase in strength of the mortal samples in calcium sulphate could be that sulphate attack has not commenced and still finding its way into the mortar matrix, while a noticeable decrease in strength was an evidence of the Sulphate attack more resisted by some cement brands than the other. In addition, the loss in strength could also be ascribed to the effect of the CPA with which the cement was replaced. It could be that the strength of each brand of the cement at 28 days in the calcium Sulphate were closely comparable to those without CPA and also cured in water, which highlighted the late strength contribution of CPA; a characteristic of any pozzolan.

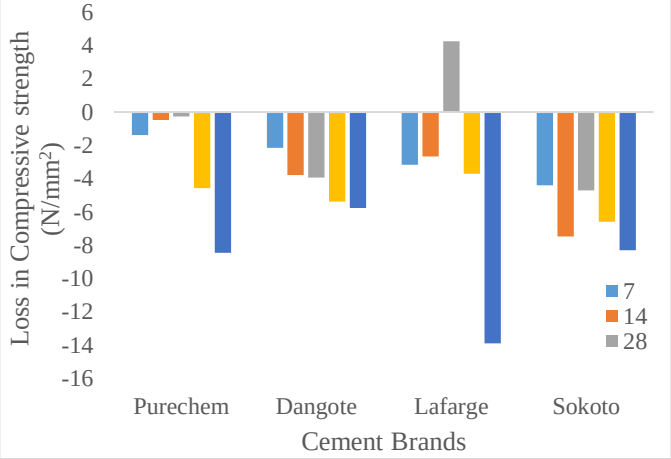


Figure 2: Loss in compressive strength against curing ages in Calcium Sulphate

3.3.2 Effect of potassium sulphate

Figures 3 and 4 show the compressive strength and loss in the compressive strength of the four brands of cement blended respectively with CPA at different curing ages in potassium Sulphate (K_2SO_4) solution. A general increase in strength across all the brands of cement was observed as shown in Figure 3 with all the ages up till 56 days of curing when a gradual loss in strength set in except for Purechem cement which started losing strength early (28 days). Quantitatively, strength of mortar made from purechem cement blended CPA cured in K_2SO_4 solution suffer a sharp loss in strength between the ages 28 and 56 days from 12.34 N/mm^2 to 8.09 N/mm^2, representing about 34%. But when compared to its strength when cured in water, the loss was about 41% (Table 4 and Figure 4).

Unlike Purechem cement, strength of mortar made from Dangote cement blended with CPA increased up to 56days before loss of strength was observed. The trend was that it had strength of 7.42 N/mm^2, 9.97 N/mm^2, 10.15 N/mm^2, 11.08 N/mm^2 at 7, 14, 28, 56 and 90 days of curing in K_2SO_4 solution as against its strength 7.18 N/mm^2, 9.25N/mm^2, 9.93N/mm^2,13.65 N/mm^2 and 14.84 N/mm^2 for corresponding curing ages in water.

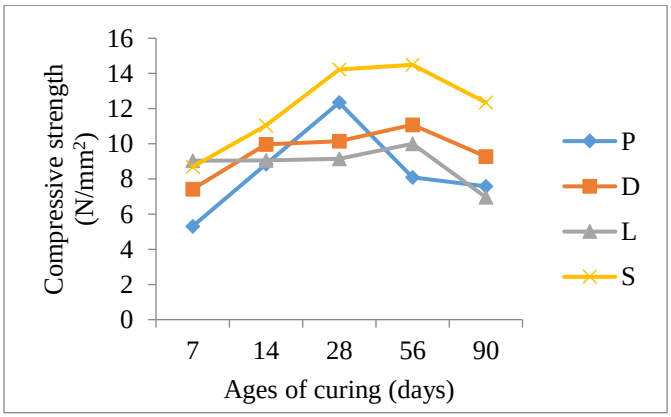


Figure 3: Compressive strength against curing ages in Potassium Sulphate Solution

Lafarge cement, on the other hand, also exhibited a gradual increase in strength from 9.03 N/mm^2 at 7days up to 10 N/mm^2 at age 56 days but the strength suddenly dropped to 6.96 N/mm^2 at 90 days. At 90 days, when compared to other cements, it was seen that Lafarge had the highest loss of strength in potassium solution with a strength loss of about 65%, followed by Sokoto cement, while Dangote cement had the lowest loss in strength. The reason for this trend could not be readily seen in the chemical composition of the cements. Perhaps, the high content of potassium in CPA contributed to the high loss in strength for Lafarge. It could also be due to low value of Tetracalciumaluminoferrite (C_4AF), which is responsible for later day strength.

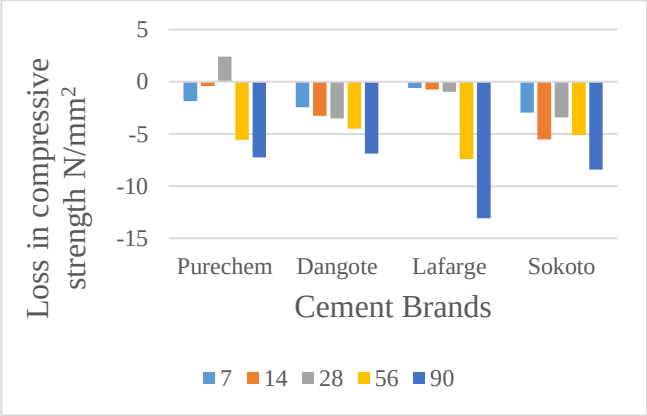


Figure 4: Loss in compressive strength against curing ages in Potassium Sulphate.

3.3.3 Effect of sodium sulphate

Compressive strength of mortars made from the four cement brands blended CPA, when cured in sodium sulphate solution ($NaSO_4$) for different curing ages is presented in Figure 5 and 6. There was a general increase in strength across all the brands of cement as the ages progress till 56 days of curing when the strength started reducing except for Purechem cement which started falling from age 28 days (Figure 5). Purechem cement possessed a compressive strength of 5.83 N/mm^2 at age 7days, which continued to increase with the ages till age 28 days to a strength value of 12.19 N/mm^2 (Figure 5). At longer ages of 56 and 90 days the strength values of 6.39 N/mm^2 and a strength loss of 8.45 N/mm^2 were observed. But Dangote cement blended with CPA had strength rose with ages from 7.66 N/mm^2 with a loss of 2.2 N/mm^2 at 7 days to 9.12N/mm^2 and a loss of strength of 6.46 N/mm^2 at 56 days followed by a reduction in strength to 8.51 N/mm^2 at 90 days with a loss of strength of 7.64 as compared to the control (Figure 6). As for Lafarge cement blended with CPA also showed a similar trend through the first 28 days then a decrease to a strength of 11.86 with a strength loss of 8.18 N/mm^2. The compressive strength of the Sokoto cement increase as well from age 7 days with a value of 9.68 N/mm^2 through age 56 days with a value of 20.58 N/mm^2, while at 90 days to 11.75 N/mm^2 yielding a loss of 9.01 N/mm^2.

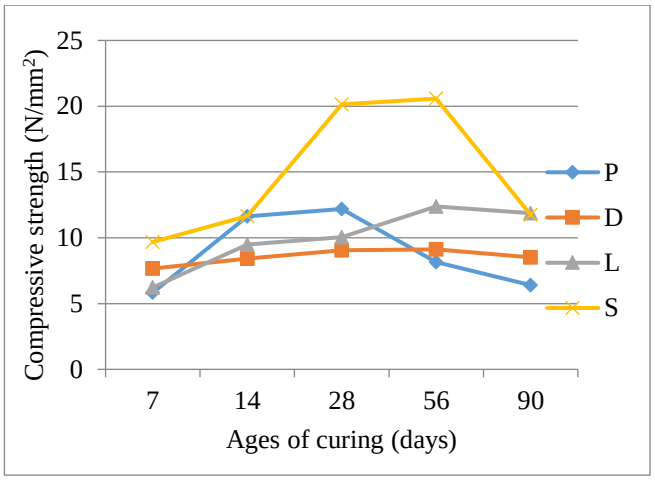


Figure 5: Compressive strength of Mortar samples cured in Sodium Sulphate at different ages

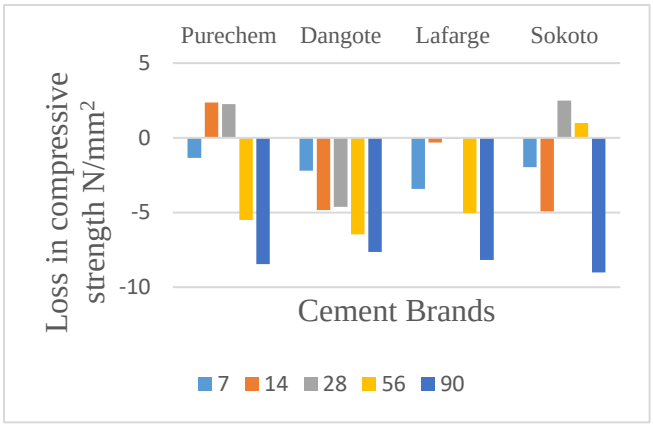


Figure 6: Loss in compressive strength against curing ages in Sodium Sulphate.

3.3.4 Effect of magnesium sulphate

As for the mortar prism cured in magnesium sulphate solution, there was general increase in strength up to 28 days before loss in strength observed thereafter (Figure 7). The case was different for Dangote cement which exhibited an increase as well strength reduction was observed 14-day curing till 90 days.

The compressive strength of the mortar made from blended Purechem cement at 7 days of curing in Magnesium solution was recorded as 9.15 N/mm^2 with 1.97 N/mm^2 strength gain, as could be observed, when compared with the control which was 7.18 N/mm^2 (Figure 8). The strength increased also at 14 days to 9.22 N/mm^2 with a strength loss of 0.03 N/mm^2. The increase continues at the 28 days at 11.74 N/mm^2 giving a strength loss of 1.81 N/mm^2, while reduction in strength became noticeable at the 56 days with value of 9.23 N/mm^2 with a strength loss of 4.42 N/mm^2, and at 90 days with a great strength loss of 11.73 N/mm^2.

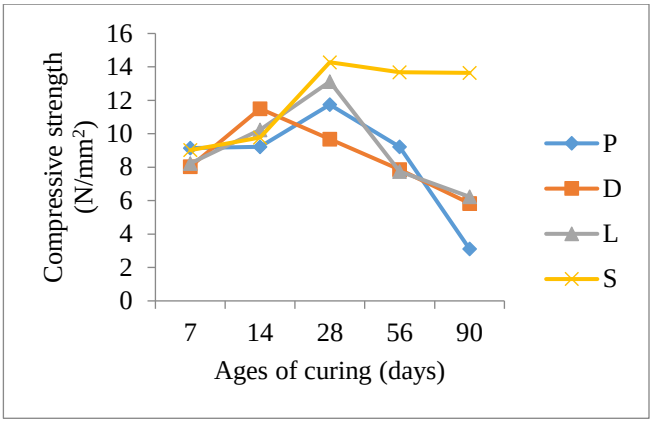


Figure 7: Compressive strength of four brands of cement mortal blended with CPA and ages of curing in Magnesium Sulphate.

At 7 days, the compressive strength of blended Dangote cement mortar in magnesium Sulphate was 8.03 N/mm^2 with a strength loss of 1.83 N/mm^2, 11.50 N/mm^2 and a strength loss of 1.75N/mm^2 at 14 days, a reduction in strength at 28 day at 9.68 N/mm^2 and a strength loss of 3.99 N/mm^2, 7.87 N/mm^2 and a loss of strength of 7.71 N/mm^2 at 56 days and 5.84 N/mm^2 at 90 days with a loss of strength of 10.31 N/mm^2. Like the Purechem cement, Lafarge cement blended with CPA rose through the 7 days at 8.22 N/mm^2, 14 days at 10.23 N/mm^2 and 28 days at 13.12N/mm^2 but started declining through the 56 days at 7.75 N/mm^2, and 90 days at 6.23 N/mm^2 resulting in high increase in the loss of strength through the last two ages of 56 days and 90 days at 9.66N/mm^2 and 13.81 N/mm^2 respectively as opposed to the slight increase that was recorded for each of the other ages. The blended Sokoto cement mortar also trended the same pattern Lafarge and Purechem trended. The strength at 7 days, 14 day, and 28 days were observed to have progressively increase from 9.02 N/mm^2, 9.78 N/mm^2 to 14.28 N/mm^2 respectively and subsequently declined at 56 days and 90 days at 13.69 N/mm^2 and 13.65 N/mm^2 respectively.

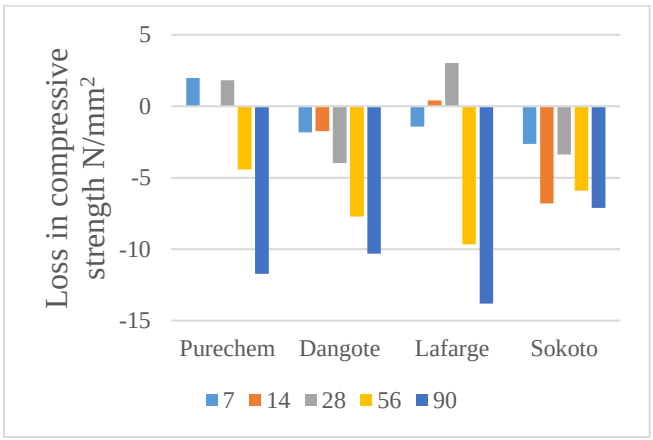


Figure 8: Loss in compressive strength against curing ages in Magnesium Sulphate

3.4 Effect of Sulphate on the Flexural strength of cement mortar

3.4.1 Effect of calcium sulphate

Table 5 shows flexural strength of mortar prism made from Portland cement brands cured in water and Calcium sulphate solution, while Figure 9 shows the loss in flexural strength of four brands of cement mortal blended with CPA at different ages of curing in calcium sulphate solution. It can be observed from flexural strength showed increase follow the pattern observed in the case of compressive strength.

Table 5: Flexural Strength (N/mm^2) of Portland Cement Brands in Water and $CaSO_4$

Cement	**Strength(N/mm^2)**					**Strength(N/mm^2)**				
Brands	**Ages of Curing (days) in water**					**Ages of Curing (days) in water $CaSO_4$**				
	7	14	28	56	90	7	14	28	56	90
Purechem	1.17	1.40	1.43	1.51	1.78	1.45	1.53	1.83	1.21	1.17
Dangote	1.80	1.95	2.02	2.38	2.40	1.42	1.45	1.58	2.01	1.76
Lafarge	1.38	1.69	1.83	1.86	2.06	1.53	2.06	1.76	1.50	1.11
Sokoto	2.08	2.15	2.20	2.31	2.42	1.7	1.95	2.09	2.22	1.83

At age 7days, the flexural strength was 1.45N/mm^2 and rose through age 28days to 1.83 N/mm^2 then fell at 56 days and 90 days to 1.21 N/mm^2 and 1.17 N/mm^2 respectively. The initial increase in strength could be attributed to effect of the CPA before it was attack by the Sulphate. It was also observed from Figure 9 that the loss of strengths through the ages was marginal. For instance, the highest loss of strength was 0.61 N/mm^2 at age 90 days of the mortal prism while there was a strength gain of 0.28 N/mm^2 at age 7 days, 0.13 N/mm^2 at age 14days and 0.4 N/mm^2, at age 28days.

For Dangote cement, the strength increased gradually through the ages, but slight loss of strength was observed at age 90 days.

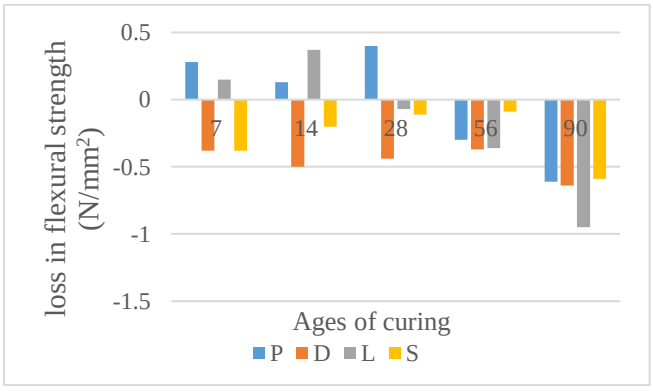


Figure 9: Loss in flexural strength against curing ages in Calcium Sulphate.

There was slight increase in flexural strength for Lafarge cement as ages increased from 7 days to 14 days when compared with the control sample. Afterwards, the strength loss was observed.
Sokoto cement shows had the highest loss in strength in the magnitude of 0.59 N/mm^2 at 90 days as compared to other brands.

3.4.2 Effect of potassium sulphate

Figures 10 and 11 show the flexural strength and loss of strength of four brands of blended cement-CPA mortal and ages of curing Potassium Sulphate solution. All the cement brands had increase in strength with ages till 28 days, when they started reducing except for Dangote and Sokoto cement that began to lose strength from 28 days.

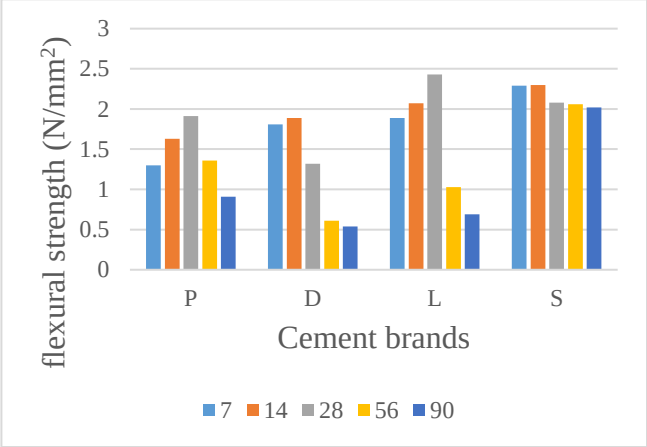


Figure 10: Flexural strength of four brands of cement mortal blended with CPA cured in Potassium Sulphate.

Blended Purechem cement mortal cured in potassium solution had increase in flexural strength through the ages 7, 14 and 28days as it also gained strength as compared to the control with values 1.30 N/mm^2, 1.63 N/mm^2 and 1.91 N/mm^2 for the flexural strength respectively and 0.13 N/mm^2, 0.23 N/mm^2, and 0.48 N/mm^2 for the strength gained respectively (Figure 10). Dangote cement was observed to be the most affected by the potassium sulphate solution as high loss of strength was observed (Figure 11). At ages above 28 days, the strength values were 1.77 and 1.86 N/mm^2 respectively.

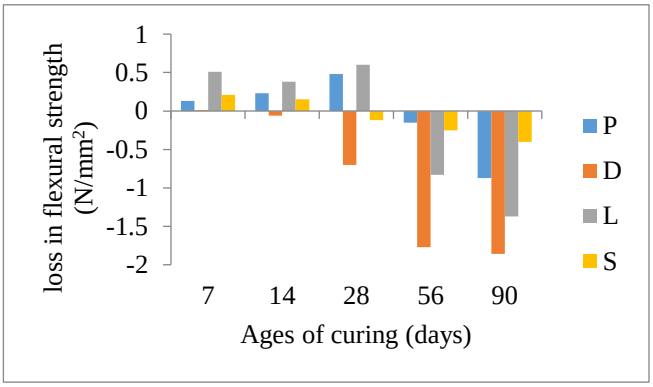


Figure 11: Losses in strength of four brands of cement mortar blended with CPA cured in Potassium Sulphate.

This observation could also be supported by the visible cracks observed on the Dangote mortar sample cured in this solution. Lafarge cement like Dangote can be observed to have increased in flexural strength at the early ages with gain in strength but declined at the later ages of 56days and 90days with high losses of strength. Strengths of 1.89N/mm^2, 2.07 N/mm^2, 2.43 N/mm^2, 1.03 N/mm^2, and 0.69 N/mm^2 were recorded across the ages 7days through 90 days respectively and loss of strength of 0.83 N/mm^2 and 1.37 N/mm^2 at the ages 56 days and 90 days respectively as against the strength gained at the early ages of 7days, 14days and 28day at the values 0.51 N/mm^2, 0.38 N/mm^2, and 0.6 N/mm^2. Sokoto cement showed a significantly strong resistance to potassium Sulphate solution like did in calcium Sulphate solution as rises in strength as it is observed from the figure through the ages and slightly declines at the ages 56days and 90days with still a significant strength and slight loss of strength with values 2.06 N/mm^2 and 2.02 N/mm^2 for the flexural strength respectively and 0.25 N/mm^2 and 0.4 N/mm^2 for the losses of strength respectively.

3.4.3 Effect of sodium sulphate

Figures 12 and 13 show the flexural strength and the loss of strength of blended cement-CPA mortar made from four brands of cement and cured in Sodium Sulphate solution for different ages respectively. Purechem and Sokoto could be observed to follow similar trend in that they increased in strength till age 28 days before loss of strength through the remaining ages, while both Dangote and Lafarge were observed to follow a similar pattern as well since they both started losing strength at age 14 days.
At ages of 7 14 and 28days, Purechem had strength of 1.39N/mm^2,1.81 N/mm^2, and 1.96 N/mm^2 respectively then started reducing thereafter to 1.05 N/mm^2 and 0.94 N/mm^2 at 56 and 90 days respectively.
Both Lafarge and Dangote cement mortar started losing strength at after 14 days till 90 days. Sokoto cement could as well be observed to have resisted sodium Sulphate solution substantially as it declined only slightly at the later ages of 56 and 90 days when other samples had higher loss in strength. The strength of 2.63N/mm^2 and 2.36 N/mm^2 were recorded with the slightest loss of strength at the ages 56 days and 90 days respectively.

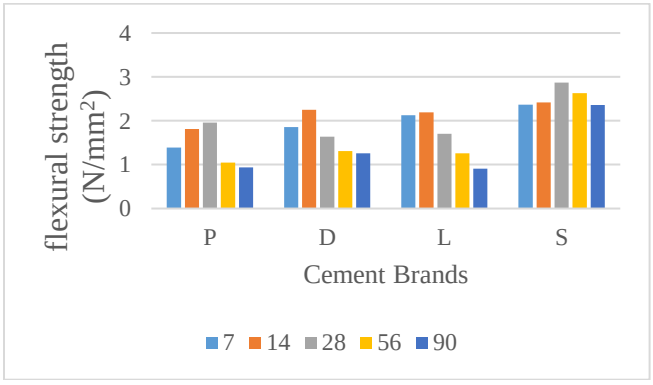


Figure 12: Flexural strength of four brands of cement mortal blended with CPA cured Sodium Sulphate.

Meanwhile, other brand shows a highly varied strength with the strongest possessing the strength value of 1.36 N/mm^2 and 1.26 N/mm^2 (that is Dangote) at the ages 56 and 90 days respectively.

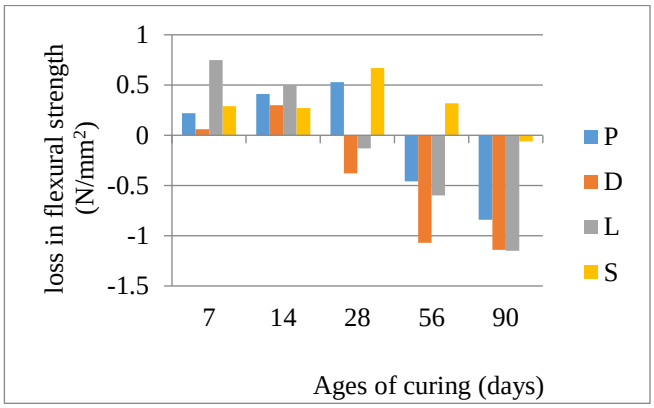


Figure 13: Losses in strength of four brands of cement mortar blended with CPA cured in Sodium Sulphate.

3.4.4 Effect of magnesium sulphate

Figures 14 and 15 show the relationship between the flexural strength and loss of strength of four brands of cement mortar blended with CPA and ages of curing in Magnesium Sulphate. A general reduction in strength across all the brands was observed from age 14 days through the later ages, which could be attributed to the aggressive effect of magnesium sulphate on the cement brands.

It can be observed that, although all the brands are greatly affected by the Magnesium Sulphate solution, Sokoto cement was still found to possess an important strength compared to other brands at a value of 0.94 N/mm^2 at 90 days while the strongest (Dangote) of other brands has 0.5N/mm^2. Also, purechem gave the least loss of strength while Dangote has the highest loss of strength which was at 1.9 N/mm^2 and thus suggesting Dangote cement as the most affected by the Sulphate solution.

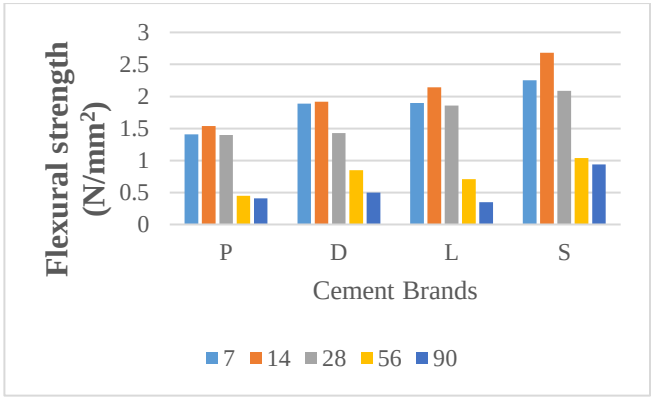


Figure 14: Flexural strength of four brands of cement mortar blended with CPA cured in Magnesium Sulphate.

This can be supported by the cracks evident on the cement mortars made from Dangote cement cured in magnesium Sulphate which may be due to the formation of ettringite which the mortar matrix as a result of the Sulphate attack.

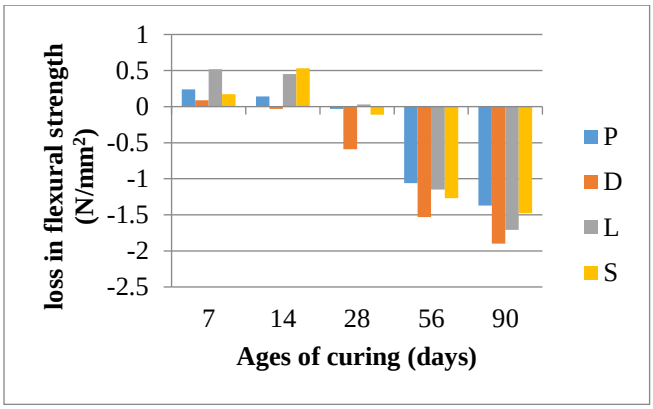


Figure 15: Losses in strength of four brands of cement mortar blended with CPA cured in Magnesium Sulphate.

3.5 The Percentage Loss in Compressive and Flexural Strength and the Sulphate Salts

Figures 16 and 17 show the relationship between the percentage loss in compressive strength of the four brands of cement and the four sulphate salt solutions at 90 days and the relationship between the percentage loss in flexural strength of the four brands of cement and the four sulphate salt solutions at 90 days. It could be observed from figure 16 that the blended cement brand with the most resistance to all the sulphate solutions is Sokoto cement brand with average percentage loss in compressive and flexural strength of 39.55% and 26.14% respectively and while the most affected blended cement brand is the Lafarge cement with average percentage loss in compressive and flexural strength of 61.11% and 62.86% respectively although it shows the strongest resistance to Sodium sulphate attack as represented in Figure 17. It could also be easily observed that magnesium sulphate salt solution is the most aggressive of all the four types of solutions as it caused in the most percentage loss in strength while calcium sulphate is the mildest considering the percentage loss in flexural strength.

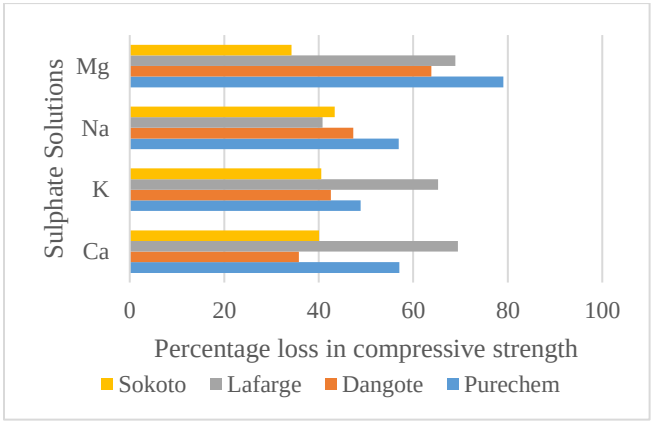


Figure 16: Percentage loss in compressive strength of the four brands of cement and the four sulphate solutions at 90 days

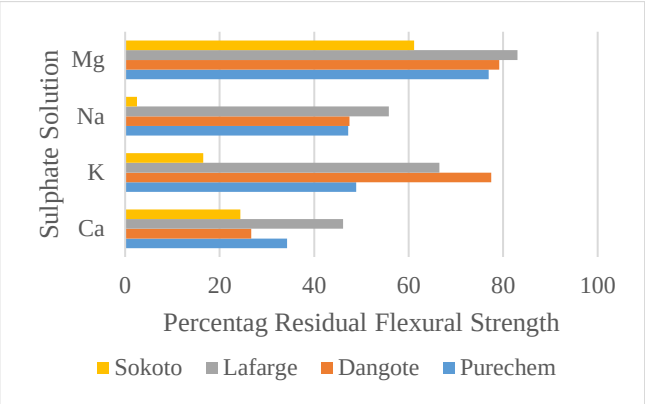


Figure 17: Percentage loss in flexural strength of the four brands of cement and the four sulphate solutions at 90 days

From Figure 17, it could be seen that Dangote cement, like Lafarge cement, is very much affected considering the percentage loss in flexural strength which is 57.71%.

4. Conclusion

From the study of the effect of four sulphate solutions on the strength of mortar made with four common brands of cement blended with cassava peel ash, it could be concluded that both the flexural and compressive strength of Lafarge cement mortar blended with CPA are the most affected by the Sulphate attack. Sokoto cement blended with CPA showed the greatest average resistant to all the Sulphate solutions. From the X-Ray fluorescence analysis of the cement brands, the oxides and mineral parameters showed the difference in reactivity of the cement brands. The values of the dicalcium and tri-calcium silicate aided the strength development.

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