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# PHYSICAL AND MECHANICAL PROPERTIES OF CEMENT MORTAR USING LIME AND BAMBOO-ASH AS PARTIAL REPLACEMENTS

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**Abstract:** The effect of varying different proportion of bamboo ash and lime as partial replacement for cement in mortar were studied. Bamboo stalks were collected and burned into bamboo ash in furnace. The results of the physical and mechanical properties of the cement and aggregate used were within the requirements stipulated by relevant standards. The mix proportion 1:6 was used out of which 2%, 4% of bamboo ash and 2%, 4% of lime were used to partially replace cement in the mortar. The compressive strength of most of the mortar cubes increases with curing days and their values lie within the required strength of 2.5 $N/mm^2$ – 6.5 $N/mm^2$ as stipulated by relevant codes. The water absorption rate was observed to increase with increase in bamboo ash and lime content, while the density decreases as the percentage of bamboo ash and lime in the mortar increases by mass. The study therefore can be concluded that in the presence of significant proportion (i.e. 4% or more) of bamboo ash the strength of mortar increased hence making it adequate for the production of masonry mortar and reduces building failure.

**Keywords:** *Bamboo ash, lime, density, compressive strength, water absorption.*

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## 1.0 Introduction

The properties of building materials dictate their field of application. Strong, durable and efficient buildings and installations may be erected only when the quality, that is, the properties of material that are built, have been correctly evaluated. The properties of building material are generally classified as physical, chemical and mechanical. In many countries, particularly Nigeria, Ordinary Portland cement (OPC) is an expensive and sometimes scarce commodity and this has severely limited the construction of affordable housing. Consequently, alternative cements provide an excellent technical option to OPC at a much lower cost and have the potential to make a significant contribution towards the provision of low-cost building materials and, consequently, affordable shelter (Abdullahi *et al.,* 2013).

Ordinary Portland cement is one of the most important binding materials in terms of quantity produced. Since it is manufactured at very high temperatures, it consumes a lot of energy. Along with huge amounts of energy consumption, it emits harmful gases, which pollute the atmosphere. Apart from energy consumption and emission of harmful gases, calcium hydroxide, a product obtained during the hydration of cement, is a nuisance for construction industry. This affects the durability of Portland cement pastes, mortars and concretes (Dhinakaran *et al.,* 2016).

Pozzolanas are materials containing silica/alumina which on their own have little or no binding property, but when mixed with lime in the presence of water will harden like cement. They are the important ingredient in the production of an alternative cementing material to ordinary Portland cement. The reaction between pozzolanic, lime and water is referred to pozzolanic reaction. The chemical composition of pozzolana varies considerably, depending on the source and the preparation technique. Generally a pozzolana will contain silica, alumina, iron oxide and a variable of oxides and alkali each in vary composition/degree (PATB, 2009).

Bamboo is one of the oldest building materials used by the human kind. It has been widely used for household products and extended to industrial applications due to advances in processing technology and increased market demand (Singh *et al.,* 2007). Bamboo ash is the product of the combustion of bamboo stems (Latin: *Bambusa*) in a furnace, on cooling; the ash is sieved using a 75um sieve to get grains commensurate to that of cement.Mortar is a workable paste used to bind construction blocks together and fill the gaps between them. The blocks may be stone, brick, cinder blocks, etc. Mortar becomes hard when it sets, resulting in a rigid aggregate structure. Modern mortars are typically made from a mixture of sand, a binder such as cement or lime, and water. Mortar can also be used to fix, or point, masonry when the original mortar has washed away. It is widely used in the construction industry. Mortar is used in the moulding of blocks, plastering of houses, concrete biscuits and so on. The materials used in the preparation of mortar include cement, fine aggregate, water, and if necessary admixtures (Ravikumar et al., 2013).

In this study, the use of bamboo ash and lime as a partial replacements in cement mortar will be investigated and is limited to that. The research on this materials will be geared towards documenting its properties especially on its viability as a compliment to cement. If its properties are found adequate for mortar making (plastering) it would be of great value especially as a local material in the construction industry. It will especially help in improving the strength of mortar used in construction and thereby reduce building failure.

### *1.1 Statement of the Problem*

Mortar, an important construction material useful for plastering and masonry unit works could be expensive in production if not given proper consideration. Hence, it is important that engineers and builders acquire basic knowledge on pozzolanic properties especially the behavioural patterns of Bamboo ash in the different percentage replacement with cement and the compressive strength of mortar produced from the partial replacement of bamboo ash and lime in mortar works. This will thereby reduce the cost of some basic constituents of mortar especially that of cement.

## 2.0 Materials and Methods

### *2.1 Materials*

The materials used for this project were ordinary Portland cement, bamboo ash, sand, lime and water. The ordinary Portland cement and lime (CaO) used were bought in Akure. The lime was whitish in colour (Figure 1). The dry bamboo stalks used were gotten from a well grown bamboo tree from a nearby bush and burnt in the furnace of the Metallurgical and Materials Laboratory of the Federal University of Technology Akure. The bamboo ash at the point of collection was greyish white in colour (Figure 2). The sand used was sourced from a sand pit depot in Akure and the grading of the sand was done. Several tools and equipment were used such as hand trowel, shovel, head pans, digital weighing balance, scoop, tampering rod and CBR machine.

Figure 1: Lime sample used

Figure 2: Bamboo ash gotten from the Furnace

Fineness, soundness, flow/workability and setting time tests were carried out on the cement used according to BS 1881-131; 1998; to ascertain its suitability. The brand of the Ordinary Portland cement used was elephant cement. Chemical composition of the cement samples were also determined using atomic absorption spectrometer. The moisture content of the sand used was determine according to BS EN 1097-5:2008 the sieve analysis conducted on the sand satisfied the requirement of ASTM C 136; for sand suitable for use in mortar; and the water used for mixing and curing was obtained from tap water available in the Structures laboratory of Civil and Environmental Engineering Department, Federal University of Technology, Akure.

### *2.2 Production of Mortar*

The mortar was prepared with an addition of lime and bamboo ash in varying proportion.

### *2.3 Fabrication of Mould*

Seven wooden moulds with dimension 180mm × 250mm × 50mm were made; each mould has 12 smaller rectangular units of dimension 50mm × 50mm × 50mm as shown in Figure 3.

Figure 3: Mould used for Mortar

### *2.4 Batching, Mixing, Placing and Curing Operation*

Batching by weight was done with a mix ratio of 1:6 in the presence of bamboo ash and lime partially replacing cement in proportion 2% and 4% each in mortar as shown in Figure 4.

Figure 4: Batching of Mortar

The mixing of cement and sand was done on the tray. The cement and sand were mixed together with 2% and 4% each of the partially replaced bamboo ash and lime or both in the presence of water to make the mortar workable. After mixing the mortar, each mould was filled and compacted in three layers of 25 blows each using a tamping rod as shown in Figure 5 and 6. After filling the moulds with mortar, the cubes were left for 24 hours to ensure it initial setting before curing in water for 7, 14, 21 and 28 days as shown in Figure 7. The density of the mortar and the water absorption rate were also determined in accordance to BS 812 Part 2: 1975. The density and water absorption rate was calculated using equation 1 and 2 respectively.

Figure 5: Compacting the Mortar

Figure 6: Filing the Mould with Mortar

Figure 7: Curing Process

$$\text{Density} = \frac{mass\ of\ concrete\ (kg)}{volume\ of\ the\ concrete} \quad (1)$$

$$\text{Water absorption rate} = \frac{mass\ of\ weight\ concrete - mass\ of\ dry\ concrete}{mass\ of\ dry\ concrete} \times 100 \quad (2)$$

## 2.5 *Testing of Specimens*

The compressive strength of the cubes specimen after curing were determined using the California Bearing Ratio (CBR) machine (a machine naturally use to determine the shear strength of soils) for the crushing of the cubes due to the size of the cubes (50mm × 50mm × 50mm). The test was conducted by placing the cast cubes into the CBR machine with the faces in contact with the flatten end of the machine in accordance to BS EN 12390-3 (2009) as shown in Figure 8 and 9. The machine was loaded, and the reading taken at a point where failure of the specimens occurred. As failure occurs, the crushing strength was read off the gauge incorporated into the machine. Due to the CBR machine used the results gotten from the gauge were multiplied by a factor of 23.8 N/div so as to get the actual load in Newton (N) that crushed the cubes. Then the average compressive strength was determined using equation 3.

$$\text{Compressive strength} = \frac{load\ applied}{cross\ sectional}\ (\text{N/mm}^2) \quad (3)$$

Figure 8: Cube to be crushed

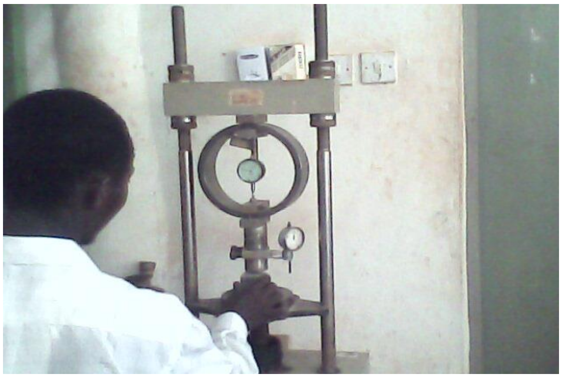

Figure 9: Placing the cube into the CBR machine for crushing

## 3.0 Results and Discussion

The summary result of the tests on the normal consistency, fineness, soundness, setting time and workability of the cement is presented in Table 1. Also, Tables 2 and 3 show the results obtained from the chemical analysis of cement and bamboo ash with the aid of atomic absorption spectrometer and also the constituent elements in part per million (ppm) concentrations present in cement and bamboo ash (the percentage of the oxides of the elements present in the cement and bamboo ash were also highlighted).

The results indicated that the cement would likely require more water to obtain consistence value of 37.5%. This value agrees with the corresponding fineness value gotten. Since fineness is a measure of surface area, material with higher surface area would be expected to take more water during hydration process and react faster. The fineness of the cement is 13% (i.e. 13% of the material was retained on 90μm sieve). The value of fineness is high as a result of increase in the rate at which cement hydrates which thus accelerates strength development.

As for the soundness, the result suggested that the cement is sound as it had a minimal expansion during thermal curing and did not exceed 10 mm which could be said to have met the standard. Furthermore, the value of the initial setting times of the cement, shown in Table 1 falls in the range of 82 and 325 minutes for initial and final setting times.

Table 1: Physical Properties of the Cement Used

| *Properties* | *Values gotten for Cement* |
|---|---|
| Normal Consistency Test (%) | 37.5 |
| Fineness Test | 13.0 |
| Soundness Test (mm) | 2.0 |
| Setting Times | |
| Initial | 82.0 |
| Final | 325.0 |

Table 2: Constituent Elements Present in Cement and Bamboo Ash

| | *Atomic absorption spectrometer readings* | | |
|---|---|---|---|
| *Elements* | *Standard Reading* | *Bamboo ash* | *cement* |
| Iron (Fe) | 113.0 | 31.3 | 19.9 |
| Copper (Cu) | 114.5 | 0.6 | 0.2 |
| Lead (Pb) | 80.6 | 0.4 | 0.1 |
| Silicon (Si) | 60.5 | 0.2 | 3.4 |
| Aluminium (Al) | 70.1 | 0.2 | 0.5 |
| Magnesium (Mg) | 151.1 | 126.7 | 70.1 |
| Potassium (K) | 140.5 | 119.3 | 55.7 |
| Calcium (Ca) | 135.6 | 130.3 | 90.5 |
| Zinc (Zn) | 90.7 | 5.7 | 1.1 |
| Sodium (Na) | 130.4 | 125.1 | 40.6 |
| Nickel (Ni) | 55.9 | 0.3 | - |
| Cadmium (Cd) | 60.6 | - | - |
| Manganese (Mn) | 110.2 | 2.9 | 0.3 |
| Cobalt (Co) | 40.1 | - | - |
| Silver (Ag) | 50.3 | - | - |
| Arsenic (As) | 35.9 | 0.1 | - |
| Selenium (Se) | 61.5 | 1.4 | 0.3 |

Table 3: Ppm Conc. and Percentage Oxides of Constituent Elements Present in Cement and Bamboo Ash

| | *Bamboo Ash* | | *Cement* | |
|---|---|---|---|---|
| *Elements* | *Ppm Conc.* | *% Oxide* | *Ppm Conc.* | *% Oxide* |
| Iron (Fe) | 230.8 | 0.014 | 146.7 | 0.009 |
| Copper (Cu) | 4.33 | 0.0003 | 1.5 | 0.0001 |
| Lead (Pb) | 4.17 | 0.0002 | 1 | 0.00005 |
| Silicon (Si) | 2.5 | 0.0004 | 46.7 | 0.008 |
| Aluminium (Al) | 2.42 | 0.0003 | 5.92 | 0.0006 |
| Magnesium (Mg) | 699.2 | 0.17 | 386.7 | 0.1 |
| Potassium (K) | 707.5 | 0.08 | 330 | 0.035 |
| Calcium (Ca) | 800.8 | 0.14 | 555.8 | 0.1 |
| Zinc (Zn) | 799.2 | 0.13 | 259.2 | 0.042 |
| Sodium (Na) | 52.4 | 0.0064 | 10 | 0.0012 |
| Nickel (Ni) | 4.5 | 0.0006 | - | - |
| Cadmium (Cd) | - | - | - | - |
| Manganese (Mn) | 21.67 | 0.003 | 2.25 | 0.0003 |
| Cobalt (Co) | - | - | - | - |
| Silver (Ag) | - | - | - | - |
| Arsenic (As) | 2.3 | 0.0003 | - | - |
| Selenium (Se) | 19.2 | 0.002 | 4.2 | 0.0004 |

As it can be seen in the Tables 2 and 3 above that calcium, magnesium, zinc and potassium were identified as the most common elements present in both cement and bamboo ash. While lead and arsenic are the least common. The percentage oxides present are also analysed. It was observed that if bamboo ash could undergo the same refining process as Ordinary Portland cement, it could turn out to be a better binder also. The results of the moisture content and specific gravity performed on the fine aggregate (sand) give 0.94 and 2.54 respectively. The graph of the particle size distribution result presented in Table 4 is shown in Figure 1.

Table 4: Particle Size Distribution Result for Fine Aggregate Used.

| *Sieve No (mm)* | *Mass retained (g)* | *Percentage retained%* | *Percentage passing %* |
|---|---|---|---|
| 4.25 | 1.8 | 0.36 | 99.64 |
| 2.36 | 1.5 | 0.3 | 99.34 |
| 1.70 | 0.8 | 0.16 | 99.18 |
| 1.18 | 6.0 | 1.2 | 97.98 |
| 0.600 | 56.0 | 11.2 | 86.78 |
| 0.500 | 78.4 | 15.68 | 71.1 |
| 0.425 | 7.1 | 1.42 | 69.68 |
| 0.212 | 145.9 | 29.18 | 40.50 |
| 0.150 | 53.0 | 10.6 | 29.90 |
| 0.075 | 6.0 | 1.2 | 28.70 |
| Pan | 143.5 | 28.7 | 0 |

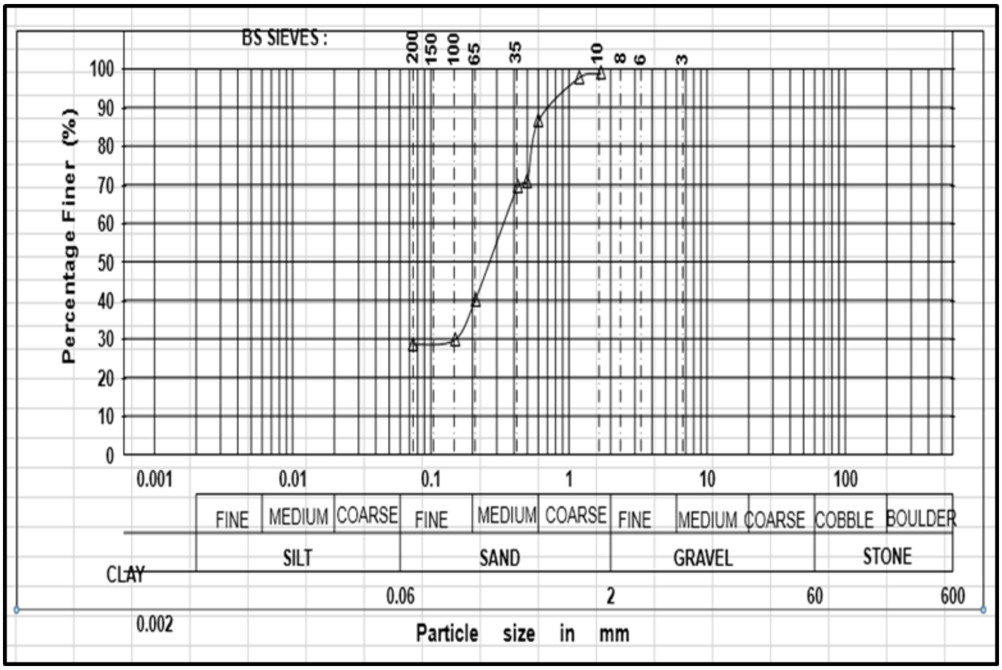


Figure 10: Particle Size Distribution Graph

From Figure 10, the sand was observed to be well-graded and it falls in the fine-coarse sand region of the graph paper.

### 3.1 Density

The density of the varying mix ratios of lime, bamboo ash and cement for different samples was gotten. Figure 11 shows the density for control sample which is Sample A (with lime 0%, bamboo ash 0%, cement 100%). It has the highest average density of 2.39 g/cm$^3$ and gradually reduces until it gets to Sample F where there was a slight increase and later decreases. The percentage replacements of cement with lime and bamboo ash used are shown in Table 5.

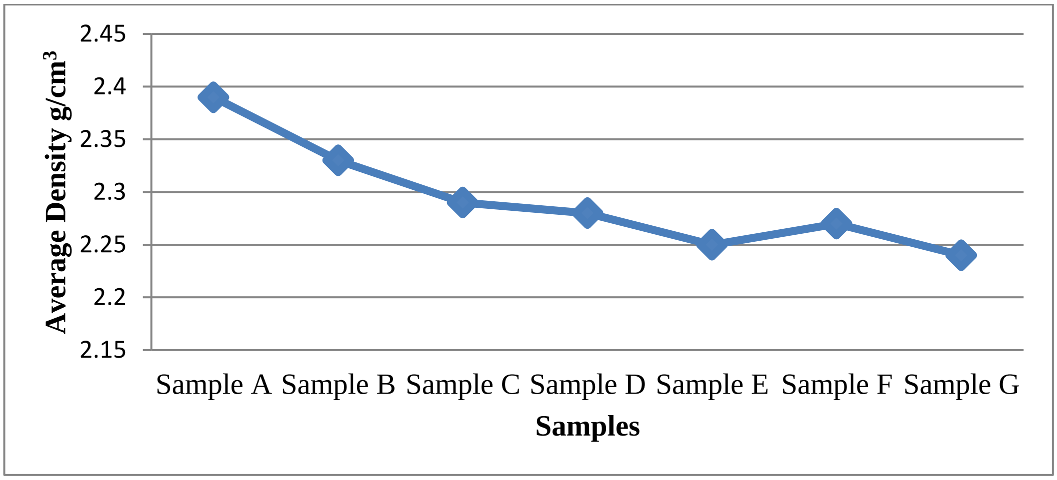


Figure 11: Average density at varying mix ratios of lime, bamboo ash and cement

Table 5: Percentage replacement of cement with lime and bamboo ash

| *Sample Label* | *Lime %* | *Bamboo ash %* | *Cement %* | *Lime (g)* | *Bamboo ash (g)* | *Cement (g)* | *No. Of cubes* |
|---|---|---|---|---|---|---|---|
| Sample A | 0 | 0 | 100 | - | - | 495 | 12 |
| Sample B | 0 | 2 | 98 | - | 10 | 485.1 | 12 |
| Sample C | 0 | 4 | 96 | - | 19.8 | 475.2 | 12 |
| Sample D | 2 | 0 | 98 | 10 | - | 485.1 | 12 |
| Sample E | 4 | 0 | 96 | 19.8 | - | 475.2 | 12 |
| Sample F | 2 | 2 | 96 | 10 | 10 | 475.2 | 12 |
| Sample G | 2 | 4 | 94 | 10 | 19.8 | 465.3 | 12 |
| | | | | 49.8 | 59.6 | 3356.1 | 84 |

### *3.2 Water absorption capacity*

The Water absorption capacity results obtained for the mortar cubes of samples A to G is shown in Table 6. Figure 3 also shows the average water absorbed by the various samples at varying curing days.

Table 6: Water Absorption Capacity of Cubes of Various Samples at Varying Curing Days (in g)

| *Age* | *Sample A* | *Sample B* | *Sample C* | *Sample D* | *Sample E* | *Sample F* | *Sample G* |
|---|---|---|---|---|---|---|---|
| 7 | 16 | 14.67 | 12 | 12 | 11.3 | 16.67 | 13 |
| 14 | 13.67 | 9.3 | 15 | 12.67 | 13 | 13 | 12.3 |
| 21 | 14.67 | 14.67 | 14.67 | 10.67 | 12 | 13 | 12.3 |
| 28 | 16 | 11 | 13.3 | 10 | 10 | 14.67 | 12.3 |

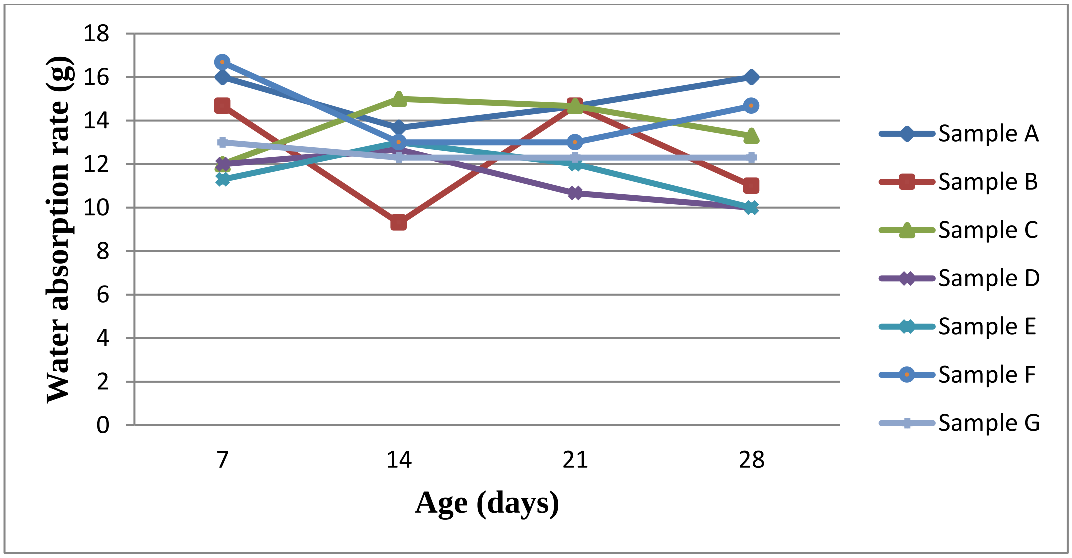


Figure 12: Water Absorption Capacity against all Samples at varying Curing Days

Figure 12 shows that the rates of water absorption in the samples are different. In sample A, after 14 days the rate of water absorbed dropped sharply and later increases after 21 and 28 days; this could be due to the variation in the voids of the cube. The rate of water absorbed in sample G after 14 days also dropped but remain steady for the rest number of days. The rate of water absorbed by the cubes had effect on their compressive strength by increasing it.

## *3.3 Compressive Strength*

The results obtained for the compressive strength of cubes crushed after 7 days to 28 days of curing were computed. Table 7 and Figure 13 show the mean compressive strength of all the crushed cubes samples and its graphical representation respectively.

Table 7: Compressive Strength of Cubes of Various Samples at Varying Curing Days

| *Age* | *Sample A N/mm²* | *Sample B N/mm²* | *Sample C N/mm²* | *Sample D N/mm²* | *Sample E N/mm²* | *Sample F N/mm²* | *Sample G N/mm²* |
|---|---|---|---|---|---|---|---|
| 7 | 3.87 | 3.03 | 3.08 | 2.89 | 4.03 | 2.82 | 3.71 |
| 14 | 5.08 | 3.68 | 1.84 | 3.87 | 4.13 | 6.06 | 4.60 |
| 21 | 5.65 | 4.24 | 3.78 | 5.05 | 4.81 | 3.33 | 5.24 |
| 28 | 5.89 | 3.16 | 4.00 | 5.49 | 4.95 | 3.68 | 4.93 |

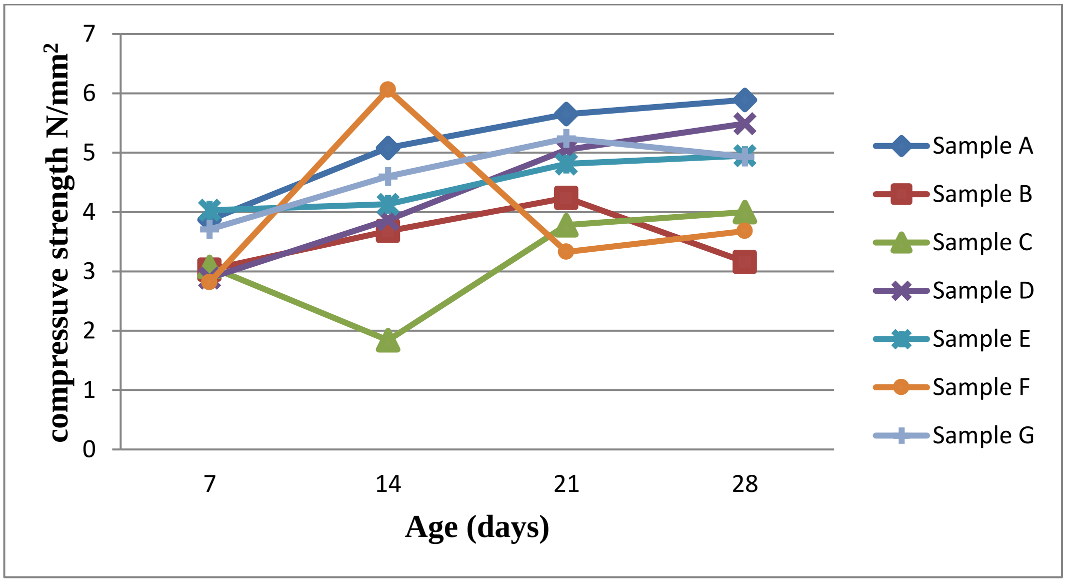


Figure 13: Compressive Strength against all Samples at varying Curing Days

From Figure 13, Sample A which was the control sample showed a steady rise in compressive strength from 7 days to 28 days attaining strength of 5.89 N/mm$^2$; Sample B and Sample G also showed a steady rise in compressive strength up to 21 days before losing strength after 28 days to attain a total strength of 3.16 N/mm$^2$ and 4.93 N/mm$^2$ respectively. Sample C and Sample F had a sharp drop and rise in compressive strength after 14 days respectively but increased steadily afterwards. Sample D and Sample E also had a steady rise in compressive strength to attain the strength of 5.49 N/mm$^2$ and 4.95 N/mm$^2$, respectively.

Generally, it was observed that with increase in the percentage of bamboo ash in the mix from 2% to 4% the final strength after 28 days increased from 3.16 N/mm$^2$ to 4 N/mm$^2$ for samples B and C and also as the percentage of lime increased from 2% to 4% in the mix the final strength after 28 days gradually reduced from 5.49 N/mm$^2$ to 4.95 N/mm$^2$

for samples D and E. This has shown that compressive strength of mortar increased with an increase in bamboo ash content and decreased with increased lime content. From BS EN 1052-1:1999, the standard strength of mortar for 1:4 to 1: 6 is between 2.5 N/mm$^2$ – 6.5 N/mm$^2$. For all the samples their final strength lies between 3.16 N/mm$^2$ – 5.89 N/mm$^2$, which signifies that all the mix ratios are still safe to use.

## 4.0 Conclusions

The physical and mechanical properties of Lime – Bamboo ash – Cement Mortar as partial replacements of mix ratio 1:6 and water – cement ratio of 90% has been carried out. It was found from the particle size distribution of the fine aggregate results that it falls within the fine-coarse region of the graph. In addition, the study has shown that Bamboo ash as a partial replacement for cement has shown significant effect on the strength of the mortar. Finally, it was discovered that as lime is increasing, there is a significant reduction in the strength of the mortar but in the presence of significant proportion of bamboo ash the strength of mortar increased.

## 5.0 Recommendation

More research work should be carried out on the potential of bamboo ash with the aim of knowing the extent to which bamboo ash in the presence of lime can replace cement in mortar works.

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