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# Enhancing the Strength and Durability Behaviour of Concrete Produced with Brown-Loamy Kaolin Clay Polymer

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**Abstract.** Clay is the most utilised natural pozzolana in Ghana, with the red-loamy clay in southern Ghana being the most widely studied. It has been established that clays geographical location presents differences in their optimum calcination temperatures and cement replacement levels. The aim of this study was to investigate the potential use of brown-loamy kaolin clay polymer in northern Ghana as a natural pozzolana. The clay was thermally activated, and it became more pozzolanic reactive at 800°C. The clay was used to replace cement at 0%, 5%, 10%, 15% and 20% based on the weight of the cement, and denoted as $A_o$, $K_5$, $K_{10}$, $K_{15}$ and $K_{20}$ respectively. Concrete cubes of size 150×150×150mm and cylinders of size 150×300mm were cast and cured for 7, 14, 28, and 90 days. The samples were tested for density, compressive strength, split tensile strength, water absorption and sulphate attack. Maximum compressive and split tensile strengths were achieved at the 15% replacement level in all curing durations. Again, there was a significant decrease in water absorption and sulphate attack up to the 15% replacement level. Beyond the 15% and up to the 20%, the decrease was minimal. The increase in strength and decrease in durability properties was significantly high in 90 days compared to 7 days. The study therefore recommends the use of brown-loamy clay up to 15% cement substitution. It use would be advantageous for concrete production in situations where high to medium workability and delays in setting times are required.

**Keywords:** Brown-loamy kaolin clay, compressive strength, split tensile strength, water absorption, sulphate attack.

## 1. Introduction

A greater proportion of the world economies are witnessing unprecedented increasing population growth, and environmental change, partly due to the rapid drive in urbanisation and industrialisation (He et al., 2020). According to the United Nations Report (2020) 55% of the world population lives in urban cities and that, 90% of urban population growth is projected to take place in Asia and Africa, particularly in India and Nigeria. As a tripling down effect Bebr et al. (2021) reported that there is a housing deficit of 268 million housing units affecting 1.26 billion people globally as a result of the rural-urban drift, and that an estimated number of 40 million housing units will have to be added to provide adequate housing for the increasing population by the year 2050. In the national front, Ghana's population according to Ghana Statistical Survey Department Report (2022), stood at a little over 31 million people in 2020, and an average population growth of 2.2 percent a year with 56.7% of the population living in urban towns, thereby widening the gap in housing development. The Report further indicates that Ghana has a housing deficit of 1.8 million units, and will require an estimated amount of 2.5 billion US Dollars to provide a minimum of 170,000 housing units annually to close the gap.

Concrete is the most utilised construction material in contemporary times around the globe for housing accommodation (Bhange et al., 2019). However, it has been reported that 60% of the total cost of housing accommodation is spent on materials due to the high cost associated with concrete materials (Adedeji, 2010). Global Cement Report (2010) also revealed that cement utilisation in concrete formulation rose from 1.8 billion metric tonnes in 1999 to 2.6 billion metric tonnes in 2005 and, then to roughly 3.5 billion metric tonnes in 2012 and is projected to reach 5 billion metric tonnes by the year 2025. Furthermore, a recent report by Bo et al. (2018) indicated that the global yearly concrete utilisation is close to 17.5 billion metric tonnes, in which the cement component is 2.6 billion metric tonnes. The continuous demand for cement in concrete production for housing and general construction purposes translate to huge economic and environmental problems. For instance, on the economic front, Bediako et al. (2012), and Millogo et al. (2016) pointed out that cement utilisation for building and construction is responsible for the continuous increase in housing cost in developing countries, often beyond the means of the poor. Again, Bediako (2015) also asserted that the raw materials for the production of cement used extensively in Ghana cost the nation not less than 270 million US Dollars yearly. The environmental impact relating to cement production is also huge. According to Flower and Sanjayan (2007), cement production processes account for 74 – 81% of the total carbon dioxide emissions.

The latest attempt to reduce cost of concrete and sustainability problems, using alternative materials for housing affordability, and carbon dioxide emissions resulting from cement manufacture processes, led to the proposition of the Green Building Technology (GBT) concept. The concept is aimed at using materials that are affordable, sustainable, non-toxic and ethical. According to Danso-Boateng (2021) green building refers to a building that in it design, construction or operation reduces or eliminates negative impacts, and can create positive impacts, on the environment. Presently, the attention of research work is shifting towards the optimisation of building materials by using locally sourced materials that are abundant (Asiamah & Danso, 2021). Studies have established that up to 70% of cement can be replaced by thermally activated clay which is environmentally friendly and sustainable (Osei & Jackson, 2012). It is against this background that variable alternatives for cement have been investigated extensively in the past four decades. In Ghana, numerous research efforts have been made in the use of calcined clay. For instance, Atiemo (2005) demonstrated that clays from Mankranso and Tanoso near Kumasi can replace cement up to 25% and 30%, respectively, for concrete production. Sarfo-Ansah et al. (2014) also found that Mankranso clay can replace up to 40% cement in concrete formulation. Recent studies also showed that calcined clay at 25% cement replacement significantly reduced alkali-silica reaction in concrete (Sarfo-Ansah et al., 2014), Nyamebekyere clay calcined at 800°C can replaced up to 20% cement in concrete (Bediako et al., 2017). In a recent study, Endene et al. (2020) have also demonstrated that Mfensi and Afari clays could be used for liner applications in Municipal solid waste landfills. Furthermore, Boakye and Khorami (2023) also observed that 20% clay content improves concrete strength and durability properties better than the control cubes.

Although, clay materials had been extensively studied in Ghana as potential cementitious material, the scope had been on red-loamy clay in southern Ghana. There is little information or literature on the potential use of brown-loamy clay in northern Ghana as an enhancer to concrete properties. The aim of this study therefore, was to investigate the potential use of brown-loamy kaolin clay polymer in northern Ghana as partial replacement for cement in concrete production. Ghana has 238,535 km$^2$ of land area with significant amount of clay deposits or reserves in commercial quantities (Ghana Geological Survey Department, 2009), and a total clay deposits estimated at 1500 billion metric tonnes (Bediako, 2015; Amankwah & Suglo, 2020), with half of these deposits located in the northern part referred to as brown-loamy clay. The clay is in abundance, and as such, housing cost savings and environmental sustainability in its use as cement substitute in concrete will be achieved over other material alternatives.

## 2. Materials and Methods

### *2.1. Materials*

The following test materials; cement, water, kaolin clay polymer, fine aggregate and granite stones were used to produce concrete samples for the experimental research study.

#### *2.2.1 Cement*

Ordinary Portland cement of grade 32N produced locally in Ghana by Ghana Cement Company Limited (GHACEM), and conforming to BS EN 197-1 (2011) requirements, was used.

#### *2.2.2 Water*

Impurities and chemical free drinkable pipe water, supplied to the laboratory by the Ghana Water Company Limited, that conformed to BS EN 1008 (2002), was used to mix the test materials.

#### *2.1.3. Brown-loamy Kaolin Clay Polymer*

Brown-loamy kaolin clay that conformed to BS EN 8615-2 (2019) specifications, was obtained from a large clay deposit in Charia, in the Wa Municipality, Ghana, and used as polymer.

#### *2.1.4. Aggregates*

Good quality sand sourced from river bed, and crushed granite stones with an average size of 10mm, conforming to BS EN 12620 (2019) specifications, were used.

### *2.2. Testing Methods and Procedures*

#### *2.2.1. Clay Milling and Properties Assessment*

The clay lumps shown in Figure 1 were air-dried to a constant weight in a laboratory environment before grinding to break up the agglomerates using a Thomas grinding machine. The clay was further pulverized into a very fine particle size (45-150 microns) using a cone crusher and a vibratory mill. The clay was passed through a sieve with an aperture size of 63$\mu m$. The powdered clay sample shown in Figure 2 was sent to the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR-Ghana) Laboratory, Kumasi for the strength activity index (SAI) and, chemical and physical property analysis.

**Fig. 1. Clay lumps**

**Fig. 2. Milled clay powder**

#### *2.2.2. Chemical Analysis*

The chemical analysis was done purposely to determine the oxide composition and contents which is an indicator of the clay functional and pozzolanic reactive properties. A sample of the powdered clay was parcelled in an air and water-tight polythene, and sent to the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR-Ghana) Laboratory, Kumasi for the strength activity index (SAI), chemical and physical properties analysis. The analysis was done based gravimetric methods as stipulated in BS EN 8615-2 (2019).

### *2.2.3. Aggregates Quality Assessment*

The aggregates were tested in conformity with BS EN 12620 (2019) specifications for the following properties: organic impurities, specific gravity, water absorption, fineness modulus, grain size distribution, abrasion strength, flakiness and elongation indices.

### *2.2.4. Mix Design*

Kaolin clay powdered material that passed through the 63μm sieve size and calcined at 800$^oC$ was blended with cement. The cement was replaced with clay based on weight in percentages of 0%, 5%, 10%, 15% and 20%. The samples were labelled $A_0$, as control sample and, $K_x$, as experimental sample with x% kaolin clay polymer (see Table 1). Based on trial mixes and with targeted cube strength of 25N/mm$^2$, a binder-to-aggregate ratio of 1:2:4, and a water-cement ratio of 0.55 were used to prepare the samples. The mixing of the materials was done manually on a clean platform. The fine aggregate, cement and kaolin clay polymer were first mixed in a dry state to a uniform mixture, before the granite stones were added. Clean water was added in two phases and mixed to a uniform consistency. Twelve cubes of size 150mm and twelve cylinders of diameter 150mm and a height of 300mm were prepared for each replacement level using the required moulds.

**Table 1. Mix design for the experiment**

| Sample | Cement (%) | Kaolin clay (%) | Sand (%) | Stones (%) | W/C ratio |
|---|---|---|---|---|---|
| $A_0$ | 100 | 0 | 100 | 100 | 0.55 |
| $K_5$ | 95 | 5 | 100 | 100 | 0.55 |
| $K_{10}$ | 90 | 10 | 100 | 100 | 0.55 |
| $K_{15}$ | 85 | 15 | 100 | 100 | 0.55 |
| $K_{20}$ | 80 | 20 | 100 | 100 | 0.55 |

### *2.2.5. Setting Times and Workability*

The standard consistency and setting times of test blocks were determined using the Vicat Apparatus in conformity with the BS EN 196-3 (2000). The test blocks were prepared with the appropriate mix designs and required water content. The blocks were then tested for the initial and final setting times using the initial set and final set needles respectively. Again, the concrete mix workability test was performed using the conical mould in conformity with the BS EN 12350-2 (2019), requirements. The concrete mix samples were prepared with the appropriate material compositions, mix proportions and required water content for the design batches. The mixture was placed in the mould in four layers and each layer tamped 25 times with a tamping rod. The top was stroke off with a hand trowel and the mould was carefully removed and turned in the vertical direction. The slump was then measured as soon as the concrete mix settlements came to a stop. The procedure was repeated for the rest of the batches.

### *2.2.6. Curing and Testing*

Concrete cubes and cylinders were de-moulded after 24 hours of casting, cured in water for 7, 14, 28, and 90 days. The samples were tested for compressive strength using the compression testing machine (Figure 3) in line with the BS EN 12390-3 (2019), split tensile strength using the universal compression testing machine (Figure 4) in line with BS EN 12390-6(2019). The other tests performed were water absorption and sulphate attack. The experimental data obtained from the strength and durability properties tests conducted were recorded, computed and analysed based on descriptive statistics using the Statistical Package for Social Sciences Version 16.0 (SPSS Version 16.0). Tables, graphs and charts were used to explain the results of the analysis.

**Fig 3. Cubes testing.**


**Fig 4. Cylinder testing**

## 3. Results and Discussion

### *3.1. Chemical Properties of Clay*

The chemical properties of the studied clay polymers are listed in Table 2. The total $S_iO_2$ + $Al_2O_3$ + $Fe_2O_3$ (88.23%) was higher than the minimum of 70% specified for clays that produce pozzolanas (BS EN 8615-2, 2019). The $S_iO_2$ content of 53.39% exceeded the minimum limit of 49%, whereas the $SO_3$ and LOI contents were below the minimum and maximum percentage values of 0.1% and 10%, respectively, indicating that the clay is chemically stable as a pozzolana. Again, the $S_iO_2$ percentage values recorded fall within the range of 55 – 70% specified for clays that yield high strength (Wu et al., 2017). The total $S_iO_2$ + $Al_2O_3$ + $Fe_2O_3$ content of the brown loamy clay used fall within the range of the total $S_iO_2$ + $Al_2O_3$ + $Fe_2O_3$ content of the red loamy clays studied in southern Ghana. The total $S_iO_2$ + $Al_2O_3$ + $Fe_2O_3$ content of Tanoso clay was 84.68% (Amankwah et al., 2015), Nyamebekyere clay 90.45% (Bediako et al., 2017), Afari clay 80.11%, Mfensi clay 89.85% (Endene et al., 2020) and, clay from an unknown deposit 93.16% (Boakye & Khorami, 2023).

**Table 2. Chemical properties of kaolin clay polymer used (%)**

| $S_iO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MnO | MgO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $SO_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|
| 53.39 | 25.91 | 8.93 | 4.56 | 0.07 | 3.50 | 1.75 | 1.60 | 0.26 | 0.01 | 0.02 |

### *3.2. Physical Properties of Clay and Aggregates*

The physical properties of the kaolin clay polymer and aggregates are presented in Table 3. Clay has a high percentage of fines, 61.2% of its particle size is less than $90\mu m$ and according to Atterberg's limits, it is classified as clay with intermediate plasticity. The kaolin clay properties conformed to the BS EN 8615-2 (2019) specifications. The aggregate properties were also within the established BS EN 12620 (2019) suitability limits.

**Table 3. Summary of materials physical properties**

| Property | Kaolin clay | Sand | Stones | BS EN Ref |
|---|---|---|---|---|
| Bulk specific gravity | — | 2.60 | 2.56 | 2.38 – 2.75 |
| Apparent specific gravity | — | — | 2.65 | 2.38 – 2.75 |
| Specific gravity | 3.03 | — | — | — |
| Liquid limit | 43 | — | — | — |
| Plastic limit | 25 | — | — | — |
| Plasticity index | 18% | — | — | — |
| Water absorption | — | 14% | 2.3% | ≤ 20% |
| Fineness modulus | — | 3.2 | 6.60 | 2.0 – 8.0 |
| Abrasion strength | — | — | 26% | ≤ 40% |
| Flakiness index | — | — | 12.7% | ≥ 15% |
| Elongation index | — | — | 9.7% | ≥ 10% |

### *3.3. Strength Activity Index (SAI)*

The mortar mixtures flow, the compressive strength of the mortar cubes at 7 and 28 days, and the SAI of the calcined clay are presented in Table 4 and plotted in Figure 5. It could be observed that the mortar mixtures recorded minimum flow of 106 to maximum flow of 114 for the control and clay mixture calcined at 0°C and 900°C, respectively. These values fall within the minimum and maximum flow percentage values of 105% and 114% recommended by the BS EN 8615-2 (2019). The compressive strength values of clay calcined at 800°C recorded the maximum average values of 36.8N/mm$^2$ and 45.9N/mm$^2$ at 7 and 28 days respectively. The strength values achieved at 800°C calcination temperature recorded 17% and 13% improvement in strength development at 7 and 28 days testing, respectively, compared to the control mortar cube values. Hence, clay thermally activated at 800°C was used to partially replaced cement for this study.

**Table 4. Mortar mixture flow and SAI at 7 and 28 days**

| Mixture | Flow (%) | 7 days compressive strength | | 28 days compressive strength | |
|---|---|---|---|---|---|
| | | Mean (N/mm$^2$) | SAI (%) | Mean (N/mm$^2$) | SAI (%) |
| Control | 106 | 31.4 | 100 | 40.5 | 100 |
| 20P600 | 107 | 32.2 | 102 | 41.9 | 103 |
| 20P700 | 112 | 32.7 | 104 | 43.8 | 108 |
| 20P800 | 110 | 36.8 | 117 | 45.9 | 113 |
| 20P900 | 114 | 34.7 | 111 | 42.8 | 106 |

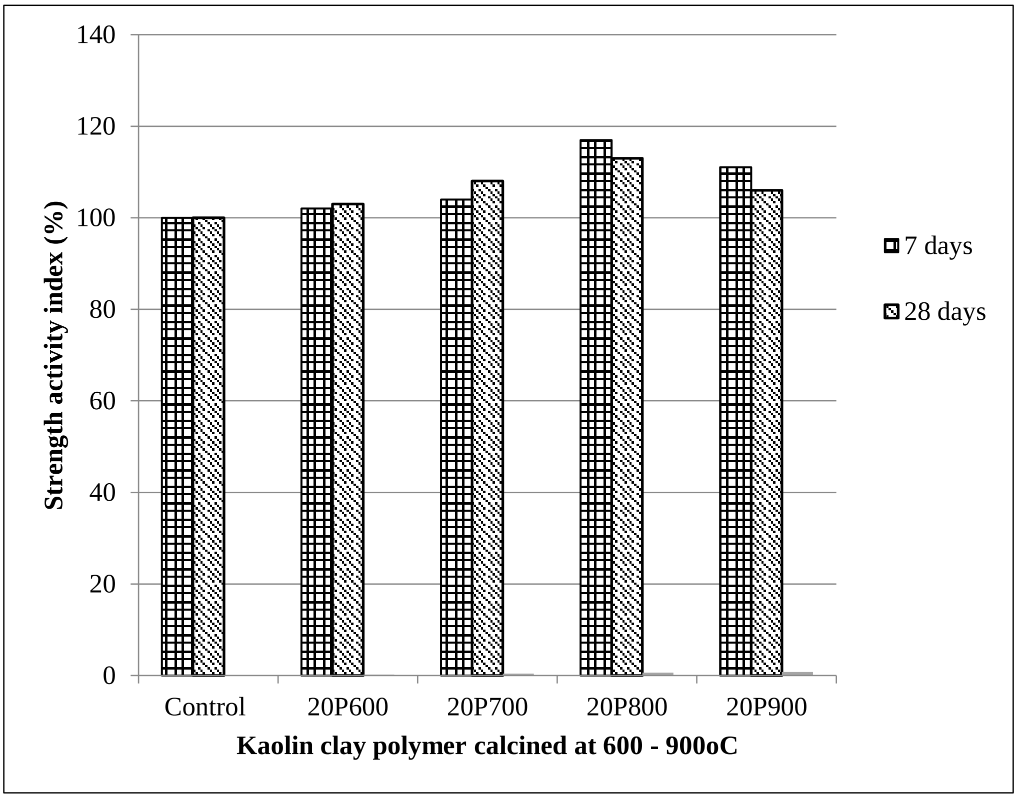


**Fig 5. Strength activity index of thermally activated clay**

### *3.4. Setting Times*

The control mortar paste ($A_0$) exhibited the lowest consistency value of 35.1%, as shown in Table 5. Beyond this, the value increased consistently with increasing kaolin clay polymer content to 37.5% for the mortar paste with 20% clay content ($K_{20}$). A similar occurrence was reported by

Amankwah et al. (2015), where the consistency of clay paste increased as the kaolin clay polymer content increased. This shows that the kaolin clay polymer needs a higher water content to form a workable mix. The initial and final setting times of the paste also increased steadily with further addition of the kaolin clay polymer for more than 112 and 284 min, respectively, as recorded for the normal paste. This development was expected because the clay had high silica (53.39%) and fines (61.25%) contents, which might have influenced the steady increase in both the initial and final setting times of the paste.

**Table 5. Effect of kaolin clay on consistency and setting times**

| Sample | Cement (%) | Clay (%) | w/b ratio | Consistency (%) | Setting times (mm) | |
|---|---|---|---|---|---|---|
| | | | | | Initial | Final |
| $A_0$ | 100 | 0 | 0.55 | 35.1 | 112 | 284 |
| $K_5$ | 95 | 5 | 0.55 | 35.8 | 123 | 297 |
| $K_{10}$ | 90 | 10 | 0.55 | 36.2 | 132 | 308 |
| $K_{15}$ | 85 | 15 | 0.55 | 36.9 | 145 | 317 |
| $K_{20}$ | 80 | 20 | 0.55 | 37.5 | 154 | 325 |

### *3.5. Workability*

From the results shown in Table 6, the experimental concrete mixes experienced a steady decline in slump values as the clay polymer content increased compared to the control mix. Similar observations of slump decline were made in the works of Amankwah et al. (2015), and, Boakye and Khorami (2023), who studied the effect of clay pozzolana on the slump behavior of concrete mix.

**Table 6. Effect of kaolin clay on concrete slump**

| Mix | Cement (%) | Clay (%) | w/b ratio | Slump (mm) | Collapsed (mm) | Workability |
|---|---|---|---|---|---|---|
| $A_0$ | 100 | 0 | 0.55 | 114 | 186 | High |
| $K_5$ | 95 | 5 | 0.55 | 103 | 197 | High |
| $K_{10}$ | 90 | 10 | 0.55 | 94 | 206 | Medium |
| $K_{15}$ | 85 | 15 | 0.55 | 87 | 213 | Medium |
| $K_{20}$ | 80 | 20 | 0.55 | 76 | 224 | Medium |

### *3.6. Compressive and Split Tensile Strengths*

From the results shown in Figures 6 and 7, it is observed that, the concrete cubes and cylinders exhibited a steady appreciation in strength as the kaolin clay polymer content inclusion was increased to 15% cement replacement and from 7 to 90 days of curing. After seven days of curing, concrete cubes and cylinders with 15% kaolin clay polymer content obtained the highest compressive strength values of 18.47 N/mm$^2$ and 2.94N/mm$^2$, which increased to 33.99 N/mm$^2$ and 5.41N/mm$^2$, after 90 days of curing, as compared to the control and other experimental concrete cubes. For all curing durations, the compressive strength and split tensile strength values increased consistently up to a clay content of 15% and declined with further addition.

The increase in strengths from 7 to 90 days of curing age was significantly high across all replacement levels. This result was anticipated because the kaolin clay polymer worked as a filler material owing to its high percentage content of fines (61.2%), as well as pozzolana due to its high silica content (53.39%). The fine particles created more filling capacity, which promoted early strength development, whereas the high silica content led to late strength development owing to the pozzolana reactivity of the kaolin clay polymer. Sarfo-Ansah et al. (2014) and Amankwah et al. (2015) observed similar characteristics of the influence of clay pozzolana on the strength behaviour of concrete cubes and cylinders.

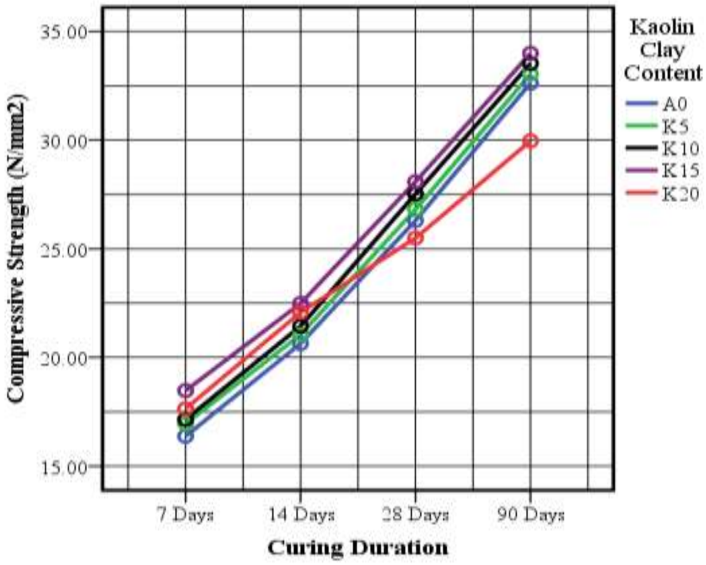


**Fig 6. Variation of compressive strength with clay content and curing duration**

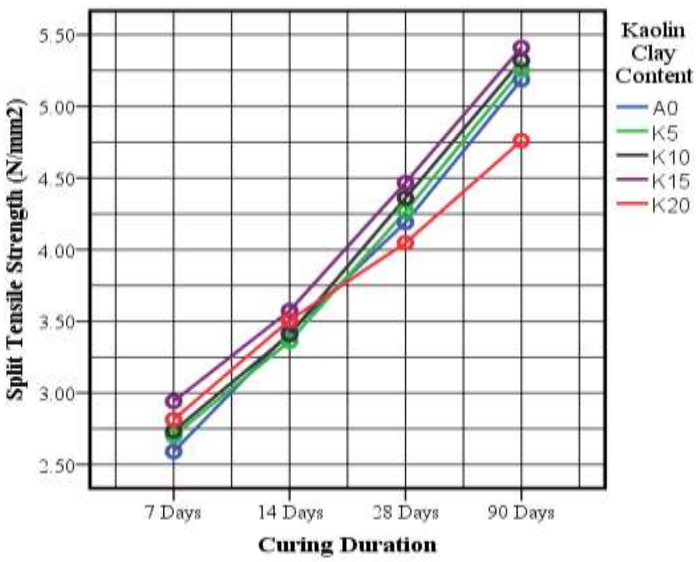


**Fig 7. Variation of split tensile strength with clay content and curing duration**

The analysis of variance (ANOVA) test results for the compressive strength values obtained are presented in Table 7. The results indicated a significant influence of the two factors on the compressive strength behaviour. P-values of 0.000 were generated for both factors, that is, curing duration, $F(1,40) = 1207.629$, $p < 0.05$, and kaolin clay polymer, $F(1,40) = 13.654$, $p < 0.05$. It can be noticed that the curing duration had more influence to the strength development than the kaolin clay polymer. From earlier discussions on descriptive statistics, this was anticipated. It is also noticed that the coefficient of correlation, $R^2 = 0.989$ is higher than 0.95. Hence, it is presumed that the model is a statistical fit to predict the compressive strength data because 98.9% of the variability can be explained by the model. This indicates that the equation was valid for up to 15% clay content after 90 days of curing. To determine the contribution levels of curing duration and kaolin clay polymer on the split tensile strength behaviour of the concrete cylinders, an analysis of variance (ANOVA) test was also conducted at a significance level of 0.05. The statistical test results shown in Table 8 recorded P-values of 0.000 for both curing durations, $F(1,40) = 842.605$,

$p < 0.05$, and kaolin clay polymer, $F(1,40) = 8.841$, $p < 0.05$. Because the variance ratio (F) value for curing duration is much greater (842.605) than that of the kaolin clay polymer (8.841), this implies that the curing duration contributed far more to the split tensile strength data than the clay polymer content. Notwithstanding, the R-square statistic generated by the model indicates that 98.5% ($R^2 = 0.985$) of the variation in the split tensile strength behaviour can be linked to the curing duration and clay polymer inclusion. With this high explanatory power of the model, the reliability of the data could be seen as excellent and valid up to the 15% kaolin clay polymer replacement level after 90 days of curing.

**Table 7. ANOVA analysis of compressive strength data (N/mm²)**

| Source | Sum of squares | df | Mean square | F-value | P-value |
|---|---|---|---|---|---|
| Model | 2034.585[a] | 19 | 107.083 | 196.112 | 0.000 |
| Intercept | 36258.450 | 1 | 36258.450 | 66403.566 | 0.000 |
| Duration | 1978.211 | 3 | 659.404 | 1207.629 | 0.000 |
| Clay | 29.822 | 4 | 7.455 | 13.654 | 0.000 |
| Duration & clay | 26.552 | 12 | 2.213 | 4.052 | 0.000 |
| Error | 21.841 | 40 | 0.546 | | |
| Total | 38314.876 | 60 | | | |
| Corrected total | 2056.426 | 59 | | | |

a. $R^2 = 0.989$ (Adjusted $R^2 = 0.984$)

**Table 8: ANOVA analysis of split tensile strength data (N/mm²)**

| Source | Sum of squares | df | Mean square | F-value | P-value |
|---|---|---|---|---|---|
| Model | 50.803[a] | 19 | 2.674 | 136.712 | 0.000 |
| Intercept | 919.790 | 1 | 919.790 | 47028.041 | 0.000 |
| Duration | 49.440 | 3 | 16.480 | 842.605 | 0.000 |
| Clay | 0.692 | 4 | 0.173 | 8.841 | 0.000 |
| Duration & clay | 0.672 | 12 | 0.056 | 2.863 | 0.006 |
| Error | 0.782 | 40 | 0.020 | | |
| Total | 971.376 | 60 | | | |
| Corrected total | 51.586 | 59 | | | |

a. $R^2 = 0.985$ (Adjusted $R^2 = 0.978$)

Furthermore, a correlation analysis between the compressive strength and split tensile strength of concrete cubes and cylinders was performed, and the results are shown in Figure 8. It appears from the results that there is a very good relationship between the compressive strength and split tensile strength of the concrete cubes and cylinders, with a coefficient of determination ($R^2$) of 0.992. The two strength properties – compressive strength and split tensile strength, are positively influenced by the inclusion of kaolin clay polymer and curing duration.

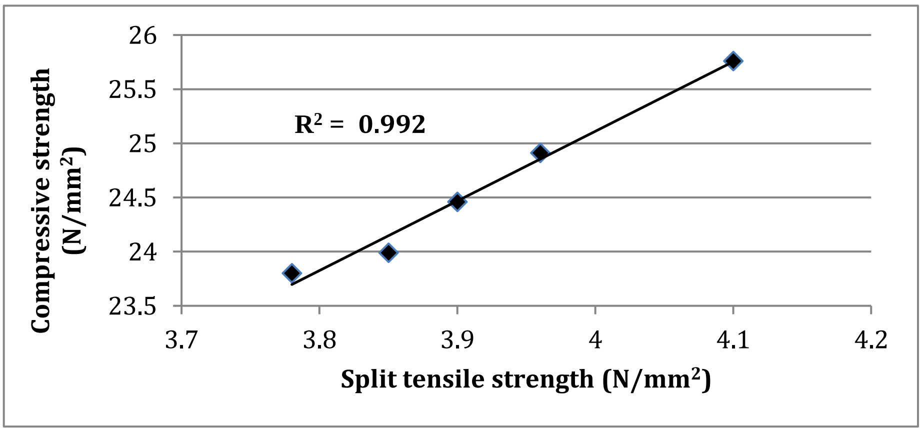


**Fig 8. Relationship between compressive strength and split tensile strength**

### *3.7. Water Absorption and Sulphate Attack*

From the results shown in Figures 9 and 10, the concrete cubes without kaolin clay polymer content experienced more water absorption and sulphate attack than the experimental cubes. It was also noticed that the water absorption and sulphate attack percentage values declined steadily from the control concrete cubes to the 20% kaolin clay polymer content concrete cubes for all curing durations. This gradual reduction in water absorption and sulphate attack as the kaolin clay polymer content increased can be attributed to the high fine percentage, which promoted densification, thus making the cubes less permeable. This trend of decreasing water absorption and sulphate attack with increasing pozzolanic material content and prolonged curing durations has been observed by other researchers. For instance, Ferraro and Nanni (2012), and Sarfo-Ansah et al. (2015) conducted similar studies and found that the rice husk ash pozzolana and calcined clay, respectively, in concrete steadily decreased water absorption and sulphate attack up to the 15% substitution level across all curing durations. They attributed this development to the high fines content of rice husk ash and calcined clay compared to that of cement.

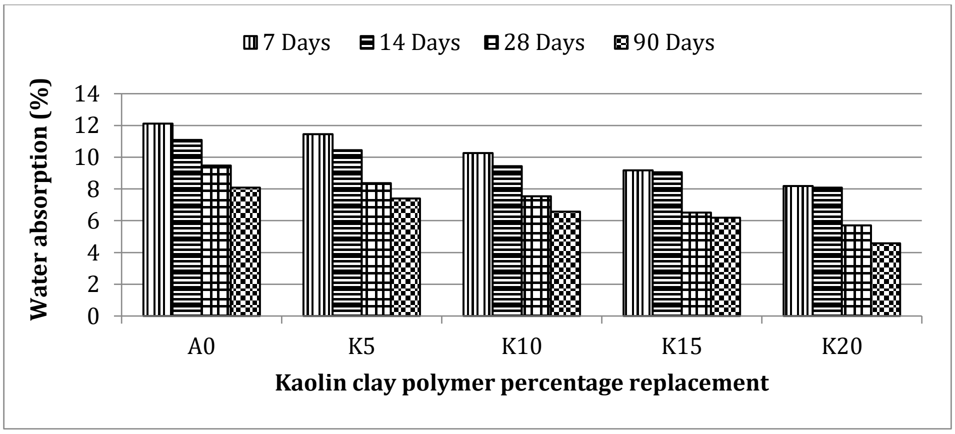


**Fig 9. Variation of water absorption with clay content and curing duration**

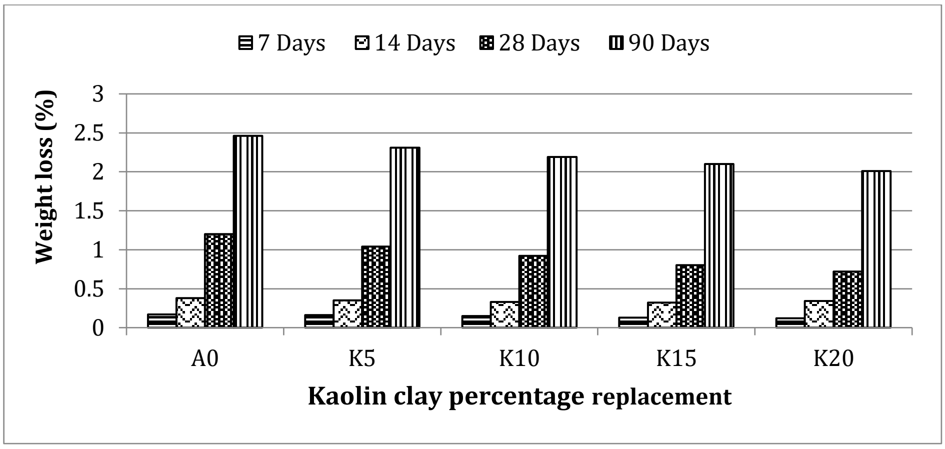


**Fig 10. Variation of sulphate attack with clay content and curing duration**

The analysis of variance (ANOVA) test results shown in Table 9 were generated and analyzed to determine the contributions of the additives and curing duration on the water absorption data. From the results, the curing duration, $F(1,40) = 117.811$, $p < 0.05$, and kaolin clay polymer, $F(1,40) = 60.896$, $p < 0.05$, contributed significantly to the water absorption data. It is also evidenced that the kaolin clay polymer inclusion contributed to the water absorption data a bit less than curing duration. Again, the R-square value of ($R^2 = 0.938$) shows that 93.8% of the variation in the water absorption percentage data can be explained by the model. This suggests that the incorporation of the kaolin clay polymer as partial replacements of cement resulted in a significant reduction in the water absorption percentage at all replacement levels across all curing durations.

**Table 9. ANOVA analysis of water absorption data (%)**

| Source | Sum of squares | df | Mean square | F-value | P-value |
|---|---|---|---|---|---|
| Model | 229.947[a] | 19 | 12.102 | 31.767 | 0.000 |
| Intercept | 4322.259 | 1 | 4322.259 | 11345.307 | 0.000 |
| Duration | 134.649 | 3 | 44.883 | 117.811 | 0.000 |
| Clay | 92.799 | 4 | 23.200 | 60.896 | 0.000 |
| Duration & clay | 2.499 | 12 | 0.208 | 0.547 | 0.870 |
| Error | 15.239 | 40 | 0.381 | | |
| Total | 4567.445 | 60 | | | |
| Corrected total | 245.186 | 59 | | | |

a. $R^2$ = 0.938 (Adjusted $R^2$ = 0.908)

## 4. Conclusions

The brown-loamy kaolin clay polymer possesses similar chemical and pozzolanic reactive characteristics similar to that of the red-loamy. It became more pozzolanic reactive at 800$^oC$ calcination temperature with flow percentage of 110 for the 7 and 28 days tests. Whiles the consistency of the paste experienced steady appreciation, both initial and final setting times equally exhibited progressive delays with further addition of the clay up to 20% content. These values fall within the acceptable range of 30 minutes minimum for initial setting and 600 minutes maximum for final setting. Again, although there was a progressive decrease of slump with further addition of the kaolin clay polymer up to 20% content, the values are less than the recommended 150mm maximum. Both compressive and split tensile strengths increased steadily up to 15% cement substitution, and dropped with further addition of the clay in all curing durations. Further addition of the kaolin clay polymer progressively reduced more of the permeable voids in the concrete composite, probably due to increase in densification resulting arising from high fines content, thereby contributing to lower water absorption and sulphate attack, as observed from the reduction in weight loss up to 20% replacement level.

From the overall outcome of the study, it is evidenced that strength and durability properties of concrete cubes and cylinders were enhanced with the addition of brown-loamy kaolin clay polymer. The delays in setting times could be an advantage for concrete production in hot and windy climates. The lower slump values obtained by kaolin clay polymer content concrete mixes make the concrete suitable for use in situations where high to medium workability are prescribed. Again, the high fines and silica contents in the clay promoted both short and long term strength development. Concrete cubes and cylinders with clay polymer content achieved maximum strength and durability at 15% cement replacement. The authors are of the opinion that the result of this study supports the use of brown-loamy clay in northern Ghana for concrete production. The study therefore, recommends that 15% of kaolin clay polymer from brown-loamy clay variety should be adopted as an optimum content for cement substitution in concrete production in areas where delays in setting times and high to medium workability are required. The utilisation of brown-loamy clay can add up to the red-loamy clay to contribute significantly to construction cost reduction. It will also provide some level of relief to environmental pollution arising from cement production processes.

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