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# Rheological Study on Strength Characteristics of Concrete Partially Replaced with Calcined Kaolin in Concrete Production

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**ABSTRACT**
Cement is the most widely used binding material in all construction works. Due to its high cost and heat liberation property, attempts have been made to replace cement in concrete using natural resources. The study involves partial replacement of cement in concrete by incorporating calcined kaolin. The chemical composition of calcined kaolin (ck), workability, compressive strength, water absorptivity and flexural strength of concrete produced by replacing 5 to 20% of weight of ordinary Portland cement with ck. The concrete cubes were tested at ages of 7, 14, 21 and 28 days. The results showed that ck is a good pozzolan with combined $S_iO_2$, $Al_2O_3$ and $Fe_2O_3$ of 84.9%. The slump and compacting factor decreased as the ck content increased indicating that concrete becomes less workable as ck content increased. The compressive strength of concrete increased with increasing ck replacement. The compressive of concrete with ck improves significantly up to 28 days. The water absorption rate increases with increase in ck contents. The strength of beam increased with increase in the content of ck. It was concluded that 5 and 10% of ck substitution is adequate to satisfied British standard recommended strength.

## I. INTRODUCTION

### 1.1 Background of the Study

There is need for affordable building materials in providing adequate housing for the teaming populace of the world. The costs of convectional building materials continue to increase as the majority of the population continues to fall below the poverty time. Thus, there is need to search for local materials as alternatives for the construction of functional but low cost building in both the rural and urban areas. Some of local materials that have been used are earthen plaster (Raheem, 2018). Continuous generation of wastes arising from industries, by product and agricultural residue. Create acute environmental problems both in term of their treatment and disposal. The construction industry has been identified as the one that absorbs the majority of suck materials as filler in concrete, if these filler have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved (Hoissain, 2015). Appropriate utilization of these materials brings ecological and economic benefits.

Environmental concern due to high energy consumption and carbon dioxide ($CO_2$) emission associated with cement production has brought about pressure to particularly substitute portland cement with pozzolans for concrete production (Ayuba et al., 2012). Some of the pozzolans are natural and others are by products (artificial), which both contain silica in amorphous form and that will react with calcium hydroxide (CH) to form more comentitious calcium silicate hydrate (C-S-H) that contribute to cement strength . However, one of the material that satisfy the requirement of sustainable development when added in appropriate proportions, improves the properties of cement, mortars and concrete is calcined kaolin (CK), a processed pozzolana (Xluping and Boyd, 2011). Calcined kaolin is produced by heating kaolin at $600^oc$. Kaolin is an alumino-siliceous material, is abundant in Nigeria (Falade et al., 2012). During heating process, the structure of kaolinite mineral transform from crystalline to Amorphous that makes it a highly reactive pozzolans (Salisu, 2007).

Recently, a lot of research works have been carried out on the usage of kaolin as supplementary cementitious material in the production of concrete, but only a few studies have been examined by incorporating calcined kaolin for the production of blended concrete in Nigeria on the use of the abundant kaolinitic deposits in the country.

## II. MATERIALS AND METHOD

### 2.1 Materials Used

The kaolin used for this research work was collected from Ikole-Ekiti, Ekiti State. The kaolin was carefully collected to avoid mixing with sand. The granite used for this report was 12mm maximum size and the sand used for this report was free from Impurities, both aggregate were obtained from local supplier in Esa-Oke. Ordinary Portland cement (Elephant Brand) was used and the water used for this study was obtained from a borehole. The water was clean and free from any visible impurities.

### 2.2 Preparation of CalcinedKaolin

The collected kaolin was calcinated in a furnance at temperature of $600^0$C. Burning process continued until the colour changed. The calcinated kaolin was sieved using 75µm sieve after cooling to obtain ash that is fine enough to react perfectly with ordinary Portland cement. Chemical analysis test was carried out to determine the chemical composition of calcinated kaolin (CK).

### 2.3 Sieve Analysis

The CK was collected and weighed, the ash was grind in the mill into finer grain and then sieved. The sieve analysis was carried out manually in the soil mechanics laboratory at the Civil Engineering Department of Osun State College of Technology using set of sieve with diameter of 1.4µm. The sieved sample was weighed and the particle size distribution was obtained and grading curve was plotted.

### 2.4 Production of Calcined Kaolin Cement Concrete

The production of the calcinated kaolin cement concrete was carried out at Civil Engineering Laboratory, Osun State College of Technology Esa-Oke. The production process comprises of batching of concrete mixture and casting of specimens.

#### 2.4.1 Batching of CalcinedKaolin Admixture

A weighing balance was used along with head pan, shovel, and concrete cube mould and tamping rod. The calcinated kaolin cement concrete consists of the mixture of kaolin ash, ordinary Portland cement, sand, granite and water. Batching of materials was done by weighing in kilogram. The mixing involved the replacement of 5, 10, 15 and 20% by the weight of ordinary Portland cement with calcinated kaolin during the mixing process. The cement and CK was mixed first before pouring fine and coarse aggregate together. Concrete without calcinated kaolin served as control. Table 1 showed the batching of the materials required for concrete samples to produce calcinated kaolin cement concrete

**Table 1: Mixed proportion for concrete samples**

| % replacement of CK | Weight of cement | Weight of CK | Water cement ratio (WCR) |
|---|---|---|---|
| 0 | 12.88 | 0 | 0.60 |
| 5 | 12.24 | 0.64 | |
| 10 | 11.59 | 1.29 | |
| 15 | 10.95 | 1.93 | |
| 20 | 10.30 | 2.58 | |

#### 2.4.2 Preparation of concrete and casting of specimens

The mixed ratio used was 1:2:4 with water cement ratio 0.60 to achieve the desirable concrete strength. Cubic samples with size 150 x 150 x 150 $mm^3$ were cast for determination of compressivestrength, strength after curing in water for 7, 14, 21 and 28 days. The concrete cubes was removed from curing tank for about 45 minutes before subjecting it to compression. In placing the mixed concrete in the mould, a scoop was moved around the edges of the mould to ensure uniform distribution of concrete.

Each layer was tamped with 35 strokes using a tamping rod. The surface area was dressed with trowel. The sample was left in the mould for 24 hours, after which the mould was removed and the concrete were cured in water for proper hydration for 7, 14, 21 and 28 curing age. The remaining concrete cubes of 150 x 150 x 150 $mm^3$ were used for water absorption test.

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### 2.5 Workability Test
Two workability tests were carried out on the samples. These are: slump test and compacting factor test.

#### 2.5.1 Slump test
Slump test was carried out using the slump cone 300mm high. The cone was placed on a smooth horizontal surface with the smaller opening at the top. The concrete were poured in three layers; each layer was tamped 35 times with standard steel rod of 16mm diameter. Immediately after filling, the cone was lifted and the decrease in the height of the slump was measured and recorded.

#### 2.5.2 Compacting Factor Test
Compacting factor test was carried out by using the compacting factor apparatus. The upper hopper was filled with concrete in such a way that no compaction occurred, the bottom clamp was released so that concrete will falls to lower hopper. The bottom door of the lower hopper was then released so that concrete falls to the cylinder; excess concrete was cut off. Compacting factor was by dividing weight of concrete in the cylinder to the weight of fully compacted concrete.

$$C.F = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}} \quad \text{.......................... Equation 1}$$

### 2.6 Absorptivity Test
This is the test carried out on concrete sample in order to investigate the rate at which concrete absorb water. This is done by immersing the concrete sample in curing tank for 25 days, the concrete sample was removed from water for 48 hours, then cured in water for 2 days again. Then weigh the concrete sample after curing for 28days and then when cured again for 2 days. The variation in weight is the rate of water absorption.

### 2.7 Compressive Strength test
The concrete cube for this project were batched, mixed and cured for 7, 14,21 and 28 days at 0, 5, 15, 20 and 25 days. At the end of curing period, the concrete cubes produced were subjected to compressive for assessing residual strength.

### 2.8 Flexural Strength Test
The flexural test of concrete was used to evaluate the strength of concrete in a beam. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending (Adedokun, 2014). The specimen was prepared by filling the concrete into the mould in three layers and was tamped 35 blows after each layer. The specimen mould used was 150 x 150 x 300 mm. It was demould after 24 hours and tested at 14 and 28 curing ages. Load was applied continuously without shock till the point of failure. The flexural strength determined by:

$$Fr = \frac{Pl}{bd^2} \quad \text{........ Equation 2}$$

Where:
b = width of specimen d = failure point depth l = supported length p = maximum load (KN)

## III. RESULTS AND DISCUSSION

### 3.1 Chemical Composition of Calcined kaolin (ck)
The result of chemical composition of calcined kaolin when compared with that of the cement is presented in Table 2

**Table 2: Chemical composition of calcined kaolin compare with cement**

| Oxide | Contents (%) | |
|---|---|---|
| | Cement | Calcined kaolin |
| $Al_2O_3$ | 4.9 | 40.0 |
| $SiO_2$ | 20.1 | 44.9 |
| $TiO_2$ | 0.2 | 0.096 |
| $K_2O$ | 0.4 | - |
| CaO | 65 | 0.802 |
| $Na_2O$ | 0.2 | - |
| MgO | 3.1 | 0.027 |
| MnO | 0.02 | - |
| $Fe_2O_3$ | 2.5 | 0.082 |
| Loss on ignition | 8.8 | 13 |

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The result showed that calcined kaolin (ck) has combined percentages of ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$) of 84.90% which is more than 70%, indicating that it is a good pozzolanic material in accordance with the requirements in ASTM but the CaO in cement is very high compared to ck. This is similar to previous work of Abdulrasheed, 2021.

**3.2 Workability of Calcined Kaolin (ck) Concrete**

The results of the slump and compacting factors carried-out are shown in Table 3 and Figure 1 respectively. Figure 1 indicate that the slump value decreases from 105 to 70 mm as the percentage replacement increased. Similarly, the compacting factor values decreases from 0.995 to 0.970 as the percentage content of ck increased. These results indicated that the concrete becomes less workable as the percentage of ck increased, meaning that more water is required to make the mixes more workable.

**Table 3: Workability of Calcined Kaolin in concrete**

| % replacement of ck | Slump (mm) | Compacting factor values |
|---|---|---|
| 0 | 105 | 0.995 |
| 5 | 98 | 0.985 |
| 10 | 90 | 0.975 |
| 15 | 85 | 0.970 |
| 20 | 70 | 0.970 |

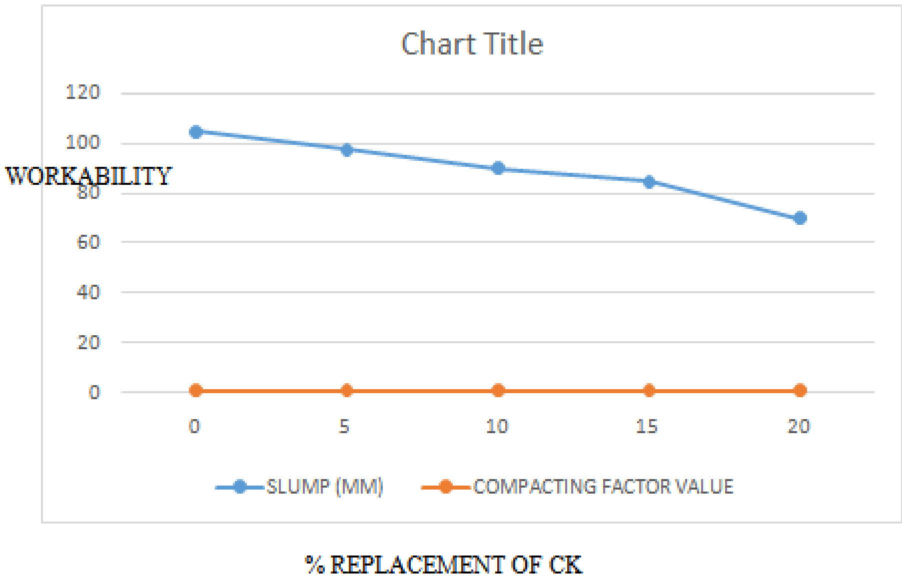


**Figure 1:** Plots of workability against % replacement of Calcined Kaolin (Ck)

**3.3 Compressive Strength of Concrete**

The effect of curing ages on the compressive strength of ck concrete is presented in Table 4 and Figure 2. The Figure indicates that compressive strength generally increases with curing period and decreases with increased amount of ck. The result at 7 days showed an increase in strength from 15.05 to 18.90 $N/mm^2$ for 20% ck replacement. Similar trend was observed at 14, 21 and 28 days as shown in Figure 4.2. These results indicate that concrete containing ck gain strength slowly at early curing age.

**Table 4: Compressive strength of calcined kaolin concrete**

| % Replacement of ck | Compressive Strength Value N/mm$^2$ | | | |
|---|---|---|---|---|
| | 7 | 14 | 21 | 28 days |
| 0 | 15.05 | 17.25 | 22.00 | 25.26 |
| 5 | 17.00 | 17.70 | 22.60 | 25.35 |
| 10 | 17.90 | 17.95 | 23.02 | 25.60 |
| 15 | 18.15 | 18.02 | 23.20 | 25.95 |
| 20 | 18.90 | 18.55 | 23.15 | 26.02 |

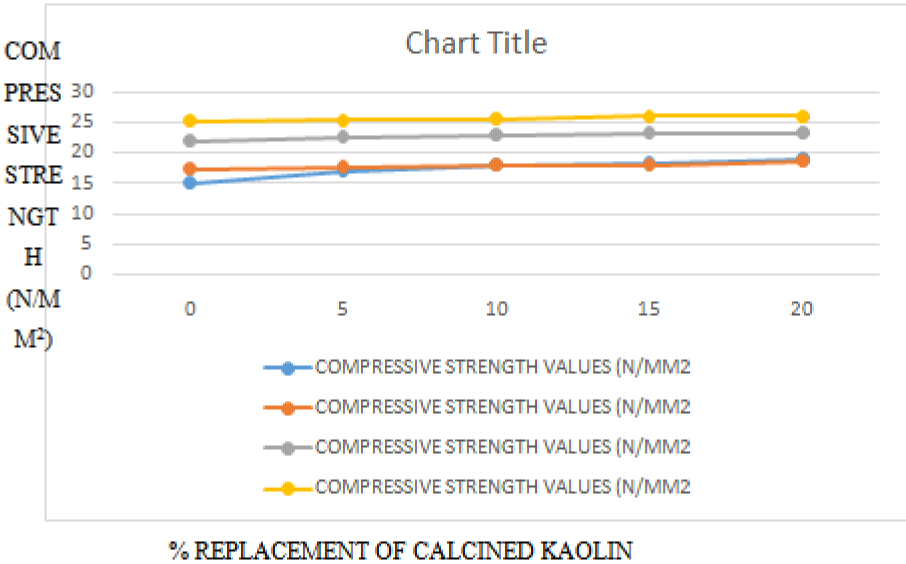


**Figure 2**: **Effect of curing age on the compressive strength of ck concrete**

### 3.4 Flexural Strength of Concrete Beam

The result obtained from the flexural strength test on hardened concrete at curing period 21 and 28 days is presented in Table 5. At 21 days, the strength of beam increase from 2.18 to 2.95 N/mm$^2$ as the percentage replacement of ck increased. This may be as a result of reaction between water and oxides of ck present when they react together. The strength of the beam at 28 days is 3.70 N/mm$^2$ which is above the recommended value for the 0% replacement. However, the significant increase in strength of ck concrete is due to the pozzolanic reaction of ck.

**Table 5: Flexural strength of ck concrete**

| % Replacement of ck | Flexural strength value N/mm$^2$ | |
|---|---|---|
| | 21 | 28 days |
| 0 | 2.18 | 3.05 |
| 5 | 2.39 | 3.18 |
| 10 | 2.47 | 3.25 |
| 15 | 2.65 | 3.55 |
| 20 | 2.95 | 3.70 |

### 3.5 Water Absorptivity of concrete

The result obtained from the water absorption test of concrete sample is presented in Table 6. The result indicates that the permeability value increased from 2.25 to 3.40% as the % content of ck increased. This is due to the reaction of oxides of iron and silicate present in ck, they are readily form reactions with other oxide most especially when water is introduced. This implies that the concrete becomes more workable as the water absorptivity is lesser than 3% as recommended by British specification values.

**Table 6: Water Absorptivity Value**

| % Replacement of ck | Rate of Absorption (%) |
|---|---|
| 0 | 2.25 |
| 5 | 2.60 |
| 10 | 2.90 |
| 15 | 3.15 |
| 20 | 3.40 |

## IV. CONCLUSIONS AND RECOMMENDATION

Calcined kaolin (CK) is a suitable pozzolanic material due to its high combined oxide content ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$ > 70%). While increasing CK content reduces workability, additional water can improve mixing. Both compressive and flexural strength improve with longer curing periods and CK content, with 5–10% CK substitution being optimal for strength gains.

**Recommendations**

- Calcination of kaolin should occur at 650°C, 700°C, and 750°C for use in concrete.
- Thermal property analysis should be conducted on CK-based concrete for further evaluation.

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