Performance of Ground Clay Bricks as Partial Cement Replacement in Grade 30 Concrete

Kartini, K., Rohaidah, M.N., and Zuraini, ZA.

***Abstract*—**Demolitions of buildings have created a lot of waste and one of it is clay bricks. The waste clay bricks were ground to roughly cement fineness and used to partially replaced cement at 10%, 20% and 30% with w/b ratio of 0.6 and tested at 7, 28, 60, 90 and 120 days. The result shows that the compressive strength of GCB concrete increases over age however, decreases as the level of replacements increases. It was also found that 10% replacement of GCB gave the highest compressive strength, however for optimum replacement, 30% was chosen as it still attained strength of grade 30 concrete. In terms of durability performances, results show that GCB replacement up to 30% was found to be efficient in reducing water absorption as well as water permeability. These studies show that GCB has the potential to be used as partial cement replacement in making concrete.

***Keywords*—**Compressive Strength, Ground Clay Bricks, Partial Cement Replacement, Water Absorption and Permeability

I. Introduction

THE usage of cement replacement materials (CRM) obtained from either by-product of other processes (pfa, silica fumes, quarry dust fine powder, etc.) or agricultural waste (rice husk ash, empty fruit bunch ash, saw dust ash, sugar cane ash etc.) into concrete mixtures have received considerable attention in recent years. However, little studies have been done in term of construction and demolition waste as partial cement replacement (PCR). In fact, large volume of construction and demolition wastes which typically thrown away without any commercial value, can be further utilized by making more sustainable use of these wastes [1]. Construction wastes include concrete, bricks and blocks, glasses, roofing tiles, timber, steel and aluminum to name a few are generated increasingly from time to time. Utilization of construction waste is required in an attempt to balance between the construction demand and environmental sustainability.

Pozzolanic materials are all siliceous/aluminous materials which, in finely divided form and in the presence of water, will react with calcium hydroxide to form compounds that possess cementitious properties [2]. According to Farrell *et al*. [3], clay bricks are manufactured by the calcination of alumino-silicate clay and possess pozzolanic properties when ground to suitable fineness. Ambroise *et al*. [4] found that clay bricks at high firing temperature (about 1000°C) form a liquid phase which on cooling solidifies to an amorphous glass phase which exhibited high pozzolanic. Environmentally, the usage of pozzolanic CRM such as ground clay bricks (GCB) can reduce the disposal problem of construction wastes and more importantly carbon dioxide (CO_2) emission during the cement manufacturing can be reduced.

Therefore, it is the main objective of this study to determine the potential of using GCB from demolition masonry as PCR materials in making concrete. The tests conducted were the compressive strength test, water absorption test and water permeability test.

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II. Experimental Work

A. Material Used

The waste clay bricks were taken from the demolished building at the project site at College Cempaka, UiTM Shah Alam. The bricks are still in good condition with little deterioration. The clay bricks were placed inside the impact crusher to reduce their size approximately to 5 mm as to ease the process of grinding. Grinding process began by putting 5 kg of crushed clay bricks inside the L.A machine with 15 nos. of ball bearings with each ball bearing weigh about 440 grams. The L.A machine is allowed to grind for 5000 revolution with 33.3 rpm. After grinding, GCB were sieved using 90 micron sieve size to determine its fineness.

The chemical compositions of the GCB using X-Ray Fluorescence Spectrophotometer was carried out and the results are as shown in Table I.

The other materials used in these investigations were Ordinary Portland Cement (OPC) of Type 1. Table I shows the chemical compositions of OPC used in this study. The mining sand as fine aggregate with maximum size of 5 mm, while the coarse aggregates are crushed granite which passing through 20 mm. The fine aggregate and coarse aggregate used were complying with the British Standard BS 812-103:1[5]. The fineness modulus for fine aggregate and the coarse aggregate were 4.61 and 2.43 respectively. The tap water free from contamination was used for the mixing and curing of concrete.

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TABLE I
CHEMICAL COMPOSITION IN GCB AND OPC

Chemical composition	OPC (%)	GCB (%)
SiO_2	15.05	63.40
Al_2O_3	2.56	25.60
Fe_2O_3	4.00	5.45
TiO_2	0.12	1.04
MgO	1.27	0.36
CaO	72.17	0.44
Na_2O	0.08	Traces
K_2O	0.41	2.78
P_2O_5	0.06	0.12
MnO	0.06	-
SO_3	2.90	0
LOI	1.33	0.7

B. Test Conducted

1. Slump Test - In determining the workability or the behavior of consistency of the fresh concrete mixes, slump test which is in accordance to BS EN 12350-2:2000 [6] was conducted.

2. Compressive Strength - The most common measure of strength of concrete is the compressive strength test. The test was conducted as prescribed in BS EN 12390-4:2000 [7]. The Compression Auto Test Machine with capacity of 1000 kN and with the rate of load employed at 3.00 kN/m was used to break the 100 mm cube specimens. As the strength of concrete increases with time, it is significant to test the cubes at the various ages of curing which are 7, 28, 60, 90 and 120 days. The concrete grade 30 was prepared according to the Designated Mix Design [8]. In this study, 4 batches of concrete mixtures were prepared with 0.6 w/b ratio. A concrete mixture with 0% GCB was used as a control mix while, the other three (3) mixtures containing of 10%, 20% and 30% of GCB. Table II shows the mix proportion for the mix.

TABLE II
MIX PROPORTION FOR GRADE 30 CONCRETE

Mixes	Mass per Unit Volume of Materials (kg/m^3)					Slump (mm)
	Cement	GCB	Water	Aggregate		
				Fine	Coarse	
OPC	350	-	210	754	1086	75
GCB10	315	35	210	754	1086	70
GCB20	280	70	210	754	1086	60
GCB30	245	105	210	754	1086	50

3. Water Absorption - This test is conducted to determine the rate of absorption of water into the concrete. Concrete specimen size of 50 mm Ø cylinder with 100 mm thickness was prepared and the test was carried out with accordance to BS 1881 -122:1983 [9]. The specimens were tested for 28, 60, 90 and 120 day of water curing. In this test, the cylinder specimens were oven dried for 72 ± 2 hours at temperature of 105 ± 5°C and then stored in air-tight containers for 24 ± 0.5 hours before subjected to testing. The concrete specimens are weighed before immersion and after immersion for 30 minutes reading and this test is repeated for every 30 minutes interval for 4 hours. In the test, the depth of water above the specimens was maintained at a depth of 25±5 mm throughout the test.

4. Water Permeability - In determining the durability of the concrete, the water permeability test based on BS 12390-8:2000 [10] was conducted. In this test, 150 mm cubical specimen was placed in the apparatus for 3 days and pressure of 0.5 N/mm^2 was applied. After 3 days, once the pressure is released, the specimen was removed and split down the center of the specimen into halved. The average depths of penetration of water were obtained and were then converted into the coefficient of permeability.

III. RESULTS AND DISCUSSION

A. Properties of Materials - Chemical composition analysis for GCB as shown in Table I indicates that GCB has the SiO_2 + Al_2O_3 + Fe_2O_3 of 94.45%, and Loss of Ignition (LOI) of 0.7%, which can be classified as Class N pozzolan as prescribed in ASTM C 618-2003 [11].

B. Workability - Table II shows that when the amount of GCB increases, the value of slump reduces, which means that mixes are slightly dried if the amount of water to be constantly maintained, or the demand of water should be increased as the percentage of replacement with GCB increased in order to enhance the fluidity and consistency of the mix. This might be because of high specific area due to high fineness of GCB, which is about 25% finer than OPC. The result of this finding is also in line with the findings of Bektas *et al*. [12], Golaszewski *et al*. [13] and Farrel *et al*. [3] which they reported that there was a marginal reduction in slump obtained as the amount of GCB added in the concrete mix increases, as it being typical for pozzolan – portland reaction where the silica-lime reaction requires more water in addition to the amount of water required for the hydration of cement.

C. Compressive Strength - The results of the compressive strength for the various mixes of GCB concrete are as shown in Fig. 1. It shows that the compressive strength of all GCB concretes is well above the targeted strength of 30 N/mm^2 taken at 28 days, and with increase of GCB in the mixes, the compressive strength reduces however, they still achieved the target strength. The control mix value taken at 28 days was 37.06 N/mm^2 whilst, for GCB concretes were 35.55 N/mm^2, 33.95 N/mm^2 and 31.53 N/mm^2 for 10%, 20% and 30% respectively. The 30% replacement is considered as the optimum GCB content in concrete in this study. Study by Toledo *et al*. [14] on GCB indicted that there is no detrimental effect in term of strength up to 20% replacement, whereas study by Bektas *et al*. [12] stated that at 25% GCB, the strength are comparable to those without GCB. Fig. 1 also showed that prolong curing of these concretes resulted in increased in strength.

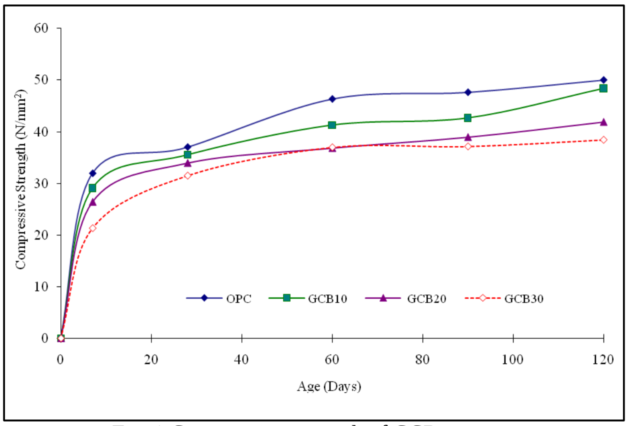

Fig. 1 Compressive strength of GCB concrete

D. Water Absorption - Fig. 2 shows the percentage of water absorption for each concrete mixes. From the Fig. 2, it can be seen that all the concrete mixes obtained percentage of absorption of less than 5%. The OPC control concrete possesses 4.48% and 4.05% value of water absorption at 28 and 60 days of age. This value is considered lower than 10% of GCB replacement with 4.67% and 4.11% taken at 28 and 60 days respectively. However, 20% and 30% of GCB replacement, the percentage of water absorption for both mixes were lower than the control OPC concrete at early age and onward. The lowest value of water absorption was at 30% GCB replacement with 4.11% taken at 28 days. Generally, it can be concluded that with higher replacement of GCB in the mix it resulted in less permeable concrete, therefore greater will be its resistance to environment or deterioration. These might be due to finer GCB particles which will filled up the spaces between the coarser cement particles resulted in improvement in the compactness of the concrete. The GCB concrete can be classified as having an 'average absorption properties' as its value at 30 minutes is between 3-5% as specified by the Concrete Society [15].

E. Water Permeability - The results of the depth of water penetrations were plotted as shown in Fig. 3. From Fig. 3, it can be seen that the percentage of GCB replacement in concrete mix affects the depth of water penetration into the concrete, and the depth of water penetration gradually decreased with prolong of curing. The depth of water penetration at 28 days for 0%, 10%, 20% and 30% replacement of GCB were 51.33 mm, 55.40 mm, 52.33 mm and 50.20 mm respectively. It shows that at 30% replacement, the concrete is very impermeable compared to OPC control concrete, and as the age of curing prolong (90 and 120 days), the depth of penetration reduces further, i.e. 27.38 mm and 23.56 mm respectively. According to the Concrete Society of London [15], the depth of water penetration between 30 to 60 mm taken can be considered as average permeability and less than 30 mm as low permeability. It also can be seen that by increasing the percentage of GCB replacement it contributes to reduction of depth of penetration. This scenario might be due to the reaction of GCB particles with $Ca(OH)_2$ and formed additional C-S-H gel and filled the capillary pores in concrete. It can be seen in Table III that the coefficient of permeability for the GCB concrete gradually reduced with the age of concrete. At 28 days, the coefficient of permeability for OPC and 30% GCB concrete were 10.29 x 10^{-11} m/s and 9.79 x 10^{-11} m/s respectively. However, further curing of concrete, i.e. at 60 days and above, 30% GCB concrete performed better in reducing the value of coefficient permeability, with coefficient of permeability of 2.15 x 10^{-11} m/s at 120 days.

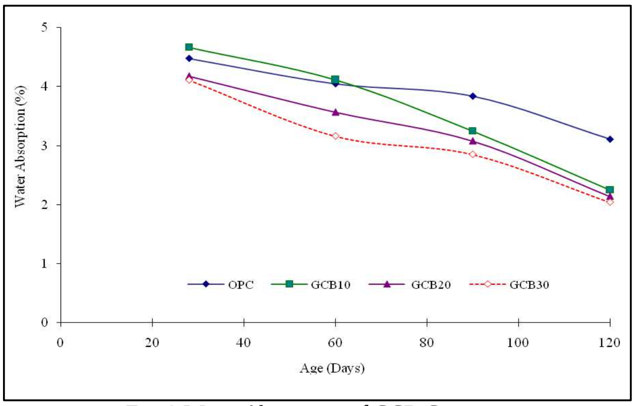

Fig. 2 Water Absorption of GCB Concrete

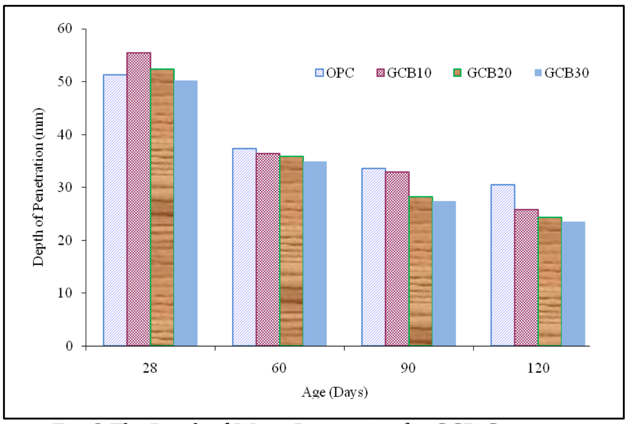

Fig. 3 The Depth of Water Penetration for GCB Concrete

Table III shows the summary of the results of the tests carried out for the GCB concrete. From the table, it can be seen that the properties in terms of water absorption and water permeability which is based on depth of penetration of water and coefficient of permeability gave a better performance at 30% replacement with GCB compared with control OPC concrete, while in terms of compressive strength even though 30% replacement gave a lower value, however it achieved the target Grade 30 concrete taken at 28 days strength.

TABLE III
SUMMARY OF THE PROPERTIES OF GCB CONCRETE

Properties	Mixes	Days of Curing				
		7	28	60	90	120
Compressive Strength (N/mm^2)	OPC	31.98	37.06	46.39	47.68	50.06
	GCB10	29.08	35.55	41.31	42.69	48.38
	GCB20	26.41	33.95	36.85	38.96	41.89
	GCB30	21.35	31.53	37.02	37.20	38.47
Water Absorption (%)	OPC	-	4.48	4.05	3.84	3.11
	GCB10	-	4.67	4.12	3.25	2.25
	GCB20	-	4.18	3.57	3.08	2.14
	GCB30	-	4.11	3.10	2.85	2.04
Depth of Penetration (mm)	OPC	-	51.33	37.37	33.56	30.53
	GCB10	-	55.40	36.42	32.85	25.75
	GCB20	-	52.33	35.92	28.18	24.36
	GCB30	-	50.20	34.99	27.38	23.56
Coef. Of Permeability (10^{-11}m/s)	OPC	-	10.29	5.46	4.35	3.60
	GCB10	-	11.86	5.20	4.16	2.57
	GCB20	-	10.60	5.02	3.28	2.30
	GCB30	-	9.79	4.75	2.90	2.15

IV. CONCLUSION

From the study carried out, it shows that there is a potential of using the GCB (30%) as PCR in concrete making by partially replacing OPC. Outcome from this, the production of cement can be reduced therefore the problems associated (depletion of raw materials for making cement, high consumption of energy, emission of CO_2, contribution to greenhouse effect, air and water pollution, etc.) with the production of cement (OPC) can also be reduced. The use of demolition waste (clay bricks) resulted in better utilization of the construction debris. The specific conclusions that can be drawn out of this experimental work are as follows:-

1. Replacing OPC with GCB as PCR materials has resulted in a marginal reduction in the slumps obtained as compared to OPC control mix, i.e. the slumps decreases as the percentage of GCB increases.
2. All GCB concrete achieved the compressive strength of Grade 30 concrete taken at 28 days. The optimum replacement chosen was at 30%.
3. 30% GCB concrete was found to be efficient in reducing water absorption as well as water permeability. These might be due to finer GCB particle thus, will fill up the spaces between the coarser cement particles. This process improves the compactness of the concrete and subsequently reduces the degree of water absorption and water permeability.

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