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Effects of Local Clay Pot Waste Powder as Partial Cement Replacement on the Mechanical Properties of Concrete

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Abstract

This research was conducted to examine the suitability of Local Clay Pot Waste Powder as a cement replacing material in the production of C-25 grade concrete as a relief for this problem, the Sample Clay pots were collected from the Ndop vicinity. The samples which were fired at the temperature of 750°C, were ground to the fineness of 400µm. Normal consistency of the paste containing Ordinary Portland Cement and LCPWP from 0% to 20% replacement in a 10% increment interval was tested and found not to have much effect. That is for normal cement, it had a consistency of 29%, for 10% replacement, 28.5% was obtained and for 20% replacement, 28% was obtained. The compressive and split tensile strength of 54 different concrete test cubes of 100x100x100mm and flexural strength of 27 beams of 40x40x160mm with the LCPWP replacing the ordinary Portland cement prepared for 25MPa concrete with water-cement ratio of 0.5 and 395 kg/m^3 cement content, we casted and crushed (for 7th, 14th and 28th days targeted compressive strength). The properties of the cubes were tested at the hardened state and a compressive strength of 25.16MPa, 15.43MPa, and 11.70MPa for the Control, 10% and 20\\% mixtures respectively were obtained. These mixtures failed to achieve the targeted strength of C-25. For the split tensile strength, a 28 days strength of 3.13MPa, 2.15MPa and 1.47MPa was obtained. From the above values, it can be concluded that LCPWP with the properties obtained in this study is not suitable to replace cement partially.

Keywords: Clay pot, Waste powder, Concrete, Pozzolana.

Abbreviations:

ASTM **:** American Society for Testing Materials

MPa : Mega Pascal

LCPWP **:** Local Clay Pot Waste Powder

1. Introduction

Due to its diverse domains of applications, Concrete is the major construction material used in all parts of the world not ex0cluding Cameroon. Concrete serves as pavements, air run ways, buildings, hydraulic structures, industrial floors etc. According to Harvey, (2018) Humans are said to be the root cause of continuous warming of Earth exceeding safe levels due to their high carbon emission to create energy and other products. Portland cement production contributes a very significant amount, 7%, in the total carbon emission due to how Portland cement is produced. Limestone and other clay-like substances are heated up to 1482.222°C and then ground with gypsum to form cement. Farmer & Cook, (2013) says Portland cement is a water-based binder used to bind aggregates together. It is an integral part of the society as it is used almost anywhere in construction due to its versatility. Portland cement binds aggregates to cast into any shape one desires. Hydration is the chemical reaction responsible for the hardening and gaining of strength of concrete. Concrete gain strength as years goes by further showing its appeal in use in construction. Additives are now being used to lessen the use of cement with cementitious materials such as fly ash, ground blast furnace slag, and silica fume (Farmer & Cook, 2013).

Some of the common partial cement replacements are: silica fume and fly ash. Silica fume is a by-product of producing silicon metals or ferrosilicon alloys (silicafume.org). Silica fume is mainly composed of silicon dioxide in a range of 85% - 98% with 15% - 2% made of carbon, silicon carbide and oxides of alkaline metals (microsilicafume.org). Fly ash is a by-product of burned coal and then fired. Calcium oxide is the dominant component of fly ash with considerable amounts of silicon dioxide and aluminum oxide (ACI Committee 234, 2006)

Clay is a substance made of earth that is plastic when moist and hard when fired. Clay is composed of silicon dioxide and aluminum oxide in a 1:1 ratio. Pottery is one of the most common uses for clay. Ndop clay materials have mixed facies with colour ranging from brown, grey, mottled and yellowish brown. The thickness of the exploitable clay layer is more than 5 m. Their mineralogical constituents are quartz, kaolinite, illite and feldspars, with kaolinite as major clay mineral. Based on the geochemistry, their source rocks might be felsic, with a mafic rock inference. These materials display high percentage in fine particles and high Atterberg limits. For all the firing temperatures, flexural strength (1.2–11 MPa), water absorption (8.03–24.27%), linear shrinkage (2.10%), weight loss (4.88–16.54%) and bulk density (1.57–2.03 g/cm3) indicate good ceramic properties for firing samples between 900 and 1100 ◦C. Most of the fired test bricks show a brick red colour with good to very good cohesion (Yongue-Fouateu et al., 2016).

Concrete structures are resisting to several natural and artificial calamities. They are exposed to environments that undergo temperature changes, sulphate attack, freezing, rubbing, scraping, skidding, sliding of impact loads due to movement on surfaces, these actions result in deterioration of concrete surfaces (ACI. 2008., Chung, and Shi, Z.-Q. 1997).

Concrete products are also characterized with problems of wear and tear when subjected to its usage. This becomes a great challenged when the product is exposed to moving load, wind, erosion and running water. The volume of the concrete gradually reduces in size and the surface becomes rough and unattractive. Therefore, to overcome this problem there is the need for the introduction of some pozzolanic materials that will help overcome this issue. The common material among such pozzolanos is clay. It is from these setbacks that the research seeks to find out the Effect of the Local Clay Pot Waste Powder (LCPWP) as partial cement replacement on the mechanical properties of concrete which can help us counteract the aforementioned problem. In addition, broken clay pots in houses and craft centers can be collected and transformed since its cannot be used for the production of other clay pots (Figure 1).

Figure 1. Phases of LCPWP Transformation

The objectives of this research is to do a comparative study of concrete produced with LCPWP so at to characterize the effects of local clay pot waste powder as partial replacement of cement on the mechanical properties of concrete. This waste clay pot powder is also known as burnt clay or Calcined clay or fired clay (biscuit clay). Specifically; To determine some physical properties of local clay pot waste powder and the mechanical properties of concrete – compressive, split tensile and flexural strength of concrete – with and without local clay pot waste powder and hence determine the best mix proportion of local clay pot waste powder as cement replacement.

2. Materials and Methods

2.1. Materials:

- Cement
- Gravel
- Sand
- Local clay pot waste powder

2.2. Methods:

2.2.1. Cement

Ordinary Portland cement shall be used and shall be obtained from retail outlets of QUIFEUROU Cement Limited. The cement shall conform to the specific standards as prescribed by ASTM (ASTM, 2013). It is of class CEM II / B-P 42.5 R cement produced locally according to the Cameroonian Standard NC 234: 2009 – 06. The physical and chemical composition and the specific surface of the Dangoté cement are recorded in Table 1 and 2 below:

Table 1. Physical Properties

Parameters	Results
Specific gravity	3.1
Apparent density	0.26
Color	Grey
Finesse	97.8%
Consistency	29%

Table 2. Chemical composition

Parameters	Results (%)
Silicon Dioxide ($Si0_2$)	20.81
Iron Oxide (Fe_2O_3)	3.72
Aluminum Oxide (Al_20_3)	5.41
Sodium Oxide (Na_2O)	0.43
SO_3 (%)	3.07
MgO(%)	0.97
CaO(%)	62.3

2.2.2. Local Clay Pot Waste Powder

In this research, clay pots were gotten from Ndop, in the North West region of Cameroon and these clay pots had been fired at a temperature range of 5000C to 8000C to form what is called Biscuit clay which is the clay pots we used. The clay pots were ground (pulverized) and passed through the sieve of 400µm. The Figure 2 shows the drills Location Map of Ndop Plain.

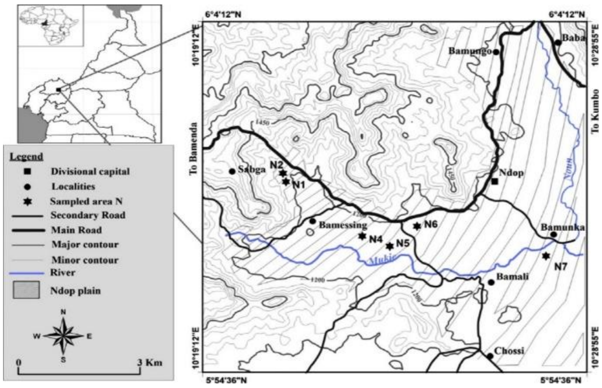

Figure 2. Drills Location Map of Ndop Plain (Yongue et al., 2016)

Mineralogy On the XRD patterns, all the samples have their major reflection peaks assigned to quartz, kaolinite, illite, feldspar and cristobalite. The bulk mineralogical composition reveals the occurrences of clay minerals with kaolinite (23–43%) as major clay mineral, characteristic of the strong chemical weathering in humid tropical climate, with illite (5–17%), few amounts of smectite, goethite and gibbsite in some samples. The main non-clay minerals are quartz (11–22%) and feldspar (13–38%). (Yongue-Fouateu et al., 2016). The Table 3 below shows the physical properties

Table 3. Physical Properties

Parameters	Results
Specific gravity	2.23
Apparent density	0.935
Color	Brown
Finesse	***400µm***

2.2.3. Fine Aggregates

The fine aggregate used in the concrete productions is good quality river sand readily available in local market. Table 4 shows the physical properties of fine aggregates.

Table 4. Physical Properties of Fine Aggregates

Specific gravity (g/cm^3)	2.724
Finesse Modulus	3.1
Apparent density (g/cm^3)	1.32
Water Absorption (%)	2.5
Sand Equivalent (%)	77

2.2.4. Coarse Aggregate

The coarse aggregates used shall be of 5/15mm and obtained from the Dreamland quarry and of approved quality conforming to approved standards of American Society for Testing and Materials (ASTM, 2013). The Table 5 below shows the coarse aggregates used.

Table 5. Physical Properties of Coarse Aggregates

Specific gravity (g/cm^3)	2.8
Finesse Modulus	5.82
Apparent density (g/cm^3)	1.4
Water Absorption (%)	1.25
Abrasion Value (%)	26.86

2.2.5. Particle size distribution analysis for aggregates

Sieve analysis with respect with material (Sand, Aggregate and Cement) weight and specific gravity was performed in accordance with BS 1377: PART 2:1990 specification. The particles size properties of the fine aggregates are as follows: Cu = 5.5, Cc = 1.03, FM = 3.1. According to Arora, (2009) a well graded soil will have a coefficient of curvature of 1 to 3, and a uniformity coefficient of 6 or more, the result below shows that the soil is a well graded soil. Holtz, (1981) noted that the Finest Modulus FM of a soil used for concrete falls within 2-4; therefore, the fine aggregate is suitable to be used. Finest Modulus for Coarse Aggregate = 5.82

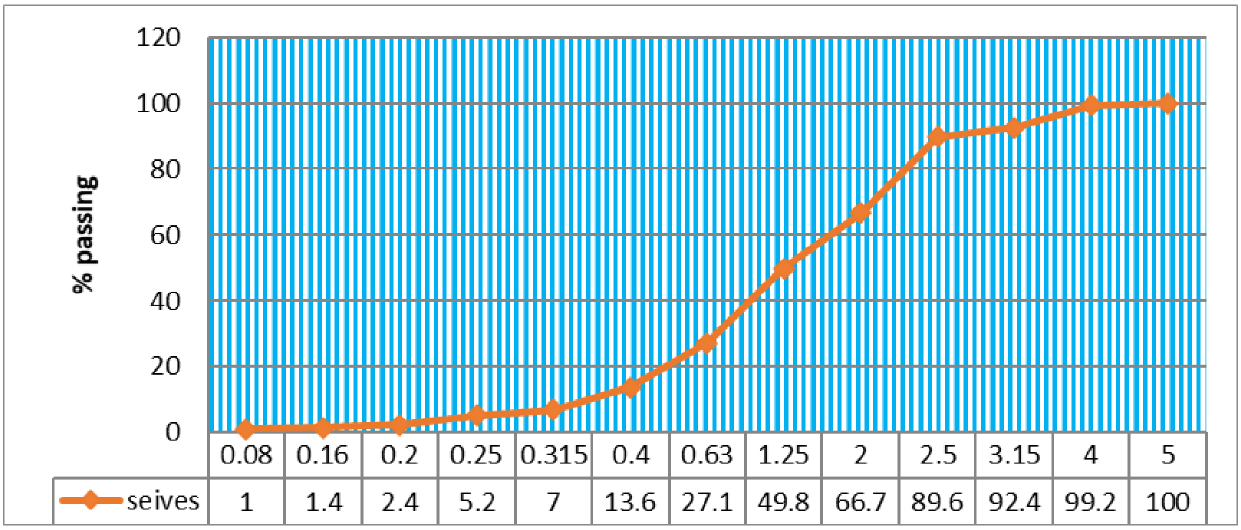

Figure 3. Particle Size Distribution curve of Fine aggregate (Sand)

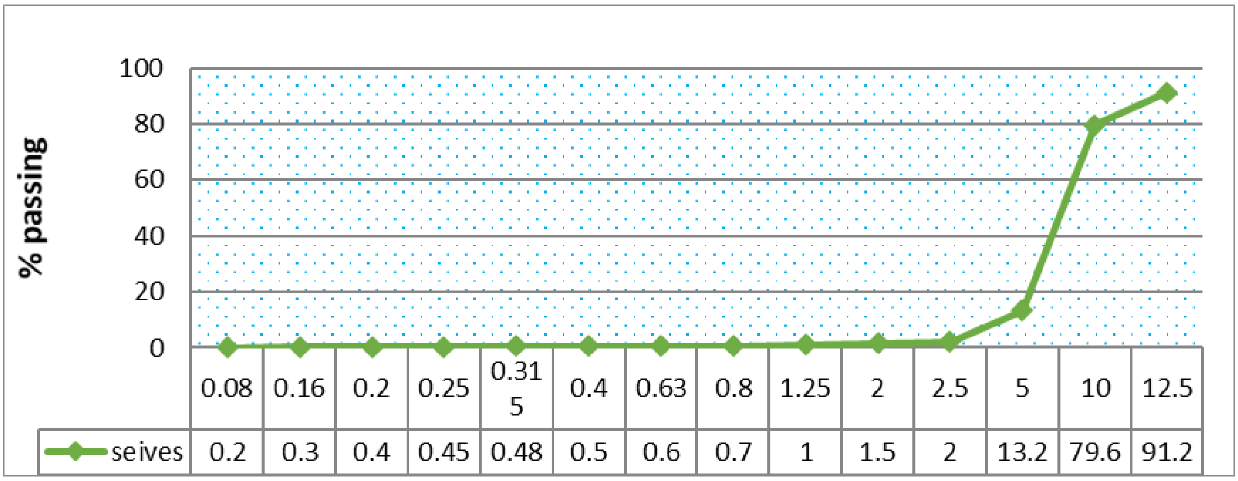

Figure 4. Particle Size Distribution curve of coarse aggregate (5/15)

2.2.6. Concrete Mix Design

The Dreux-Gorisse method was adopted. This method aims to determine based on criteria of workability and resistance defined by the specification; nature and quantities of materials required for the production of a cubic meter of concrete. The Compressive strength of concrete after 28 days (fc_{28}) chosen for this study was 25MPa. Concrete mix shall be made of using a binder, sand and aggregates. The quantity of materials used in this study is as follows;

Table 6. Summary of Total Material dosages required for concrete cubes and beams

S/N	Materials	0% (Control)	10%	20%
1	Cement (Kg)	(8.1)	(7.29)	(6.48)
2	LCPWP (Kg)	(0)	(0.81)	(1.62)
3	Sand (Kg)	(14.5)	(14.5)	(14.5)
4	Gravel 5/15 (Kg)	(24.3)	(24.3)	(24.3
5	Water (L)	(0.5)	(0.5)	(0.5)

2.2.7. Consolidation

Batching was done by weight A total of 54 cube specimens for the compression and split tensile test, 27 rectangular beam specimens for the flexural test were cast. This made it possible for 6cubes of 100 X 100X 100mm and 3 beams of 40 X 40 X 160mm to be casted for each percentage of LCPWP replacement that is 0%, 10% and 20%. Therefore, overall, 81 specimens were cast to investigate the compressive strength, split tensile and flexural strength of concrete containing various percentages of Local Clay Pot Waste Powder.

2.2.8. Curing

After all moulds are filled with concrete mixture, these were placed in a cool, dry room and let them set for about 24 hrs. Once the concrete hardens in the moulds, the specimen was extracted and placed in the curing tank. Each batch of specimen must be designated at their respective curing tank to avoid mishandling of specimens. The curing tank must be consisting of large container with water at 20 degrees Centigrade, the standard temperature for curing. The specimens were immersed in the curing tank for 7, 14, and 28 days. Twenty-seven specimens were collected at each day interval for the determination of strength of the concrete.

2.3. Testing of Specimens:

The specimens casted were tested at 7, 14 and 28 days respectively for Compressive, Flexural & Split tensile strength tests. The cylinders specimens are tested by using Compression Testing Machine of capacity 3KN in GEOSTRUC laboratory. The beams are tested in flexural Testing Machine of capacity 1 kN.

2.3.1. Tests on Hardened Concrete

2.3.1.1. Compressive Strength Test of Concrete (ASTM C 39 – 94)

After 7, 14, and 28 days in the curing tank, the concrete cubes specimens were taken out and placed on a clean and absorbent surface and were tested after 1 hour. A cement paste was placed on its top and bottom to assure that the specimen has smooth and even surfaces. The concrete cube specimens then undergone compression using the Universal Testing Machine (UTM) and the compressive strength of the concrete was computed using the formula

$$\sigma_C = \frac{P}{A}$$

Where P = critical load at failure given by UTM (N), A = cross-sectional area of specimen (mm^2),

σ_C = compressive strength (MPa)

2.3.1.2. Split-Tensile Strength Test (ASTM C496)

The concrete cube specimens then undergone splitting tension using the Universal Testing Machine (UTM) and the split-tensile strength of the concrete was computed using the formula

$$\sigma_T = \frac{2P}{\pi L d}$$

Where, P = critical load at failure given by UTM (N), L = length of specimen (mm), d = height of specimen (mm), σ_T = split-tensile strength (MPa).

The Figure 5 below shows the chart of the research:

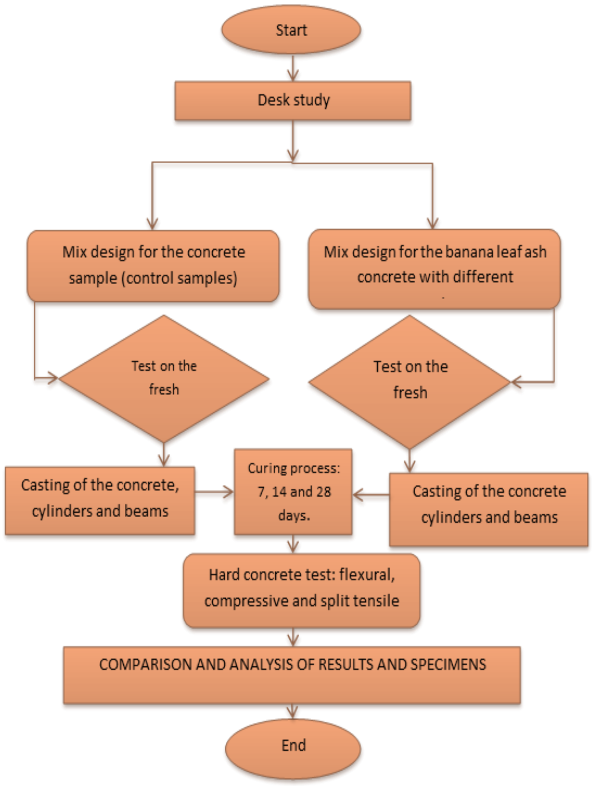

Figure 5. Chart of the research

3. Results and Discussions

3.1. Results:

3.1.1. Slump Test for Fresh Concrete (ASTM C 143 – 76)

The Figure 6 bellow shows the result of the slump test.

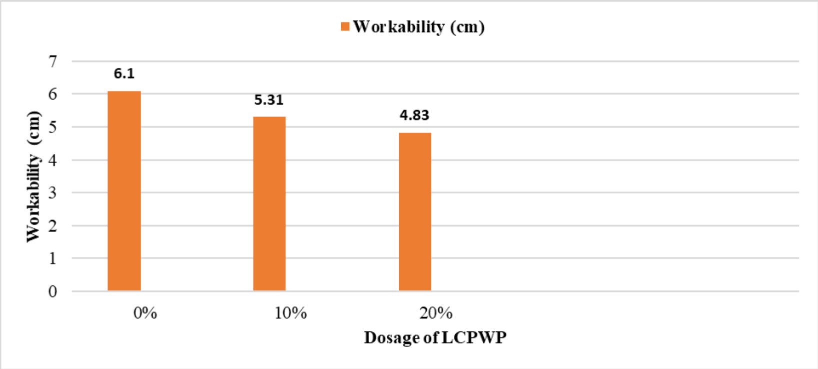

Figure 6. Slump test

Slump test measures the workability of the fresh mixed concrete. The slump test indicates the consistency or stiffness of the concrete by means of standard set by the ASTM. It was observed that the slump remains the same upon the increment of the percentage of LCPWP as partial cement replacement therefore the water remains constant at 6cm which was used for the concrete design.

3.1.2. Tests on Hardened Concrete

3.1.2.1. Compressive Strength Test of Concrete (ASTM C 39 – 94)

The Figure 7 Shows the compressive strength of concrete at 7, 14 and 28 days

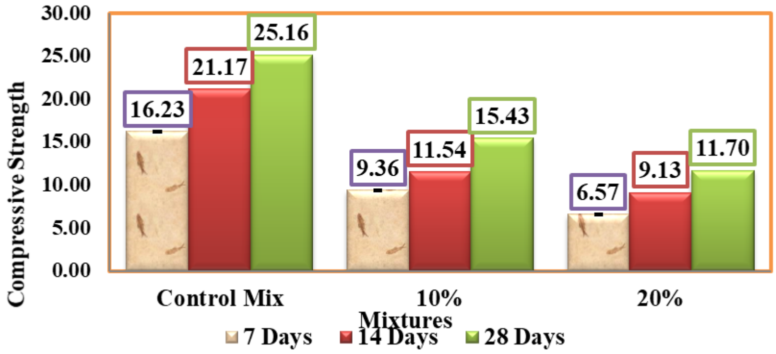

Figure 7. Compressive Strength against Mixtures

The figure above shows the result of the compressive strength test by performing the standard test for compressive strength on a Universal Testing Machine (UTM) in accordance to ASTM C 39 – 94. Based on the result of the compressive strength test, both Mix 1 and Mix 2 exhibited very low compressive strength for as the curing days increased. None of the mixtures were able to attained to the designed strength of the concrete at 28days which was 25MPa.

3.1.2.3. Split-Tensile Strength Test (ASTM C496)

The Figure 8 below shows the Split Tensile Strength against mixtures.

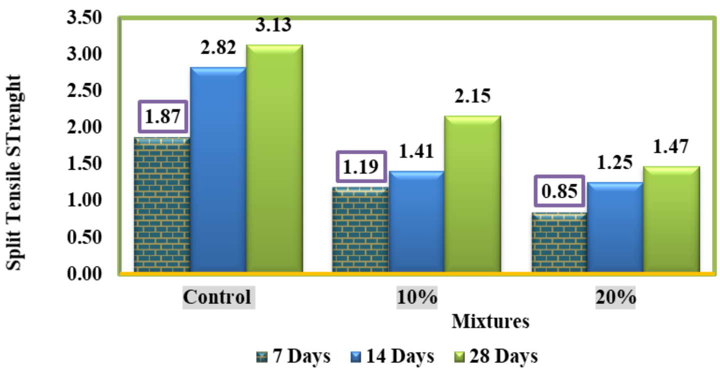

Figure 8. Split Tensile Strength against mixtures

Based on the result of the split tensile strength test, only the control mix showed the highest split tensile strength. Mix 1 and Mix 2 were below the control mix.

3.5.3. Flexural Strength Test

The Figure 9 Shows the flexural strength of concrete at 14 and 28 days

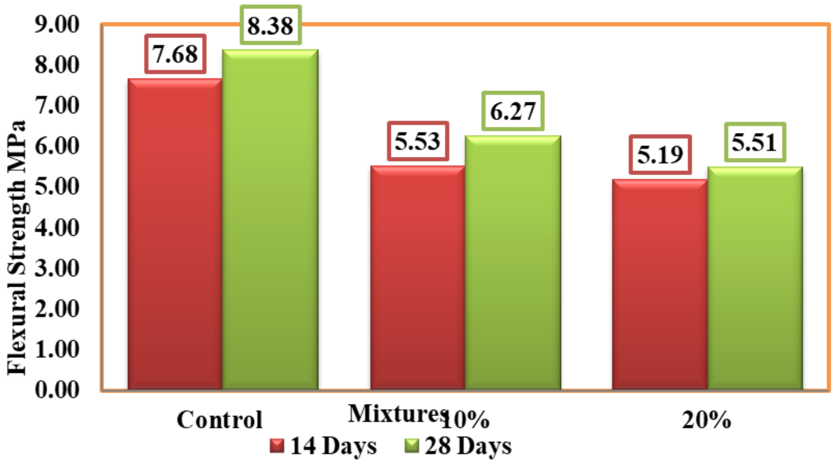

Figure 9. Flexural Strength

3.2. Discussions:

Looking at all the test carried out, it can be said concluded that LCPWP amongst other things is less dense than cement with a specific gravity of 2.23 as compared to that of cement which is 3.1. in addition, it affects the standard consistency of the cement paste by lowering in a very small quantity, the amount of water needed. Cement constitutes limestone and clay in a percentage of 80 to 20% respectively, and from this constitution, when LCPWP is introduced into the cement sample, it turns to increase the percentage of clay in the cement. From the results outlined in above, the compressive, split tensile and Flexural strength of the concrete specimens reduced when the percentage of LCPWP is increased. This finding is independent in relation to Job (1998) in his research on "Concrete Made with Pulverized Burnt Clay as Partial Replacement of Cement his study covered three grades of concretes; 20, 25 and 30 MPa with OPC replacement by pulverized burnt clay of 0%, 10%, 20%, and 30% and he concluded that there is an increase in both the initial and final setting times of cement past upon addition of PBC but the setting times are within the range recommended for plain cement paste. High workability OPC/PBC concrete also gave a satisfactory performance up to a 28-day compressive strength of 30 MPa. There was no noticeable deterioration observed since strength continued to increase as hydration progressed, rather only concretes without PBC attained 70% of their design strengths at 7days of curing.

4. Conclusion

With this independence and according to this research findings, it can be said that, LCPWP has a significant negative effect on the mechanical properties of concrete and can't be used for partial cement replacement. It implies that more studies have to be carried out on this LCPWP so as to determine ways of mending its negative effect on the mechanical properties of concrete. Concrete which is the main constituent of Civil engineering structures requires a maximum performance. The race to performance of concretes motivated this study on the effect of LCPWP on concrete which is a material that is already one of its constituents. The work done in this research considered several parameters that affect the physical and mechanical properties of concrete. This will be insufficient to characterize the use of LCPWP in civil engineering. Extensive studies should be done on this natural resource. Views the chemical compositions, firing temperatures, fineness modulus just to name a few. The results obtained in this research, and for future efficient use of these composite materials, the researchers recommend the following:

- More studies should be carried out on the purification and utilization of fired clay.
- The study of fired clay as a drainage material.

In other ways, following the results obtained, special attention will be given to:

- The firing of clay to improve the mechanical properties of concrete at average and long terms.
- The study of the effect of the LCPWP reaction with the water in the curing of the cement;
- Study of the contribution of LCPWP to the chemical resistance of concrete.

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