MECHANICAL CHARACTERISTICS OF NORMAL CONCRETE PARTIALLY REPLACED WITH CRUSHED CLAY BRICKS

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ABSTRACT

The quantities of clay bricks in our nation have been on the increase significantly (approx. 45.9tonnes annually in Nairobi) without consideration for potential reuse or recycling increasing the risk to public health due to the scarcity of waste landfill. This growing problem can be alleviated if new disposal options other than landfill can be found. However, increased construction activity and continuous dependence on conventional materials of concrete are also leading to scarcity of the construction material resulting to increased construction cost. This study aims at replacing the past research work on the use of clay bricks aggregate as possible partial substitute for conventional coarse aggregate in concrete. Moreover, from the study, an optimum mechanical strength property of crushedclay bricks in concrete was identified.

Crushed clay bricks originate mostly from broken and over-burnt bricks. There were considered as partial substitute for coarse aggregate in concrete for this study. The replacement proportions were varied from 0%, 20%, 40%, 60%, 80%, and 100% by weight for natural aggregates.A detailed analysis of the results of previous work done by various researchers are presented. Testsresults of this work are of importance in assessing the mechanical properties determined through splitting tensile tests, flexural tests, compressive tests and pull out force tests at 7 and 28 days.

The study indicates that considerable knowledge has been accumulated on the use of waste ceramic products, but more study needs to be done on effects of shapes and sizes of these aggregates

on physical and mechanical properties of the new concrete with aggregates partially replaced with crushedclay bricks. This may lead to better and more efficient recycling and utilization of waste clay bricks in our environment.

Key Words: clay bricks, concrete, aggregates, replacement, recycling, mechanical strength

1. INTRODUCTION

Cement and aggregate, which are the most important constituents used in concrete production, are the vital materials needed for the construction industry. This inevitably has led to a continuous and increasing demand of natural materials used for their production. Parallel to the need for the utilization of the natural resources emerges a growing concern for protecting the environment and a need to preserve natural resources, such as aggregate, by using alternative materials that are either recycled or discarded as a waste.

Construction industry as the end user of almost all the bricks materials, is well poised to solve this environmental problem which is partly its own. The use of waste products in concrete not only economical but also solves some of the disposal issues. Crushed ceramic aggregate can be used to produce lightweight concrete, without affecting strength (Kanaka and Raja, 1992).

The high consumption of raw materials by construction sector, results in chronic shortage of building materials and the associated environmental damage. In the last decade, the construction industry has seen various researches conducted on the utilization of waste products in concrete in order to reduce the utilization of natural resources. Veera Reddy (2010) concluded that replacement of coarse aggregate by ceramic scrap in excess of 20%, leads to reduction of strength below normal concrete mix.

Lopez et al., (2007), observed that this substitution process would increase slightly the compressive strength, nevertheless, researches carried out so far by reusing clay bricks in concrete are scarce and have not fully evaluated mechanical properties of the new concrete, which are key issues. This therefore forms part of a study area that needs to be fully looked into. Above studies, shows that there is a strong need to use crushed clay bricks materials in concrete in an environmental friendly way, (Lopez et al., 2007).

2. BACKGROUND

The main objective of this study is to establish the performance and optimum quantity of crushed clay brick used as a coarse aggregate to produce concrete. The main variables of concrete mixes taken into considered in this study were the replacement ratio of clay brick to coarse aggregate, cement content, water cement ratios; the mechanical properties of the new concrete. The properties of concrete made with crushed clay bricks replacing natural aggregates. The bricks were crushed in order to obtain a usable aggregate. The properties investigated were the density, the compressive strength, indirect tensile strength, flexural strength and pull out force of hardened concrete, which was cured in water maintained until the age of testing.

3. MATERIAL PROPERTIES AND TESTS

All materials used in this study are locally available. The materials used to develop the concrete mixes in this study were fine aggregate (river sand), normal coarse aggregate, crushed clay bricks, cement, and water. In the subsequent parts, the different materials used in this study are discussed.

A) Cement

The most common cement used is an ordinary Portland cement. The Ordinary Portland Cement of 32.5 grade (Mombasa cement OPC) conforming to (BS12, 1996).Tests conducted on cement gives the following parameters as shown in table 3.1 below.

Table 3.1: Properties of cement used in this research

Sr. No.	Physical properties of Mombasa cement	Results	Requirements as per BS 812-1990
1	Specific gravity	3.15	3.10-3.15
2	Standard consistency (%)	33%	30-35
3	Initial setting time (min)	80min	30 minimum
4	Final setting time (min)	257min	600 maximum
5	Compressive strength (at 28 days in N/mm^2)	33.70	32.5N/mm^2 minimum

B) Fine aggregate

Those fractions from 150micron to 4.75mm are termed as fine aggregate. The fine aggregate sample used in this experiment was purchased from local sand suppliers at Juja Kiambu County. The river sand was washed and screened, to eliminate deleterious materials and over size particles. Fine aggregate shall be clean sharp natural & crushed sand & shall be within standards (BS882, 1992).

Table 3.2: Sieve analysis test for fine aggregate

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve and retained (gm)	Wt. retained (gm)	% age retained	Cumul. retained	% age passing
9.5	493.0	493.0	0.0	0.0	0.0	100.0
4.75	482.0	482.5	0.5	0.1	0.1	99.9
2.36	386.0	395.5	9.5	1.9	2.0	98.0
1.18	447.0	539.5	92.5	18.5	20.5	79.5
0.6	409.0	568.0	159.0	31.8	52.3	47.7
0.3	393.0	538.5	145.5	29.1	81.4	18.6
0.15	365.0	434.5	69.5	13.9	95.3	4.7
pan	300.5	324.0	23.5	4.7	100.0	0.0

C) Coarse aggregate

The size of coarse aggregate used in this research was between 4.75mm to 19mm. The natural coarse aggregates from crushed basalt rock, conforming to (BS812-103.1, 1985) were used. Crushed clay bricks were obtained from Kenya

Clay products Ltd waste piles. The clay bricks were crushed to the same size of 4.75mm to 19mm conforming to those of natural coarse aggregate. Theflakiness index for the crushed bricks was 12.54%, which is belowthe requirement 15% (BS812-105.1, 1989).

Figure 3.1: Natural aggregate and clay bricks aggregate

Table 3.3: Sieve analysis test for natural coarse aggregate

Sieve size (mm)	Wt. retained (gm)	% age retained	Cumul. retained	% age passing	Lower limit	Upper limit
38.1	0	0.00	0.00	100.00	100	100
19	14	0.70	0.70	99.30	90	100
15	440.5	22.03	22.73	77.28	40	80
10	1455	72.75	95.48	4.53	20	55
5	89.5	4.48	99.95	0.05	0	10
2.38	0	0.00	99.95	0.05	0	10
0	1	0.05	100.00	0.00	0	5
TOTAL	**2000**	**100.00**				

Table 3.4: Sieve analysis test for clay bricks aggregate

Sieve size (mm)	Wt. retained (gm)	% age retained	Cumul. retained	% age passing	Lower limit	Upper limit
38.1	0	0.00	0.00	100.00	100	100
19	15.5	0.78	0.78	99.23	90	100
15	508.5	25.43	26.20	73.80	40	80
10	1198.5	59.93	86.13	13.88	20	55
5	258.5	12.93	99.05	0.95	0	10
2.38	5.5	0.28	99.33	0.67	0	10
0	13.5	0.68	99.73	0.00	0	5
TOTAL	**2000**	**100.00**				

Table 3.5: Physical properties of fine aggregate and coarseaggregate

Property	Fine aggregate	Coarse aggregate	
		NCA	CBA
Fine modulus	2.52	2.20	2.12
Bulk specific gravity	2.45	2.53	2.86
Bulk specific gravity (SSD)	2.51	2.52	2.097
Apparent specific gravity	2.61	2.45	1.82
Absorption capacity	2.53%	2.71%	14.95%

D) Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Impurities in water may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface, and may lead to corrosion of the reinforcement. Since it helps to form the strength giving cement gel, the quantity and quality of water should be looked into very carefully. For these reasons, the suitability of water for mixing and curing purposes was considered. In this research, portable watersupplied by Thika Municipality Water and Sewerage Company at room temperature was used in all mixes.

E) Mix proportion and designation

The present investigation studied the replacement of natural aggregate by crushed clay bricks. The class 20 concrete was prepared by prescribed mix of ratio 1:2:4. At the beginning of the mixture, cement binder and water-cement ratio (0.55), and sand were chosen to be constant.

The mix was made with crushed clay bricks aggregates replacing 0, 20, 40 60, 80 and 100 percent by weight of the normal coarse aggregate

Table 3.6: Materials required as per mix proportion

Quantities	Cement (Kg)	Water (Kg)	Fine Agg. (Kg)	Coarse Agg. (Kg)
Per m^3 (to nearest 5kg)	336	185	635	1233
Per trial mix of $0.005m^3$	1.682	0.925	3.177	6.167
Ratio	1	0.55	1.89	3.67

Table 3.7: Percentage variation between normal coarse aggregate and clay bricks aggregate

Mix	Normal coarse aggregate (%)	Clay bricks aggregate (%)
M100	100	0
M80	80	20
M60	60	40
M40	40	60
M20	20	80
M0	0	100

4. TEST RESULTS AND DATA ANALYSIS

This section focuses on the effects physical and mechanical effects of crushed clay bricks replaced independently in concrete mix.

Effect of clay bricks aggregates on dry density of concrete

Concrete density was determined as per the guidance of (BS1881-114, 1983).From the 28th day results, it was found out that a reduction of concrete density up to 15.6% was observed when clay bricks aggregate in sample M0 replaced 100%by weight of the coarse aggregate. In comparison with the density of 100% natural coarse aggregate concrete the average amount of decrease in unit weights of concretes with 0%, 20%, 40%, 60%, 80% and 100% crushed brick as coarse aggregates were 15%, 14.6%, 11.5%, and 10% reductions were observed for samples 80% (M20), 60% (M40), 40% (M60), and 20% (M80) clay bricks aggregate replacement respectively. The rate of decrease in density of mixed aggregate concrete was found to decrease almost linearly with increase in clay bricks content.

The low specific gravity of the clay bricks, 2.17, as compared to the natural coarse aggregates, 2.84, produced a decrease in the concrete density of the clay brick concrete, as shown in Figure 4.1. Since clay bricks are nearly one and half times lighter than the normal coarse aggregate, it was expected that the mass density of the mix would be significantly lower.

From the general analysis, density of all mixes with different proportions of clay bricks showed a reduction in density as age increased (Figure 4.1). This was attributed to the fact that water in the concrete was being used for hydration and absorbed by the clay bricks aggregates.

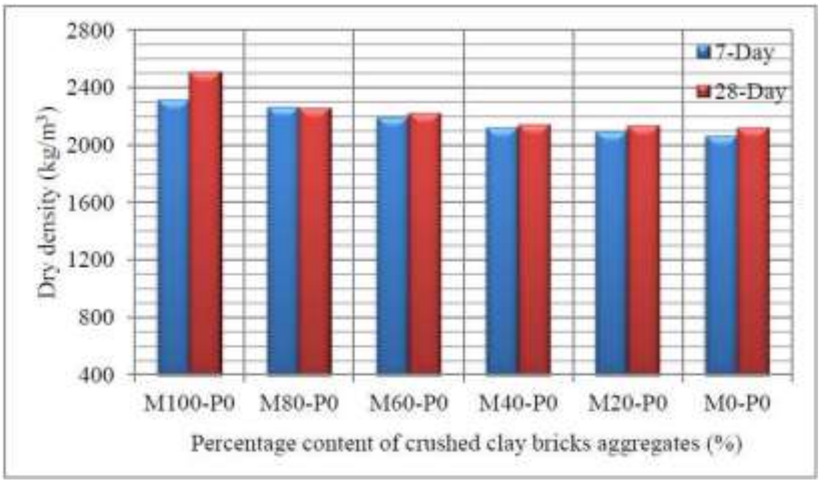

Figure 4.1: Dry density of clay bricks aggregates replaced with NCA in concrete.

Effect of clay bricks aggregate on compressive strength

In this study, the cube specimens of size 150mm x 150mm x 150mm of hardened concrete were tested in accordance with (BS1881-116, 1983). The samples were tested in compressive machine as shown in Figure 4.2 below. Figure 4.3 illustrates the trend of strength development with different proportion of clay bricks in the concrete specimens prepared for 7 and 28 days at constant water/cement ratio 0.55. The 7th and 28th day results presented in the figure show exclusive NCA M100 (control specimen) having the highest strength of 17.92N/mm^2 while exclusive CBA M0 with the least strength of 11.35N/mm^2.

Figure 4.2: Photo showing failure in concrete cube tested for compressive strength

From the results, a reduction in compressive strength of 8.1%, 17%, 32.6%, 35.4%, and 36.7% were obtained for 20% (M80), 40% (M60), 60% (M40), 80% (M20), and 100% (M0) respectively replacement of clay bricks aggregates. The decrease of the strength was made in comparison to the control specimen 0% (M100).

The strength drop with the clay bricks aggregates mix can be attributed to the mortar that remained on the surface of the clay bricks aggregate cracks in aggregate itself (which could occur during the crushing) and the aggregates strength. The other possible reason for reduction in compressive strength could be that compressive strength relates to factors such as density, size interlocking and rigidity of the aggregates.Therefore replacing aggregate by clay bricks aggregate decrease the compressive strength as expected.

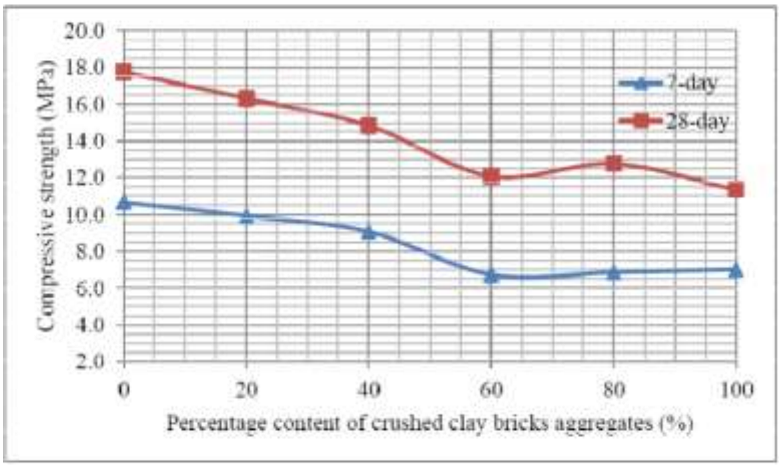

Figure 4.2: Effect of clay brick aggregate on compressive strength

Optimal clay bricks aggregate in concrete mixes

The Table 4.1 below shows a summary of the 28-day strength used to generate figure 4.4 to determine the prediction equation. The 28th day strength data for compressive was used to give general equation predicting the ultimate strength at each stage of clay bricks replacement.

Table 4.1: Summary of the 28-day compressive strength for concrete with different portions of NCA and CBA

Sr. No.	Mix	Clay bricks	28-days compressive strength (MPa)
1	M100-P0	0	17.92
2	M80-P0	20	16.46
3	M60-P0	40	14.87
4	M40-P0	60	12.08
5	M20-P0	80	11.57
6	M0-P0	100	11.35

In figure 4.4, a least square linear regression shows the relationship (Equation 1.0) to predict the compressive strength of mixed aggregate concrete for the strength-range studied.

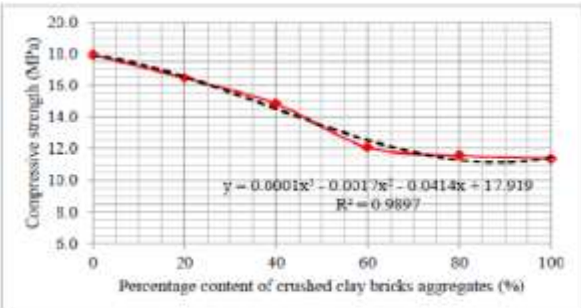

Figure 4.3: Effect of variation of clay brick aggregate and natural coarse aggregate on compressive strength

$$f_c = 17.9187 - 0.0414x - 0.0017x^2 - 0.0001x^3 \quad (1)$$

Where f_c is compressive strength in MPa and x being the percentage of clay brick aggregate replacing NCA.

By referring to the data listed in Table 4.1, mathematical nonlinear regression and numerical analysis methods were employed to determine the optimum content of crushed clay bricks. The optimum value is limited to C20 concrete mix with a water-cement ratio of 0.55 and was determined as 18.72%, the corresponding expected 28-days hardened concrete compressive strength was 16.20MPa.

Effect of clay bricks on split cylinder tensile strength

Cylinders measuring 200mm height and 100mm diameter were used. This test was performed in accordance with (BS1881-117, 1983). Figure 4.5shows the split tensilesamplestest set up in UTM.The graph shown in figure 4.6 illustrates the variation of the split tensile strength of specimens with different replacement percentage of coarse aggregates by clay bricks. The split tensile strength at 28-days of the cylinder shows a decreasing trend as 4.1% (M80), 10.8% (M60), 28.4% (M40), 26.4% (M20), and 39.2% (M0) samples below the reference mix, that is, M100.

Figure 4.4: Splitting tensile strength test for concrete sample

One of the reasons that splitting tensile strength of the concrete with clay bricks is lower than the conventional concrete is that bond strength between cement paste and clay bricks particles is poor. Besides, pore structures in concrete with clay bricks are much more than conventional concrete.

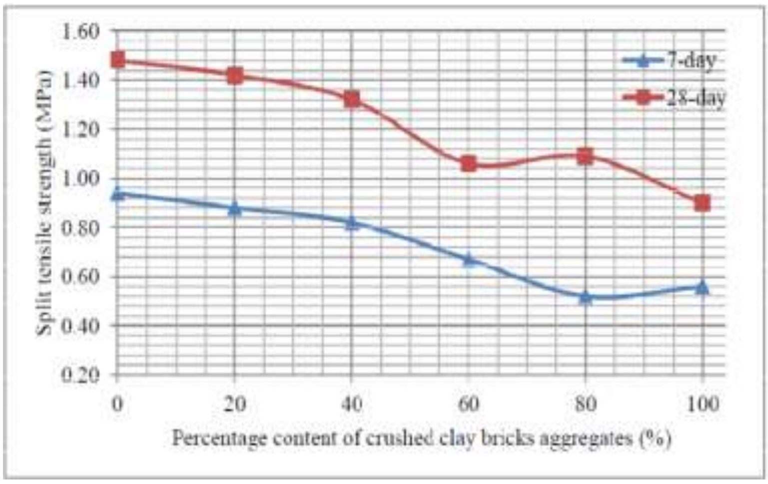

Figure 4.5: Split tensile of cylinders for variation of clay bricks and NCA

Relationship between split tensile strength and compressive strength

From the above split tensile strength results, linear logarithmic trend to relate with compressive strength was obtained as shown in Figure 4.7. This gave a prediction equation (2) shown below for C20 concrete with clay bricks aggregates.

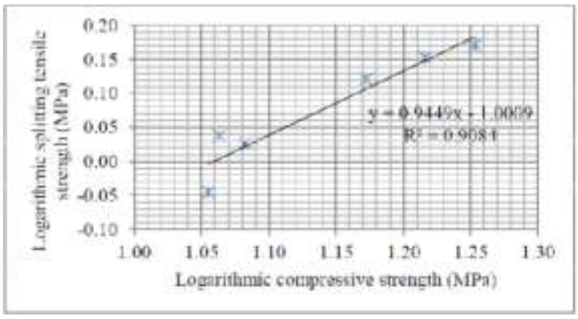

Figure 4.6: Variation of 28-day splitting tensile vs compressive strength

Effect of clay bricks aggregates on flexural strength

The standard specifies a method for the determination of the flexural strength of specimens of concrete beams of size 100mm x 100mm x 500mm. The test were done in accordance to (BS1881-118, 1983).The beams were tested for a span of 450 mm for 100 mm specimen by applying two equal loads placed at third points. The test procedure was as shown in Figure 4.8 below.

The graph shown in figure 4.9 illustrates the variation of the flexural strength of specimens with different replacement percentage of coarse aggregates by clay bricks. The flexural strength at 28-days of the cylinder is seen to be in decreasing trend of 11.1% (M80), 29.4% (M60), 31.1% (M40), 35.3% (M20), and 42.9% (M0) samples below the reference mix, that is, M100.

Figure 4.7: Set up of flexure beam and final failure in Universal Testing Machine

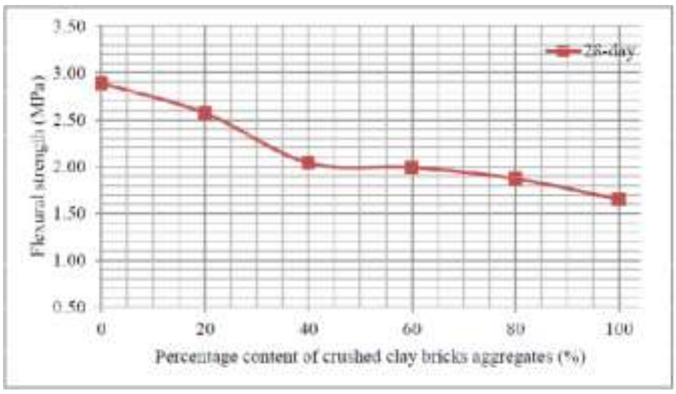

Figure 4.8: Graph of flexural strength and variation in clay bricks (percentage)

Relationship between flexural strength and compressive strength

Flexural strength can be predicted where compression strength of concrete with clay bricks is known or computed by using the equation (3) obtained from logarithmic relation shown in Figure 4.10 below.

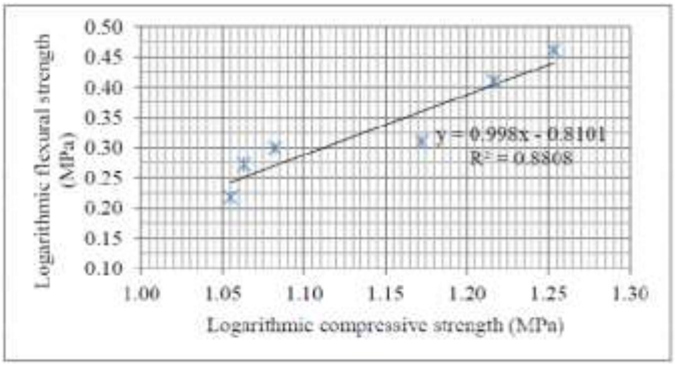

Figure 4.9: Variation of 28-day flexural strength vs. compressive strength for concrete with clay bricks

$f_{fs} = 0.1548 f_c^{0.9980}$ (3)

Where f_{fs} is flexural strength and f_c compressive strength in MPa.

Effect of clay bricks aggregate on pull out force

The test was done in accordance to (BS1881-207, 1992). The load were applied at a rate of 2kN/sec and distributed on the specimen surface by a square steel plate with size of 200mm and a hole at the center. The steel bar was gripped rigidly on the actuator side such that the top section of the concrete cylinder was pressed against bearing steel plate, (see Figure 4.11).

Tests results showing the trend development on pull out force with different proportions of clay bricks were generated as shown in figure 4.12

Figure 4.10: Pull out testing apparatus and procedure

The graph shown in figure 4.12 illustrates the variation of the pull out force of specimens with different replacement percentage of coarse aggregates by clay bricks. Figure 4.12 shows a reducing trend of 11.1% (M80), 16.3% (M60), 21.2% (M40), 37.3% (M20), and 17.1% (M0) samples below the reference mix, that is, M100 without clay bricks content

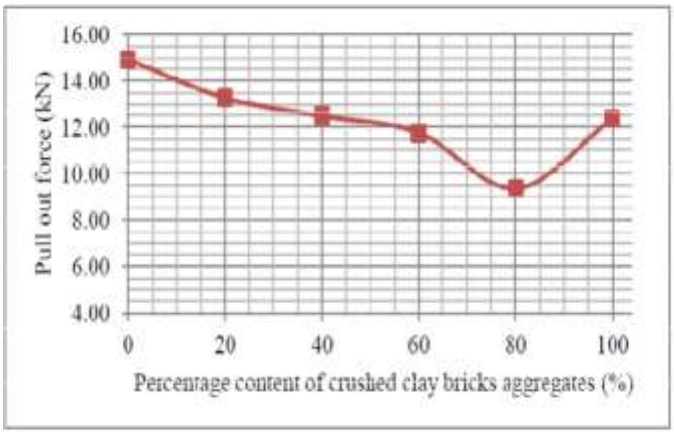

Figure 4.11: Graph of pull out force and variation in clay bricks (percentage)

Relationship between pull out force and compressive strength

The graph in Figure 4.13 relates the linear logarithmic trend between pull out force and compressive strength. This gave the relationship between pull out force and compressive strength of C20 concrete as shown in equation (4) below.

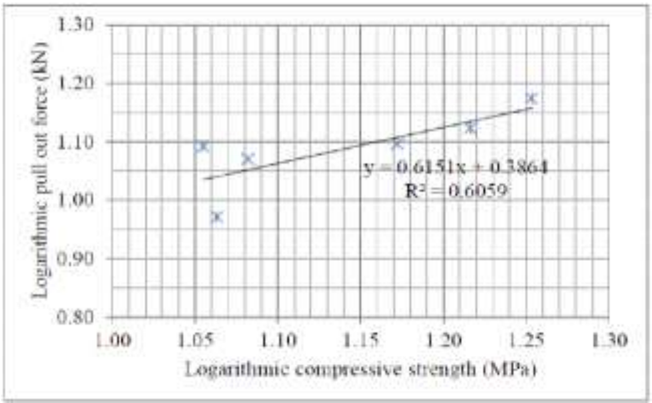

Figure 4.12: Variation of 28-day pull out force vs. compressive strength for concrete with clay bricks

$f_{pf} = 2.434 f_c^{0.6151}$ (4)

Where f_{pf} is pull out force and f_c compressive strength in MPa.

5. CONCLUSIONS

The general objective of this research was to study the physical and mechanical properties of a concrete produced by replacing part of the natural coarse aggregates with crushed clay bricks produced locally. The following conclusions are highlighted from the output of this research and can be summarized as follows:

1. The concrete with clay brick resulted to reduced density compared to control (normal concrete); a reduction in concrete density of up to 15.6% was observed when clay bricks aggregate in sample M0 replaced 100% by weight of the coarse aggregate.

   This gives a significant reduction of the weight of the products and when used in building will reduce the overall weight of the building, resulting in saving in structural elements including the foundations.
2. The test results show that the addition of clay bricks aggregate resulted in a significant reduction in concrete mechanical strengths as follows;
   a) A 36.7% reduction in full replacement of concrete is found due to the use of clay brick aggregate instead of NCA for the strength range of concrete studied at 100% clay bricks aggregates.
   b) The reduction in tensile strength with clay bricks aggregate in concrete wasfound to be 39.2% of reference/ control concrete without replacement for 100% replacement of NCA with clay bricks aggregates.

c) About 17.1% reduction in pull out of concrete is found due to the use of clay brick aggregate instead of natural coarse aggregate for 100% replacement of NCA with clay bricks aggregates.

d) The flexural strength of concrete decreased by about 42.9% from control concrete mixfor 100% replacement of NCA with clay bricks aggregates.

e) For concrete mixes containing the optimal content (18.72%) of clay bricks, gave a slight reduction on the mechanical properties. The compressive strength showed 9.6%, flexural strength 10%, pull out force 11.5% and splitting tensile strength 2.7% reduction as compared
to the control mix

The use of crushed clay bricks aggregates addresses many issues. These include; reduction of the environmental threats caused by waste clay bricks, introduction of an alternative source of aggregates in concrete.

The use of 18.72% replacement gives an optimum strength of 16.20MPa with density of 2460. This optimal results show that concrete can be used in non-load bearing members such as lightweight concrete walls, building facades, or other light architectural units, thus the concrete with clay bricks mixes could give a viable alternative to the normal weight concrete. This also solves environmental threats caused by waste clay bricks, introduction of an alternative source to aggregates in concrete that leads to conservation of natural aggregates.

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