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Effects of sulphuric acid on the compressive strength of blended cement-cassava peel ash concrete

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Abstract. Influence of sulphuric acid on compressive strength of concrete made with blended cement-cassava peel ash was investigated in this study. This is with a view to determining the level of resistance of such concrete to acidic exposure. Cassava peel ash (CPA) prepared from uncontrolled burning was used to substitute cement at 5, 10, 15 and 20% by weight of cement as binder. Concrete mix proportions of 1:2:4 (batching by weight) were prepared with the slump value within 60±10 mm while water-binder ratios (w/b) were being noted. A total of 90 cubes of the concrete mixture of sizes 150 mm were cast and cured in fresh water (as control), 0.5, 1.0 and 1.5 M concentrations of sulphuric acid solution (H_2SO_4) for 7, 28, 56 and 90 days. The compressive strength was determined at the expiration of each curing age. The results showed that the w/b increased with increase in the quantity of CPA in the mixture. Compressive strength of concrete made with cement-CPA as binder and cured in fresh water was comparable to that of normal concrete when up to 15% CPA was used, but relatively low strength was obtained when cured in H_2SO_4 solutions, depending on the quantity of CPA. Leaching of Porlandite in the concrete cubes was observed with worse condition in the case of concrete containing 20% CPA in sulphuric acid solution of 1.5 M. The compressive strength reduced with increase in concentrations of the acid as well as with increase in the content of the CPA. It is concluded that CPA did not mitigate the adverse effects of sulphuric acid on the compressive strength of blended cement-CPA concrete.

Keywords. Blended cement-cassava peel ash, water-binder ratio, compressive strength, sulphuric acid solution, acid concentration, slump

Introduction

The use of industrial and agricultural wastes as pozzolan or as supplementary cementitious materials (SCMs) in concrete production is becoming popular and attracting attention of many researchers. However, the durability of such concrete in an unfriendly environment has been a major concern. Durability of concrete, as defined by

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ACI Committee 201[1], is its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. A durable concrete will retain its original form, quality and serviceability when exposed to the environment. One of such environment, which concrete could be exposed to, is acidic. According to Zivica et al, [2], acid attack on concrete may come from different sources such as air pollution and bacterial contamination.

It is well established in literatures [2 - 6] that acidic environment is deleterious to concrete durability because acid neutralizes the alkalinity of concrete by reacting with the hydration products of the concrete matrix to form gypsum and ettringite. The chemical reaction of this neutralization phenomenon with sulphuric acid is given by Zivica and Bajza [3] as in Equations (1) and (2). Both gypsum and ettringite possess little structural strength, yet they have larger volumes than the compounds they replace. This results in internal pressures, formation of cracks and eventually, the loss of strength [7]. Consequently, the concrete becomes vulnerable to aggressive exposure.

$$H_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4.2H_2O \text{ (gypsum)} \quad (1)$$

$$3CaSO_4 + 3CaO.Al_2O_3.6H_2O + 25H_2O \longrightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \text{ (ettringite)} \quad (2)$$

Adesanya and Raheem [8] studied the effects of H_2SO_4 and HCl on the concrete produced with different proportions of corn cob ash (CCA) blended with cement. Their results showed that CCA was responsible for the reduced water absorption of the concrete, and when up to 15% of CCA replaced cement, the resistance to chemical attack was improved. Also, the performance of fly ash (FA) and stone dust (SD) blended concrete in acidic environment was investigated by Verma et al [9]. They found that the residual strength of concrete containing FA and SD was comparable with that of normal concrete, when the mixture of about 40% stone dust and up to 30% FA were used.

In the recent past, cassava peel ash (CPA) has been found to be pozzolanic [10]. Salau et. al [11, 12] studied the strength characteristics and effect of elevated temperature on the concrete produced with partial replacement of cement with cassava peel ash. They reported that performance of concrete containing up to 15% CPA was comparable with that of normal concrete and recommended that up to 10% could be used in the case of structures exposed to 400°C. Olonade et al. [13] also used cassava peel ash, derived from uncontrolled burning, blended with cement to produce sandcrete blocks with positive results. However, the performance of concrete made with blended cement-CPA concrete in acidic environment has not been reported. Therefore, the thrust of this paper is to investigate the effect of sulphuric acid on the strength properties of the concrete containing cassava peel ash as partial substitute for cement.

1. Materials and methods

1.1 Materials

The cement used for the study was ordinary Portland cement (CEM I). Cassava peels were burnt into ashes in an incinerator and sieved through 150 sieve size. It was used to replace cement, partially, to produce the binder for the concrete. The chemical composition of both the cement and CPA was determined. River sand and granite of maximum nominal sizes of 3.18 mm and 19 mm were used as fine and coarse aggregate respectively. Potable water was used for mixing. The sulphuric acid was procured from the Department of Chemistry, Obafemi Awolowo University, Ile-Ife, and different concentrations of its solution were prepared in the laboratory.

1.2 Mixing, curing and testing concrete specimens

Concrete mix proportion of 1:2:4 (cement/CPA: sand: granite) was batched by weight. Cement was substituted with CPA in the proportions of 5, 10, 15 and 20% of the weight of cement. In order to maintain the same consistency, water-binder ratio was varied until slump was within 60±10 mm. The choice of the slump was to achieve medium workability for general concrete work [14]. Seventy-two (72) concrete cubes of sizes 150 mm were cast, and moulds were removed after 24 hours and cured by total immersion in sulphuric acid (H_2SO_4) solutions of different concentrations of 0.5, 1.0 and 1.5 M for 7, 28, 56 and 90 days. At the expiration of each curing age, cubes were tested for compressive strength. Another 18 cubes were cast and cured in fresh water for the same ages to serve as controls. Average of three readings was recorded for each curing age result. All the concrete cubes were cured under the laboratory conditions, with average minimum and maximum temperatures within 25^0C and 35^0C respectively.

2. Results and discussion

2.1 Chemical composition of cement and CPA

The chemical composition of both the cement and CPA is presented in Table 1. It is observed that the dominant oxide in the cement and CPA are CaO and SiO_2 respectively. CaO is the main source of binding and hardening compound in cement, when reacted with water (hydration reaction), which is very low in CPA. But, the SiO_2 in CPA reacts with $Ca(OH)_2$ (by product of cement hydration) to produce more binding property (Pozzolanic reaction). The advantage of reduction in the consumption of cement leading to reduction in the greenhouse effects of cement usage is being exploited by the use of pozzolan in concrete production.

Table 1. Chemical composition of the cement and cassava peel ash

Material	Oxides (%)								LOI
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	
Cement	20.80	3.10	2.50	64.50	1.70	0.23	0.85	2.50	3.40
CPA	36.79	7.57	2.23	8.20	2.9	1.37	18.74	1.52	15.10

2.2 Effect of CPA on Water-Binder Ratio

In order to maintain standard consistency for all the concrete mixes, the slump value was kept within the range 60±10 mm and the water-binder ratio (w/b) to achieve this was determined for each concrete mix. The results of the w/b at different content of CPA are presented in Table 2. It is observed that the w/b increases with increase in CPA content. A w/b of 0.60 was obtained in case of normal concrete (0% CPA) while concrete containing 5%, 10%, 15% and 20% have w/b of 0.63, 0.68, 0.73 and 0.76, respectively. The reason for this behaviour could be attributed to higher water absorption potential of cassava peel ash [11]. The implication is that more water would be required to produce concrete containing CPA depending on the amount used. However, the amount of water in a concrete matrix is a major factor that influences most engineering properties of concrete, it is expected that the inclusion of cassava peel ash would have effect on the performance of concrete.

Table 2. Water-binder ratios at constant slump of cement-CPA concrete

CPA Content (%)	Water-binder ratio at slump 60 ± 10 mm
0	0.60
5	0.63
10	0.68
15	0.73
20	0.76

2.3 Effect of curing cement-CPA concrete in h_2so_4 solution on compressive strength

Concrete cubes produced from various proportion of CPA as replacement for cement were cured in sulphuric acid solution of different concentrations. The compressive strength of the cubes was determined at the end of each curing age. The results are presented in Table 3 along with those cured in fresh water. Considering the compressive strength of the cubes cured in fresh water, it is observed that the strength increases with age and reduces with increase in CPA content. However, the strength of cement-CPA concrete tends to merge up with those of normal concrete, especially at later age (56 days and above) when not more than 15% CPA is used. For instance, 28-day strength of normal concrete is 19.84 N/mm^2 while 5% CPA concrete has strength of 18.56 representing about 94% of the normal concrete strength. Similarly, the strength of 10, 15 and 20% CPA concrete are 17.26 (87%), 14.74 (75%) and 12.78 N/mm^2 (65%), respectively. These results agree with what Salau et al [12] reported.

Table 3. Compressive strength of cement-CPA blended concrete at different curing ages

Curing Media	Curing Ages (Days)	Residual Strength (N/mm^2)				
		Amount CPA (%)				
		0	5	10	15	20
Fresh Water	7	14.59	13.53	13.37	12.87	10.63
	28	19.84	18.56	17.26	14.74	12.78
	56	20.80	19.58	18.87	17.18	14.30
	90	21.03	20.00	19.78	18.67	15.31
0.5M H_2SO_4	7	13.98	13.12	12.28	11.99	11.78
	28	18.48	17.56	16.07	14.77	14.35
	56	17.51	16.61	15.78	13.91	12.91
	90	16.31	15.34	15.01	13.23	12.05
1.0 M H_2SO_4	7	12.39	11.76	11.05	10.88	9.66
	28	11.39	10.57	10.28	9.34	9.07
	56	10.01	9.93	9.22	9.05	8.76
	90	9.52	9.23	8.98	8.45	8.21
1.5M H_2SO_4	7	10.51	10.48	9.36	8.74	7.78
	28	10.13	9.25	9.04	8.25	7.03
	56	8.99	7.49	7.34	6.82	6.20
	90	7.53	7.12	7.01	6.12	6.02

On the other hand, compressive strength of concrete cubes cured in H_2SO_4 solution differs considerably from those obtained when cured in fresh water. The trend is that the strength reduces with increase in concentrations of the acid and the duration of curing. Figure 1 shows the typical trend at age 90 days. For instance, compressive strength (CS) of concrete cubes cured in 0.5, 1.0 and 1.5 M H_2SO_4 solution are 16.31, 9.52 and 7.53 N/mm^2 respectively for normal concrete, while the CS of 5 and 10% CPA, cured in the same media for the period (90 days), are 15.34, 9.23, 7.12 and 15.01, 8.98 and 7.01 respectively. At the same age, least strength is obtained in concrete with the binder containing 20% CPA, and when cured in 1.5 M for 90 days (6.02 N/mm^2). Of interest is the marginal decremental change observed in CS due to the effects of the sulphuric acid at the same concentration for each of the concrete made with up to 15% CPA replacement. At 90-day curing age, taking the CS of concrete cured in fresh water as reference, the percentage reduction in CS for 0.5M H_2SO_4 solution at 0, 5, 10 and 15% CPA replacement ranges basically between 22 and 24%. For 1.0M of the acid, the percentage reduction in CS ranges between 53 and 55%, while the CS, when cured in 1.5M H_2SO_4 solution, ranges essentially between 64 and 65%, respectively.

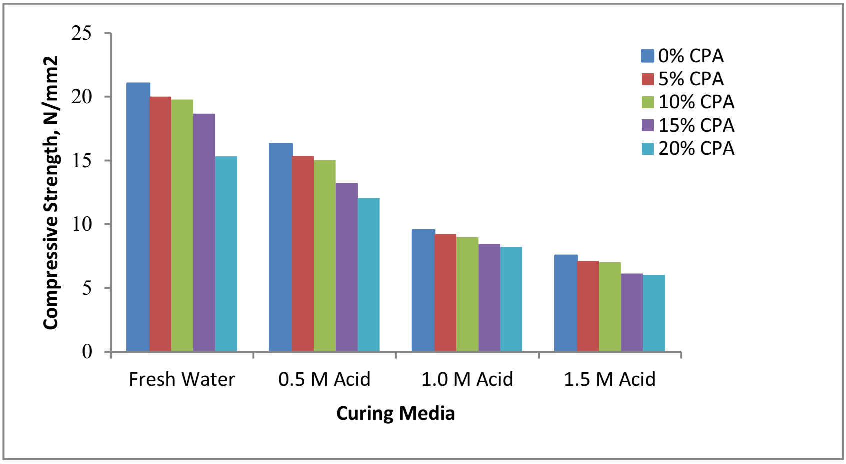

Figure 1. Compressive strength of cement-CPA concrete in different curing media at age 90 days

Similarly, mass of the concrete cubes is observed to be gradually reducing. This effect may be attributed to the effect of curing in sulphuric acid solution. Figure 2 shows the plot of average mass of the concrete cubes against the curing ages in different media. It is shown that the mass of the concrete cured in fresh water is almost the same (standard deviation is about 0.03). This result is comparable with what Salau et al (11) reported. The reason for this may be due to the relative low specific gravity of CPA compared to that of cement. However, gradual reduction in mass is observed in the concrete cubes cured in H_2SO_4 solution. This effect shows that H_2SO_4 solution causes reduction in the mass of concrete. The pattern is that, at early age of 7 days, there appear to be minimal change in the mass of the concrete cubes cured in all the media, but as the age increases, the mass also decreases. It is shown that concrete loses more weight (about 20%) between the ages 7 and 90 days, when cured in 1.5 M H_2SO_4 solution compared to the concrete cured in fresh water (0.6%). Moreso, about 4% and 10% of the mass were lost, when cured in 0.5M and 1.0M H_2SO_4 solution, respectively. The progressive reduction in mass may be attributed to weaker compound (gypsum) that is formed as a result of neutralization reaction between H_2SO_4 and $Ca(OH)_2$, consequently leading to lowering of the compressive strength (Equation 1).

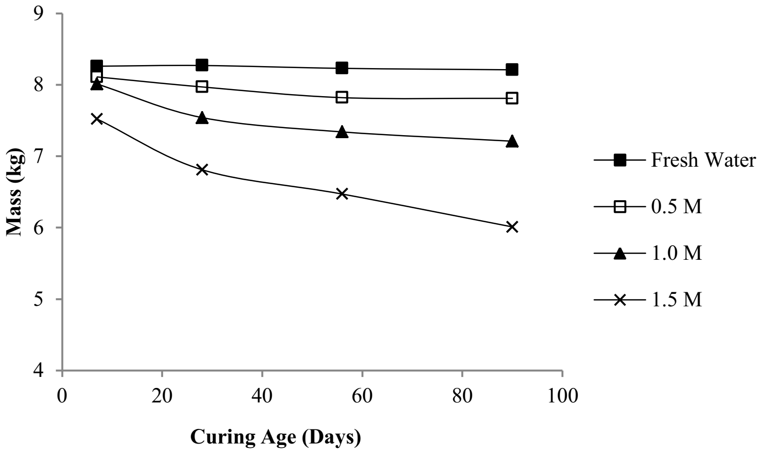

Figure 2. Effect of acid concentration on the mass of cement/CPA concrete

Figure 3. Typical leaching of $Ca(OH)_2$ from concrete cubes in the H_2SO_4 solutions at 90-day curing age

These results suggest that the concentration of sulphuric acid had appreciable effect on the performance of cement-CPA concrete and presence of CPA does not improve concrete resistance to sulphuric acid attack. This may be because sulphuric acid leaches and neutralizes calcium hydroxide $Ca(HO)_2$, a by-product of cement hydration, which was to react with the silica in the CPA for later strength development (pozzolanic reaction). This reaction tends to produce *fragile* concrete that contains several pores (Figure 3). It can be deduced also, that the sulphuric acid inhibits the pozzolanic reaction of CPA in the mix and made the concrete to be more permeable with low strength, when compared to the control. Therefore, concrete made with blended cement - CPA may not be used to make facilities for wastewater disposal and treatment, where there are high chances of H_2SO_4 solution generation. Nevertheless, there is the need to investigate the effect of sulphuric acid solution on cement-CPA concrete cured in fresh water for a longer period to permit pozzolanic reaction.

In addition, Figure 4 shows comparative rate of strength reduction of the concrete over that of normal concrete at 90 days curing age. The rate appears very high in concrete cured in fresh water and 0.5M while it is very low in the concrete cured in 1.0M and 1.5M of H_2SO_4 solution, respectively. This shows that other secondary products may be forming at higher concentrations of H_2SO_4 solution that reduces the rate of deteriorating effects of the acid over the curing ages.

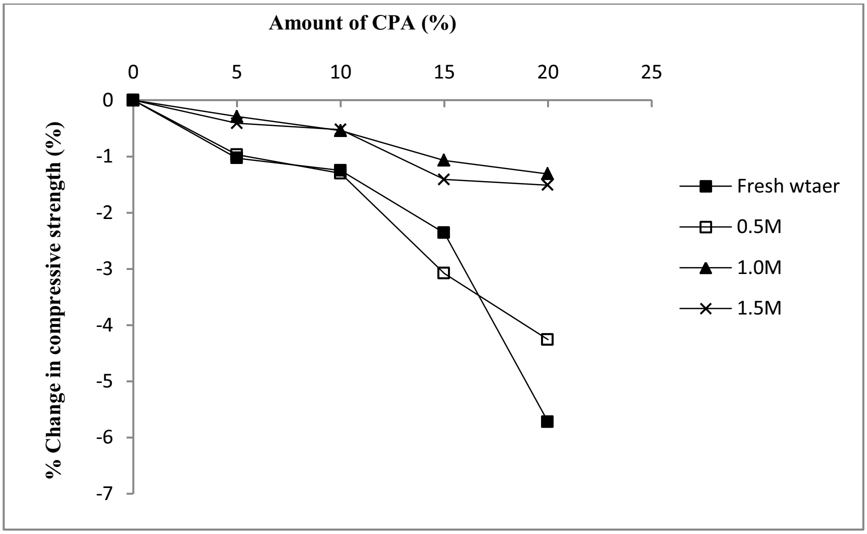

Figure 4. Change in comparative strength of concrete made with binder of different percentages of CPA in varying concentration of H_2SO_4 at 90-day curing age

3. Conclusions

The effect of curing blended cement-cassava peel ash concrete in different concentrations of sulphuric acid has been studied and the following conclusions were reached:

1. Water-binder ratio (w/b) increases with increase in the quantity of CPA in the mixture.
2. Sulphuric acid solution causes reduction in the mass of cement-CPA concrete due to the leaching effect of the acid.
3. Concrete made from blended cement-cassava peel ash possesses relative low compressive strength, when cured in sulphuric acid.
4. Sulphuric acid solution inhibits pozzolanic reaction between CPA and calcium hydroxide (by-product of cement hydration) to take place. Thus, making CPA to be inactive in the mixture.
5. This research is on-going. There is need to further study the effect of sulphuric acid solution on cement-CPA concrete cured in fresh water for longer period to allow pozzolanic reaction to take place.

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