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Durability of Ternary Blended Cement Concrete in Sulphuric Acid

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Abstract
This study investigated the durability of concrete made of ordinary Portland cement (OPC), bamboo leaf ash (BLA) and pulverized burnt clay waste (PBCW) as binders in sulphate environment. Ternary blending of OPC, BLA and PBCW at ten (10) levels (100:0:0; 90:5:5; 90:10:0; 90:0:10; 80:5:15; 80:10:10; 80:15:5; 70:10:20; 70:15:15; 70:20:10) were used in producing 480 concrete cubes of size 100 mm and cured for 28 days in water. Further exposure to sulphuric acid (H_2SO_4) of 0, 1, 3 and 5% concentrations was done for a maximum of 120 days. Strength deterioration factors were thereafter calculated as a measure of acid attack resistance for the blended cement concrete. Results show that concrete containing PBCW and BLA performed better in H_2SO_4 than that of the control. Therefore, it can be concluded that the incorporation of BLA and PBCW in concrete improved its durability in sulphate laden environment.
Keywords:durability, sulphuric acid, bamboo leaf ash, pulverized burnt clay waste, strength deterioration

1. Introduction

In cement industries, continuous attempts are being made to reduce the cost of production of Portland cement and the consumption of the raw materials, protect the environment and enhance the quality (strength and durability) of cement and concrete. One way of achieving this is to use certain low cost materials called pozzolans for partial replacement of Portland cement in concrete production (Dwivedi *et al.*, 2006; El-Sayed and El-Samni, 2006; Dipayan, 2007; Goyal *et al.*, 2008; Murthi and Sivakumar, 2008). Incorporation of pozzolan in concrete production improves many properties of concrete which include plasticity and workability of fresh concrete, low heat of hydration, low thermal shrinkage, reduced permeability, improved resistance to sulphate and other chemically aggressive agents, and increased long term strength of hardened concrete (Al-Dulaijan *et al.,* 2003; Al-Akhras, 2006; Chindaprasirt *et al.,* 2008; and Singhal *et al.,* 2008). Many works have been done which affirm the improved resistance of concrete to chemical attack by making use of various pozzolans in concrete production (Hossain, 2006; Murthi and Sivakumar, 2008; Ademola and Buari, 2014).

Bamboo is the vernacular or common term for members of a particular taxonomic group of large woody grasses (subfamily *bambusoideae,* family *Andropogoneae/Poaceae*). Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries; it is considered a composite material because it consists of cellulose fibres imbedded in a lignin matrix. Bamboo trees are always found in clusters. The annual production of bamboo all over the world is about 20 million tonnes but about 10 million tonnes are produced in India, China and Japan (Vatsala, 2003). Bamboo is consumed in various industries such as food, brewing, construction, agriculture, fibre, paper, textile, board etc. and they generate its leaves as waste, these can be used as raw material for the manufacture of bamboo leaf ash (BLA) to use as pozzolan. Likewise, clusters of bamboo trees amass huge deposit of leaves beneath them as waste. Waste from burnt clay products can also serve as raw material in cement manufacture, they exist as mounting heaps of waste around clay product industries. Studies by Syagga *et al.* (2001), Shihembesta and Waswa-Sabuni (2002) and Bektas *et al.* (2008) indicate that waste burnt clay has pozzolanic properties for production of pozzolan cement.

Concrete is one of the strongest and durable materials used for construction, however, its exposure conditions can inhibit its overall performance during its service life. The erroneous assumption that concrete durability is a factor absolutely dependent on compressive strength in the earlier ages has led to the collapse or threatening deterioration of many concrete structures (Shetty, 2002). Likewise, the belief that concrete is a very durable material requiring little or no maintenance is largely true except when it is subjected to aggressive environment. Hence, both strength and durability of concrete have to be considered explicitly. The rate of loss of strength of concrete in its natural environment measures its durability and one of the contributing factors to deterioration of concrete is chemical attack.

Two major forms of chemical attacks affect long-term durability of concrete, viz, sulphate attack and acid attack. Sulphate attack is more aggressive and deteriorating (Al-Akhras, 2006). Among the various sulphates with devastating effect on concrete are magnesium sulphate and ammonium sulphate. Out of various acids with potential of attacking concrete, sulphuric acid and hydrochloric acid are more severe. However, sulphuric acid has two sides to its attack. It doubles as both sulphate attack and acid attack, hence, it consumes calcium hydroxide, calcium silicate hydrate, calcium aluminate hydrate and monosulphate which are all compounds making up cement concrete (Borsoi *et al.*, 2000). Hence, its attack on concrete is severe and damaging (Balanchandran and Vipulanandan, 1995; Borsoi *et al.*, 2000; ACI 201-2R, 2008; Shetty, 2006; Reddy *et al.*, 2012).

2. Materials and Method

Elephant product of ordinary Portland cement produced to the requirements of BS EN 197-1 was used for the research. Bamboo leaves were got from various areas at Obafemi Awolowo University, Ile-Ife while burnt clay brick waste was sourced from a collapsed St. David Grammar School building, Ile-Ife, Nigeria. Sharp sand free from deleterious materials was used as fine aggregate while granite of maximum size 19 mm was used as coarse aggregate.

Bamboo leaves were gathered and sun dried to reduce moisture content, burning to ashes was then carried out in a drum and quick cooling on clean surface. The resulting ash was then calcinated to 1000°C and sifted to 150 micrometres (µm) size. Likewise, collected burnt clay brick waste was pulverized to powder with a ball mill and sifted to 150 micrometres (µm) size. X-ray fluorescence chemical analysis of the used OPC, BLA and PBCW was carried out to determine their chemical compositions. Likewise, their physical properties were determined. Ten different mixes were prepared from the pozzolans (OPC, BLA and PBCW) as shown in Table 1. Three replicates of 100 mm concrete cubes were cast per replacement level and cured in water for 28 days, a total of 480 cubes were cast. The control mixture was proportioned for a target strength of 25 N/mm^2 at 28 days of water curing. These were thereafter exposed to 0%, 1%, 3% and 5% of sulphuric acid solution for 30, 60, 90 and 120 days. Compressive strength were determined for concrete cubes cured in water for 28 days and in acid for 60, 90 and 120 days after the 28 days water curing.

The deterioration of concrete cube specimens exposed to acidic medium was investigated by measuring the strength deterioration factor (SDF) (Hewayde *et al.,* 2007; Murthi and Sivakumar, 2008) given in Eq. 1. The compressive strength of three replicates of each percentage replacement's concrete cube was determined and the average reported.

$$\mathrm{SDF} = \frac{F_{cw} - F_{ca}}{F_{cw}} \times 100\% \quad (1)$$

Where F_{cw} = Average compressive strength of concrete cube specimen in 0% sulphuric acid

F_{ca} = Average compressive strength of concrete cube specimen in respective concentration of sulphuric acid (1%, 3% and 5%).

3. Results and Discussion

Standard consistency gotten for OPC, BLA and PBCW were 28%, 100% and 50% and their specific gravity were 3.14, 2.00 and 1.70 respectively. Chemical properties of these materials are shown in Table 2. This table shows that BLA contains higher silica content than PBCW while PBCW is higher in alumina and ferrite content. As categorized by ASTM C 618, BLA falls under class F pozzolans while PBCW is a class N pozzolan.

As stipulated by BS EN 197-1, both BLA and PBCW have a silica content higher than 25%. Also, the combined oxide content (SiO_2 + Al_2O_3 + Fe_2O_3) of BLA and PBCW is higher than the minimum of 70% requirement for classes F and N pozzolans stated by ASTM C 618. Likewise, the same standard limits maximum loss on ignition (LOI) of class F and N pozzolans to 6% and 10%, respectively. BLA and PBCW satisfied this specification since they exhibited 4.20% and 1.68% LOI. Hence, BLA and PBCW can be classified as suitable pozzolans for blended cement manufacture.

For this study, it was observed that as the replacement of OPC with BLA and PBCW increases, the blended cement concrete becomes stiffer and less workable. The compressive strengths of the blended cement concrete cubes in water at 28 days curing are shown in Table 3.

From Table 3, the control specimen achieved 116.7% of the target strength while replacement levels 4, 3 and 6 achieved 100.3%, 73.1% and 72.0% of the target strength respectively. Therefore, blended cement concrete containing 10% of PBCW satisfied the 25 N/mm^2 target strength while that containing 10% BLA and 10% PBCW has higher replacement level with good performance and had strength similar to that of the control at longer days of curing as known for pozzolanic cement concrete.

Compressive strength (CS) after exposure to various concentrations of sulphuric acid and their corresponding strength deterioration factors (SDF) are shown in Table 4. At 60 days exposure in 1% of H_2SO_4, there was a reduction of 13.4% in compressive strength for replacement level 1 (control) and the least was a reduction of 2.1% at level 10 while there was a strength increment at level 6 and 8 (0.1% and 2.1%) respectively. After exposing the specimens for 90 days in 1% of H_2SO_4, the least reduction in strength was at level 4 (10.8%) and level 3 (13.0%) while at 120 days of exposure, replacement level 1 and 4 reduced in strength by 39.7 and 9.5% respectively and the percentage strength reduction of level 4 was the least.

At 3% concentration of sulphuric acid, compressive strength was generally lower than that of 1% for corresponding exposure periods. At 60 days of exposure, the control (level 1) and replacement level 2 were reduced by 18.8% and 18.9% while only replacement level 8 had an increment of 1.4%. Replacement level 10 had the least strength reduction of 1.1%. After 90 days of acid exposure, the control replacement had the largest strength reduction of 34.2% while replacement level 4 had the least strength reduction of 12.7%. Replacement levels 3 and 6 had the next least strength reduction of 20%. 120 days of sulphuric acid exposure had the greatest effect on the blended cement concrete. The control replacement's strength was reduced to almost half (48.5%) that of the 0% acid concentration. Replacement levels 9 and 10 were next after level 1 with percentage reduction of 44.4 and 40.7 respectively. Replacement level 4 had the least reduction of 11.9% followed by level 3 with 25.5% reduction while level 5 and 6 had 30.9% reduction.

5% sulphuric acid concentration had the maximal effect on the blended cement concrete. At 60 days of exposure, the control replacement suffered the greatest strength reduction of 26.9% while replacement level 10 had the least strength reduction of 3.0%. Replacement level 4, 5 and 6 had percentage strength reduction of 19.1%, 16.8% and 9.6% respectively. After 90 days of exposure to 5% sulphuric acid, the control replacement level had the largest strength reduction of 37.4% while replacement level 4 had the least strength reduction of 16.5%. Replacement levels 3, 5 and 6 had percentage reductions of 23, 27.7 and 29.3 next to level 4. At 120 days of exposure, the control replacement level suffered heavily by a reduction of 52.1% while replacement level 4 had the least strength reduction of 19%. Replacement levels 3, 5 and 6 suffered 30.0%, 37.7% and 38.9% strength reductions respectively.

Figures 1 to 3 explains further the trend of the compressive strength as the replacement level increases after 60, 90 and 120 days exposure to various concentrations of H_2SO_4. At 60 days of exposure as presented in Figure 1, the deleterious effect of sulphuric acid concentration on the compressive strength became visible at replacement level 1 up to 6 where it ceases to have obvious effect further (plots cluster together). In Figure 2 and 3 representing 90 and 120 days of exposure respectively, there exists a wide gap between the effects of each concentration of acid on the compressive strength of each replacement level. 5% of sulphuric acid at 120 days of exposure had the most deleterious effect on the BLA and PBCW blended cement concrete. In all the three charts, replacement level 4 had peak values. Figures 1 to 3 made it obvious that the higher the concentration of acid and exposure period, the higher the deleterious reduction in compressive strength of the blended cement concrete.

Generally, the strength reduction became more manifested with increase in percentage concentration of sulphuric acid and exposure age of the blended cement concrete. At 60 days of exposure, there were some strength increment, that is, the deleterious ettringite being produced by the sulphuric acid reaction was still filling available pores in the concrete cubes (Meng-Cheng *et al.,* 2013). The strength reduction became more pronounced at 3% and 5% of sulphuric acid and exposure periods of 90 and 120 days. From the foregoing, it would be recommended that when concrete will be exposed to severe acid/sulphate environment, OPC in concrete can be replaced by 10% PBCW for better durability, however, in the case of mild environment of concrete exposure, replacement levels 5 or 6 can be adopted.

4. Conclusion

Incorporation of BLA and PBCW in concrete improved its resistance to sulphuric acid attack in both mild and severe conditions. In mild conditions, a replacement of 10% PBCW and 10% BLA can serve as optimum, but in severe conditions, 10% of PBCW had best performance.

For better knowledge of the pozzolans' behaviour, other durability parameters of the blended cement concrete can be undertaken, these include permeability, diffusivity, absorption, alkali-silica reaction, freeze and thaw, corrosion, abrasion etc.

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Table 1

Percentage Replacement of Cement with Bamboo Leaf Ash and Pulverized Burnt Clay Waste

Replacement levels	Cement (OPC)	Bamboo Leaf Ash (BLA)	Pulverized Burnt Clay Waste (PBCW)
1	100%	0%	0%
2	90%	5%	5%
3	90%	10%	0%
4	90%	0%	10%
5	80%	5%	15%
6	80%	10%	10%
7	80%	15%	5%
8	70%	10%	20%
9	70%	15%	15%
10	70%	20%	10%

Table 2
Chemical Properties of Materials Used

Elemental oxides (%)	OPC	BLA	PBCW
SiO_2	16.82	72.97	52.17
Al_2O_3	4.35	2.85	27.86
Fe_2O_3	2.43	2.31	13.05
CaO	60.39	4.98	0.71
MgO	1.43	1.23	0.52
SO_3	1.64	0.55	0.00
K_2O	0.16	6.07	0.13
Na_2O	0.02	0.00	0.00
Mn_2O_3	0.04	0.41	0.20
Cr_2O_3	0.01	0.05	0.03
P_2O_5	0.21	2.37	0.05
TiO_2	0.24	0.41	1.40
LOI	9.84	4.20	1.68
IR	1.67	80.71	88.04
Free Lime	0.36	0.05	0.00
$SiO_2 + Al_2O_3 + Fe_2O_3$	23.6	78.13	93.08

Table 3
Compressive Strength at 28 Days of Water Curing

Replacement levels	Compressive strength	Percentage target strength (%)
1	29.2	116.7
2	16.5	65.9
3	18.3	73.1
4	25.1	100.3
5	15.4	61.6
6	18.0	72.0
7	13.7	54.9
8	11.5	46.0
9	13.9	55.7
10	11.1	44.3

Table 4
Compressive strength and SDF of BLA and PBCW Blended Cement Concrete Cubes Exposed to 0, 1, 3 and 5%

Exposure period (days)	RL	0%	1%		3%		5%	
		CS (N/mm^2)	CS (N/mm^2)	SDF (%)	CS (N/mm^2)	SDF (%)	CS (N/mm^2)	SDF (%)
60	1	31	26.8	13.4	25.2	18.8	22.7	26.9
	2	29.2	25.3	13.1	23.7	18.9	22.3	23.4
	3	32.3	28.5	11.9	27.3	15.5	26.2	19.1
	4	33.6	29.7	11.7	27.8	17.2	27.2	19.1
	5	30.7	26.8	12.5	26.2	14.7	25.5	16.8
	6	25.8	25.8	-0.1	24.7	4.4	23.3	9.6
	7	24.5	23.5	4	22.5	8	22.3	8.7
	8	21.9	22.3	-2.1	22.2	-1.4	20.8	4.7
	9	21.4	20.2	5.8	20.2	5.8	19.3	9.7
	10	17.9	17.5	2.1	17.7	1.1	17.3	3
90	1	31.7	23.8	24.7	20.8	34.2	19.8	37.4
	2	31.2	26.7	14.4	24.7	20.9	23.7	24
	3	33.3	29	13	26.7	20	25.7	23
	4	34.9	31.2	10.8	30.5	12.7	29.2	16.5
	5	31.3	25.5	18.6	24.7	21.3	22.7	27.7
	6	28.8	24.3	15.4	23	20	20.3	29.3
	7	24.9	21.5	13.8	19	23.8	16.5	33.8
	8	24.9	19.3	22.5	18	27.8	15.8	36.5
	9	22.7	18.8	17	17.5	22.9	14.7	35.4
	10	19.9	16.5	16.9	15.5	22	13.3	32.9
120	1	32.3	19.5	39.7	16.7	48.5	15.5	52.1
	2	32	25.2	21.4	21.8	31.8	21	34.4
	3	33.3	26.7	20	24.8	25.5	23.3	30
	4	35	31.7	9.5	30.8	11.9	28.3	19
	5	31.8	23.7	25.7	22	30.9	19.8	37.7
	6	29.2	21.7	25.7	20.2	30.9	17.8	38.9
	7	24.8	19.8	20.1	17.5	29.5	14.5	41.6
	8	24.9	17	31.7	15.7	37.1	13.5	45.8
	9	23.1	15.3	33.5	12.8	44.4	11.7	49.4
	10	20.5	13.7	33.3	12.2	40.7	11.3	44.7

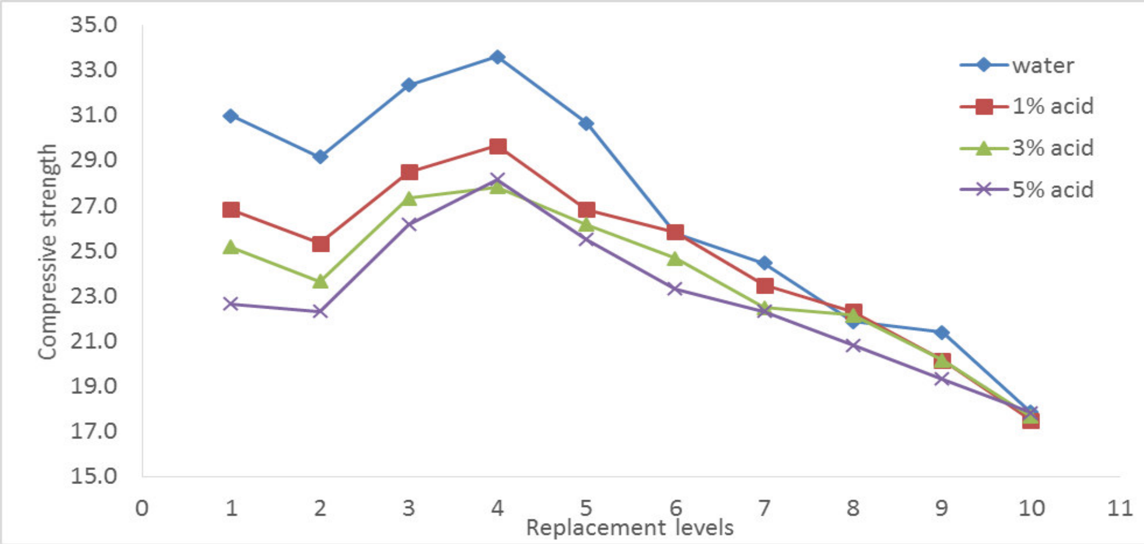

Figure 1 Variation of compressive strength with replacement levels exposed to sulphuric acid for 60 days

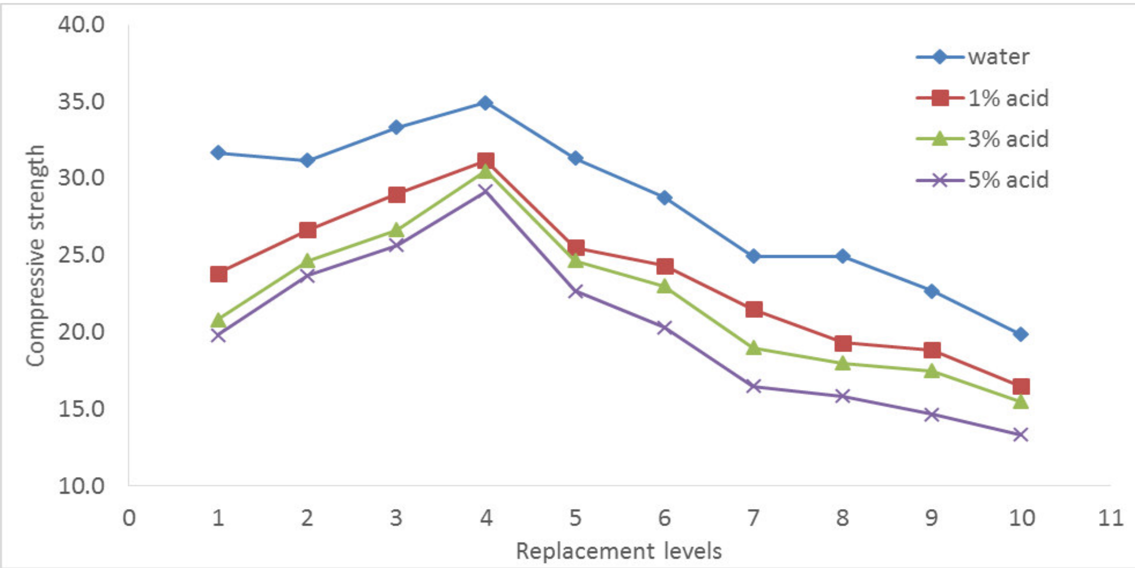

Figure 2 Variation of compressive strength with replacement levels exposed to sulphuric acid for 90 days

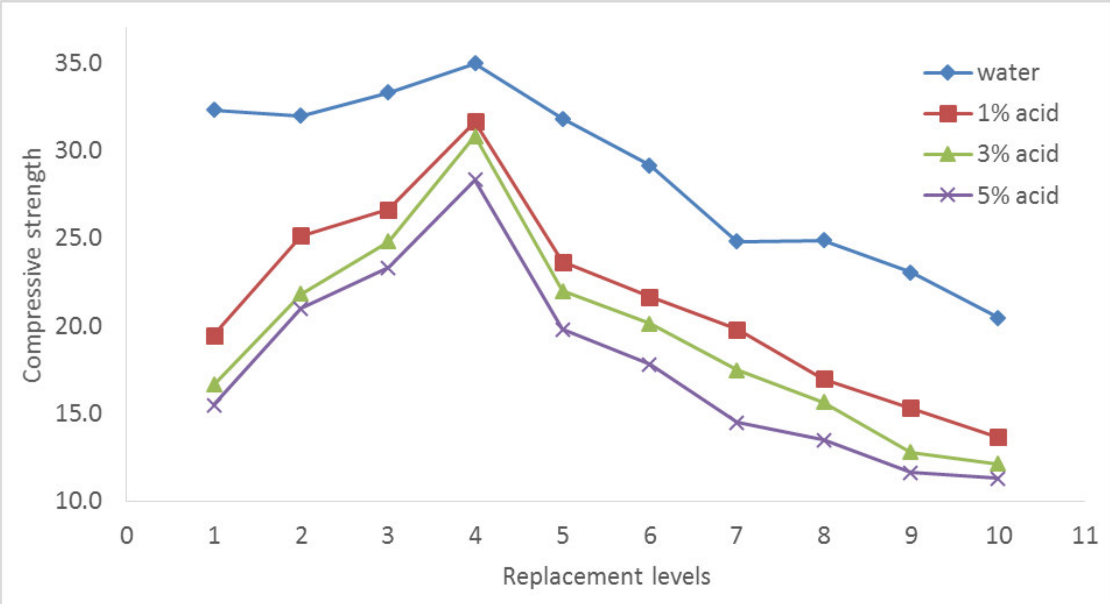

Figure 3 Variation of compressive strength with replacement levels exposed to sulphuric acid for 120 days