Effect of Pulverized Burnt Clay Waste Fineness and Replacement Level on the Compressive Strength of Blended Cement Concrete

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Abstract

Pozzolanic blended cement concretes typically gain compressive strength at later ages beyond the 28-day, and this does not favor its use when early age strength is required. In this paper, the effect of pulverized burnt clay waste fineness on the compressive strength of concrete has been investigated. Two different fineness of pulverized burnt clay waste classified as coarse and fine portion were obtained by sieving the original pulverized burnt clay waste portion through sieve sizes No. 100 (150 µm) and No. 200 (75 µm), respectively. Pulverized burnt clay waste dosages of 0% (control), 10% and 20% by weight of binder were used. It is found that the compressive strength of the concrete depends on the fineness and proportion of pulverized burnt clay waste. Result shows improvement in compressive strength at all curing ages with the fine portion pulverized burnt clay waste having the highest strength and improved early age compressive strength.

Keywords: Pulverized burnt clay waste, pozzolans, compressive strength, fineness, replacement level

INTRODUCTION

Numerous researches have been directed towards the utilization of industrial and agricultural wastes as supplementary cementitious materials (SCM), otherwise called pozzolans for concrete production. Some of these wastes include fly ash (FA), silica fume (SF), blast furnace slag, rice husk ash (RHA), pulverized burnt clay waste (PBCW), saw dust ash (SDA), metakaolin, and a host of others. It is generally accepted that the utilization of pozzolanic materials as partial replacement for cement not only reduce cement demand, but also improves the mechanical and durability properties concrete. This has been attributed to the refinement in the porosity and pore size distribution of the cement paste. The refinement improves its later age strength[1], material transport properties (permeability, sorptivity, and diffusivity), that is, decreased permeability[2], increased resistance to sulphate and sulphuric acid attack[3,4], improved resistance to chloride penetration[5], improved resistance to thermal cracking, and mitigation of alkali-silica reaction[6].

Aside significant improvement in the durability of blended cement concrete, where early age compressive strength of concrete is concerned, especially for reinforced concrete works where concrete structures are expected to have gained sufficient strength to withstand loads at the 28-day, the use of these SCM as partial replacement for cement is still in doubt. This is because they rely on later ages for strength development. Furthermore, the use of pozzolans in concrete production increases the demand for water, which consequently affects the strength of concrete.

Literature has revealed that the total surface area of cement represents the material available for hydration[7]. Thus, the fineness of the cement and pozzolanic particles determines the rate of hydration. The fineness of pozzolans have been found to significantly influence concrete properties by improving pozzolanic reactivity as a result of increased specific surface area (SSA), thereby refining the concrete pore structure[1]. Research reports[1, 2, 6, 8] on the influence of various fineness of FA on strength and durability properties of its blended cement concrete and mortar have shown that finer FA significantly improve the early age strength and likewise improve the durability properties of concrete. Therefore, fineness plays an important role in defining concrete strength. The use of PBCW can be traced back in history to the Romans. When natural pozzolans such as volcanic ash was not available, the Romans made use of powdered brick obtained from crushed clay bricks, tiles or pottery to mix lime to obtain a strong and durable binding material.

Studies from previous works on PBCW have shown that the substitution of PBCW as a partial replacement for cement improves both the strength and durability properties of the blended cement mortar and concrete[9-13]. However, literature on the effects of varying PBCW fineness and replacement level on the compressive strength of blended cement concrete have not been well established. This paper therefore investigates the influence of PBCW fineness and replacement level on the compressive strength of blended cement concrete with a view to assessing improvement of its early age compressive strength.

RESEARCH SIGNIFICANCE

The search for alternatives to conventional materials can only be met by what a particular environment can afford. While SCM such as FA and SF are not readily available in developing countries such as Nigeria, PBCW could be a viable alternative. PBCW has been established as a SCM for concrete production. Like any other SCM, when partially substituted for cement in concrete, it improves the later age strength and durability properties. However, when early age strength is required for a 28-day structural concrete, PBCW blended cement concrete results in a slow development of compressive strength. An attempt is made to investigate the influence of the fineness of PBCW on the compressive strength of its blended cement concrete considering different replacement levels of PBCW to cement.

EXPERIMENTAL PROCEDURE

Materials

ASTM Type I Portland cement (PC) and pulverized burnt clay waste (PBCW) were used as the binder. The PBCW was obtained from burnt clay bricks from a demolished school building in Osun State, Nigeria. The burnt clay bricks were pulverized in a milling machine and then separated into two fineness portions classified as coarse (CP) and fine (FP). This was achieved by using the No. 100 (150 µm) and No. 200 (75 µm) sieves, respectively. Thereafter, the determination of the physical and chemical properties of PC and PBCW (CP and FP) was conducted. Locally available crushed granite aggregate, passing through 0.80 in. (20 mm) sieve but retained on 0.20 in. (5 mm) sieve, and specific gravity of 2.8 was used as coarse aggregate. For the fine aggregate, river sand passing through 4.75 mm sieve with a fineness modulus of 2.45 and specific gravity of 2.63 was used. Portable water was used for mixing with a water-to-binder ratio (w/b) of 0.5 adopted for all mixes. Mapefluid–N200, a Type F superplasticizer was used to keep the consistency of concrete mixes to a medium slump 2 - 3.6 in. (50 – 90 mm) in accordance with BS EN 206-1[14].

Research design

Coarse (CP) and fine (FP) portions of the PBCW were used to replace the PC at 0% (control), 10% and 20%. In addition to the 10% and 20% PC replacement levels, excess of CP and FP contents by 5% and 10%, giving total binder contents of 105% and 110%, respectively, were also included. This technique of using larger quantity was adopted from a research on FA fineness were the excess content was used to upset the slow pozzolanic reaction[5]. For instance, when PC was replaced by 10% by weight with CP or FP, the dosage by weight of CP or FP used were 10%, 15% and 20%. Thus, the binder content used becomes 100%, 105% and 110% for both FP and CP blended cement concrete. Thirteen different mix proportions were developed and tested for compressive strength in this study and shown in Table 1.

Table 1: Mix composition of concrete

Mix	Composition lb/ft^3 (kg/m^3)						
	PC	FP	CP	Sand	Granite	Water	SP
P1	23.4 (375)	0.0 (0)	0.0 (0)	59.3 (950)	81.2 (1300)	11.7 (188)	0.1 (1.5)
F1	21.1 (338)	2.3 (38)	0.0 (0)	59.3 (950)	81.2 (1300)	11.7 (188)	0.1 (2.4)
F2	21.1 (338)	3.5 (56)	0.0 (0)	59.3 (950)	81.2 (1300)	12.3 (197)	0.2 (3.3)
F3	21.1 (338)	4.7 (75)	0.0 (0)	59.3 (950)	81.2 (1300)	12.9 (206)	0.6 (10.0)
C1	21.1 (338)	0.0 (0)	2.3 (38)	59.3 (950)	81.2 (1300)	11.7 (188)	0.1 (1.8)
C2	21.1 (338)	0.0 (0)	3.5 (56)	59.3 (950)	81.2 (1300)	12.3 (197)	0.2 (3.2)
C3	21.1 (338)	0.0 (0)	4.7 (75)	59.3 (950)	81.2 (1300)	12.9 (206)	0.5 (7.8)
F4	18.7 (300)	4.7 (75)	0.0 (0)	59.3 (950)	81.2 (1300)	11.7 (188)	0.6 (10.4)
F5	18.7 (300)	5.9 (94)	0.0 (0)	59.3 (950)	81.2 (1300)	12.3 (197)	0.7 (11.3)

F6	18.7 (300)	7.0(113)	0.0 (0)	59.3 (950)	81.2 (1300)	12.9 (206)	0.7 (11.7)
C4	18.7 (300)	0.0 (0)	4.7 (75)	59.3 (950)	81.2 (1300)	11.7 (188)	0.6 (10.1)
C5	18.7 (300)	0.0 (0)	5.9 (94)	59.3 (950)	81.2 (1300)	12.3 (197)	0.7 (11.0)
C6	18.7 (300)	0.0 (0)	7.0(113)	59.3 (950)	81.2 (1300)	12.9 (206)	0.7 (11.3)
Replacement level of mix (PC:FP:CP) %							
P1 = (100:0:0), F1 = (90:10:0), F2 = (90:15:0), F3 = (90:20:0), C1 = (90:0:10), C2 = (90:0:15), C3 = (90:0:20), F4 = (80:20:0), F5 = (80:25:0), F6 = (80:30:0), C4 = (80:0:20), C5 = (80:0:25), C6 = (80:0:30).							

Test program

From the thirteen concrete mixtures shown in Table 2, 195 cube specimens were cast and cured in water at room temperature for a maximum period of 118 days following standard procedure[15]. Within this period, compressive strength test was conducted at 3, 7, 28, 58 and 118 days. Specimen size for the compressive strength test was 4 in. (100 mm) and tested in accordance with the requirement of BS EN 12390-3[16]. The reported compressive strength is the average of three replicates. Strength activity index (SAI) was determined from the average compressive strength results.

Analytical investigation

As specified by the ASTM C311-07[17], the strength activity index determined from the average compressive strength results can be defined as

$$\text{Strength Activity Index (SAI)} = f_a/f_o \quad (1)$$

where

f_a = average compressive strength of blended cement concrete cube; and

f_o = average compressive strength of control concrete cube.

EXPERIMENTAL RESULTS AND DISCUSSION

Characteristics of pulverized burnt clay waste

The chemical composition, fineness, and specific gravity of PC, FP and CP are shown in Table 2.

Table 2: Chemical composition, fineness, and specific gravity of PC and PBCW

Chemical composition (%)	OPC	PBCW	
		FP	CP
SiO_2	16.82	52.18	52.17
Al_2O_3	4.35	27.84	27.86
Fe_2O_3	2.43	13.06	13.05
CaO	60.39	0.73	0.71
MgO	1.43	0.51	0.52
SO_3	1.64	0.00	0.01
K_2O	0.16	0.14	0.13

Na_2O	0.02	0.00	0.00
LOI	9.84	1.67	1.68
	29	32	34
	3.94	0	3.93
Specific gravity	3.14	1.83	1.71

Concerning the chemical composition, classifying PBCW as FP and CP through sieving does not have any effect on the chemical composition as both FP and CP showed similar chemical properties. This is similar to many reports on fly ash that concluded that classifying and grinding does not significantly affect chemical composition[8,18]. According to ASTM C 618-08[19] categorization, FP and CP fall under Class N pozzolan. Both FP and CP have a combined oxide content (SiO_2 + Al_2O_3 + Fe_2O_3) higher than the minimum 70% (93.08%). With FP and CP having a silica content of 52.18% and 52.17%, respectively, both can chemically combine with calcium hydroxide (produced by the hydrating PC) in the presence of water to form stable calcium silicates which have cementitious properties. Similar chemical composition of PBCW have been reported in different research[10,11] with only a slight variation in composition which may be attributed to different sources, geological condition and method of processing.

The fineness obtained for FP by percentage of mass retained on 45 and 90 µm sieves is 32% and 0%, respectively, while for CP, 34% and 3.93% is obtained. As expected, this shows that the FP is finer than CP, since FP was obtained from samples passing through No. 200 (75 µm) sieve unlike the CP from No. 100 (150 µm) sieve. However, the PC has a higher fineness than both FP and CP. If SCM have the same fineness as the PC, better performance could be expected in blended cement concrete. The specific gravity of FP (1.83) is slightly higher than CP (1.71) possibly due to the smaller and finer nature of FP with the ability to fill up more space than CP.

Workability

The slump test was used to measure the workability of the wet concrete mix produced for all blended cement concretes following the standard procedure[20]. The slump values of the mixtures are shown in Table 3. Table 3 reveals that as the percentage of PC replacement increases and with excess FP and CP contents, the quantity of the superplasticizer required for mixing to achieve the target slump value of 2 – 3.6 in. (50 - 90 mm) also increases. That is, the blended cement concrete becomes stiffer and less workable as the FP and CP contents increase in the mix. Result reveals that mix proportions containing FP required more superplasticizer than their corresponding CP mixes owing to increased SSA of FP that corresponds to improved fineness.

Table 3: Slump test result

Mix	Slump, in. (mm)
P1	2.2 (55)
F1	2.2 (55)
F2	2.2 (55)
F3	2.6 (65)

C1	2.2 (55)
C2	2.2 (55)
C3	2.4 (60)
F4	2.4 (60)
F5	2.6 (65)
F6	2.6 (65)
C4	2.6 (65)
C5	2.6 (65)
C6	2.6 (65)

The correlation analysis of the workability parameters shown in Table 4 reveals that, SP has the strongest influence to achieve increase in slump (Pearson correlation; P = 0.956). Likewise, the SP quantity required is increased and influenced by the fineness of the PBCW with FP (P = 0.408) to require SP than CP (P = 0.266).

Table 4: Correlation analysis of workability parameters

	PC	FP	CP	SP	slump
PC	1				
FP	-.326	1			
CP	-.326	-.718	1		
SP	-.837	.408	.266	1	
Slump	-.754	.314	.314	.956	1

Compressive strength

The results of the compressive strength of the blended cement concretes are presented in Table 5. It can be seen that the compressive strength increases with curing age for all the mix, and decreases with increase in the FP and CP contents in the mix at 3, 7 and 28 days curing period compare with the control mix (P1). On the 28-day, the control specimen achieved the highest compressive strength of 3.92 ksi (27.0 kN/mm^2) while other replacement levels resulted in compressive strength between 2.15 – 3.63 ksi (14.8 – 25.0 kN/mm^2). Mixes F1, F2 and F3 attained strength greater than the control (P1) at 58 and 118 days curing. Mixes C2 and C3 also attained greater strength than the control at 118 days. Improvement in later age strength of the blended cement concrete confirms that PBCW, like other pozzolans improves later age strength through decrease in porosity and continues pore refinement.

Table 5: Compressive strength of concrete

Mix	Compressive strength, ksi (kN/mm^2)				
	3 days	7 days	28 days	58 days	118 days
P1	1.93 (13.3)	2.36 (16.3)	3.92 (27.0)	4.06 (28.0)	4.16 (28.7)
F1	1.51 (10.4)	1.99 (13.7)	3.35 (23.1)	4.16 (28.7)	4.42 (30.5)
F2	1.68 (11.6)	2.16 (14.9)	3.63 (25.0)	4.26 (29.4)	4.48 (30.9)
F3	1.33 (9.2)	2.00 (13.8)	3.50 (24.1)	4.31 (29.7)	4.55 (31.4)
C1	1.35 (9.3)	1.94 (13.4)	3.25 (22.4)	3.38 (23.3)	4.02 (27.7)

Mix	Compressive strength, ksi (kN/mm^2)				
C2	1.41 (9.7)	2.05 (14.1)	3.44 (23.7)	3.95 (27.2)	4.31 (29.7)
C3	1.09 (7.5)	1.96 (13.5)	3.36 (23.2)	4.03 (27.8)	4.32 (29.8)
F4	1.03 (7.1)	1.77 (12.2)	3.10 (21.4)	3.41 (23.5)	3.89 (26.8)
F5	1.38 (9.5)	2.05 (14.1)	3.38 (23.3)	3.60 (24.8)	3.96 (27.3)
F6	1.23 (8.5)	1.81 (12.5)	2.93 (20.2)	3.10 (21.4)	3.42 (23.6)
C4	0.91 (6.3)	1.68 (11.6)	2.94 (20.3)	3.23 (22.3)	3.44 (23.7)
C5	0.86 (5.9)	1.36 (9.4)	2.49 (17.2)	2.81 (19.4)	3.09 (21.3)
C6	0.77 (5.3)	1.15 (7.9)	2.15 (14.8)	2.49 (17.2)	3.02 (20.8)

Replacement level of mix (PC:FP:CP) %

P1 = (100:0:0), F1 = (90:10:0), F2 = (90:15:0), F3 = (90:20:0), C1 = (90:0:10), C2 = (90:0:15), C3 = (90:0:20), F4 = (80:20:0), F5 = (80:25:0), F6 = (80:30:0), C4 = (80:0:20), C5 = (80:0:25), C6 = (80:0:30).

The result reveals that at all curing age, the FP blended cement concrete samples, F1 to F6 show improved compressive strength than their corresponding CP blended cement concretes C1 to C6. It implies that the finer the PBCW, the higher the compressive strength. The improved strength can be attributed to increased SSA of FP, which demonstrates a packing effect by filling up voids left by mixing water during evaporation.

Likewise, mixes F2, C2 and F5, which are excess increment of 5% in FP and CP contents at 10 and 20% PC replacement, attained strength greater than the conventional mix (F1, C1 and F4, respectively) at 3, 7 and 28-day. Mix C5 with strength less than conventional mix C4, however, showed an exception to the increase in strength attained with excess 5% CP content. This implies that the excess FP and CP contents in mix F2, C2 and F5 causes an improvement in the pozzolanic reaction time with cement hydration product (calcium hydroxide). Furthermore, at 58 and 118 days, mix F2, C2 and F5, containing 5% excess FP and CP, and mix F3 and C3 containing 10% excess FP and CP were observed to attain strength also greater than their conventional blended cement concrete (F1, C1 and F4).

In contrast to the behavior observed at 3, 7 and 28-days, at 58 and 118-days, mixes F3 and C3 (both at 10% excess FP and CP and at 10% PC replacement) result in strength greater than F2 and C2 which contains 5% excess FP and CP. In a recent publication[5], the use of excess FA content in its blended cement concrete shows ability to offset the slower reaction of FA by causing more FA to react with $Ca(OH)_2$ leading to increased formation of calcium silicate hydrate responsible for strength. The improved strength results in increased densification of the blended cement concrete, which further increases strength. This phenomenon of increasing strength using excess blended cement as reported in a recent research[5] could also be attributed to the increased strength observed with the blended cement concrete with FP and CP mixes especially at 10% PC replacement. Based on the experimental results, 10% replacement of PC competed favorably with conventional concrete without pulverized burnt clay, and is therefore the optimum replacement level at all curing ages.

Strength activity index

Table 6 reveals the strength activity index (SAI) for all mixes at the different curing ages. It can be observed that with increasing curing age, the SAI for all the mixes also increases. At the age of 3, 7 and 28 days, the SAI for the blended cement concrete range between 40 – 87%, 49 – 91% and 55 - 93%, respectively. Only mixes C4 to C6 and C5 to C6 at 7 and

28 days, respectively, did not attain a SAI of 75% specified by ASTM C 618-08[19]. The result indicates that all the FP mixes (F1 to C6) and only mixes C1 to C3 for the CP at 10% PC replacement were able to attain increase in the early strength development of concrete in comparison to the control (P1). The incorporation of finer PBCW and addition of excess PBCW content (especially with FP) improves the strength of concrete due to continuous liberation of excess $Ca(OH)_2$ at ages beyond 28-days by the PBCW (FP) that gave higher SAI value.

Table 6: Strength Activity Index

Mix	Strength activity index (%)				
	3 days	7 days	28 days	58 days	118 days
P1	100	100	100	100	100
F1	78	84	86	102	106
F2	87	91	93	105	108
F3	69	85	89	106	109
C1	70	82	83	83	96
C2	73	87	88	97	103
C3	56	83	86	99	104
F4	53	75	79	84	94
F5	71	87	86	89	95
F6	64	77	75	76	82
C4	48	71	75	80	83
C5	45	58	64	69	74
C6	40	49	55	61	73

Replacement level of mix (PC:FP:CP) %

Mix	Strength activity index (%)

P1 = (100:0:0), F1 = (90:10:0), F2 = (90:15:0), F3 = (90:20:0), C1 = (90:0:10), C2 = (90:0:15), C3 = (90:0:20), F4 = (80:20:0), F5 = (80:25:0), F6 = (80:30:0), C4 = (80:0:20), C5 = (80:0:25), C6 = (80:0:30).

CONCLUSIONS

Based on the results obtained, classifying PBCW to different fineness through sieving have an insignificant effect on the chemical composition of the different sieved PBCW portions. Incorporation of PBCW in concrete reduces the workability of fresh concrete increasing the demand for superplasticizer to make a consistent mix. It can be concluded from the results that irrespective of the fineness, PBCW blended cement concretes have low compressive strength relative to conventional concrete (without pozzolan) at early ages of hydration but increases at later ages. However, the finer the PBCW, the better the early and later age strength of the blended concrete with the ability to also gain more strength than conventional concrete at later age. The tendency is that, the fine PBCW has an increased SSA, which have a packing effect, therefore, filling the small voids in the pore structure of the blended concrete and then helping with strength development as well, especially at later ages of curing.

In addition, the results show that the compressive strength can further be improved by increasing the PBCW content beyond the conventional replacement level by up to 5% for early age and up to 10% for later age strength for a total binder content of 105 and 110%, respectively. The process of using excess PBCW to improve strength is however achieved better with finer PBCW. This improvement was because of the excess pozzolan forcing more silica in the pozzolan (activated by the high pH during hydration) to react with calcium hydroxide a product of cement paste hydration. 20% cement replacement with FP-PBCW (F3) has been found to be an optimum replacement level for PBCW blended cement concrete, as against the 10% reported by previous researchers.

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