PROPERTIES OF BANANA FIBRE REINFORCED FLY ASH CONCRETE

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Abstract—This study investigates the effects of partially replacing cement with fly ash on some properties of banana fibre reinforced concrete. Grade 25 concrete specimens incorporating 0, 10, 20, 30 and 40% fly ash were reinforced with 0.5% volume fraction of 30mm long banana fibres. The compressive strength, flexural strength and splitting tensile strengths were determined at 7, 28, and 90 days. The pHs and water absorptions of the specimens were also determined at 28 and 90 days of curing. At 90 days curing age specimens with 10% partial replacement of cement with fly ash achieved the highest compressive strength of 34.57 N/mm² while the control specimen achieved a compressive strength of 32.20 N/mm². Reinforcement of concrete with 0.5% volume fraction of banana fibre improved the flexural and splitting tensile strengths of concrete by 25.00 and 19.29% at 28 days and 25.5% and 18.24% at 90 days curing periods respectively. Partial replacement of cement with fly ash resulted in lower flexural strengths at early curing ages but the strengths recovered at 90 days curing age. Banana fibre reinforced specimens with 10 and 20% replacements of cement with fly ash achieved higher flexural strengths than plain concrete at 90 days. The mix with 10% replacement of cement with fly ash achieved 19.29 and 18.24% increase in splitting tensile strength at 28 and 90 days of curing respectively compared to plain concrete. Partial replacement of cement with fly ash resulted to significant reduction of the pH of the concrete specimens, which is beneficial for the durability of banana fibre in concrete matrix. Partial replacement of cement with fly ash also improved the water absorption of banana fibre reinforced concrete. This Study recommends that cement should be partially replaced with maximum of 20% fly in banana fibre reinforced fly ash concrete in order to improve the durability of banana fibres without undermign the mechanical properties of the concrete.

Keywords—compressive strength, flexural strength, splitting tensile, water absorption, banana fibre, fly ash, concrete

I. INTRODUCTION

Fibre is a small piece of reinforcing material possessing certain characteristic properties and it could be circular, triangular or flat in cross-section [1]. Fibres used for reinforcement purposes include fine chopped steel, polypropylene, nylon, Glass and Cellulose (natural fibres). Fibre has been used to reinforce building materials for thousands of years. For instance, Chaunhan and Chaunhan [2] reported that mankind has used natural fibres for centuries for various applications in order to meet the basic requirements of shelter, food and cloths. Today synthetic or natural fibres are being added to concrete mix to improve its properties irrespective of whether it will be reinforced with traditional steel reinforcement or not.

Fibres are broadly classified into man-made and natural fibres. Man-made fibres are made from synthetic materials like steel and natural polymers while natural fibres originate from vegetable, animal and mineral sources. Presently, the use of natural fibres in composites is preferred over man-made fibres due to their numerous advantages, which include light weight, high strength to weight ratio, corrosion resistance and other advantages such as biodegradability, low cost and wide spread availability [3]. According to Rawi and khafagy [4] many investigations have already been carried out on various mechanical properties and physical performance of concrete materials using natural fibres from coconut husk, sisal, hemp, sugar cane bagasse, bamboo, jute, wood and other vegetable fibres and these investigations showed encouraging commercial prospects of these new materials for application in low cost housing construction.
Banana a fibrous material with high content of fibre, which is abundantly available in Nigeria, could be used as reinforcing material in concrete. Banana fibre, a ligno-cellulose fibre, obtained from pseudo-stem of banana plant (musa spp.) is a bast fibre with relatively good mechanical properties [5]. Awward, Mabsout, Hamad and Khatib [6] showed that the introduction of banana fibres in concrete produced acceptable result. However, the performance of natural fibres in concrete matrix has some deficiencies. These deficiencies are related to degradation of the fibres by the alkaline cement paste environment and increase of fibre dimensions related to variations of humidity [7]. Banana fibre being a natural fibre is likely to degrade in an alkaline environment of concrete just like other plant fibres. To improve the durability of natural fibre reinforced concrete, two main approaches may be adopted. The first approach involves improving the durability of natural fibre using water-repellant agents or fibre impregnation with sodium silicate, sodium sulphite or magnesium sulphate [8]. The second approach involves improving the durability of vegetable fibre in concrete by modification of the concrete matrix. This involves reducing the alkalinity of the composite by adding pozzolanic by-products such as rice husk ash, blast furnace slag, or fly ash to ordinary Portland cement (OPC).

Gram [9] performed tensile tests on fibres subjected to a concentrated solution of calcium hydroxide and found that the tensile strength was substantially reduced. He also found that in carbonated concrete with a pH of less than 9, fibres preserved their flexibility and strength, but in non-carbonated zones, the fibres were fragile. The work recommended the reduction of water-cement ratio and the use of high content of silica fume as a solution. Silica fume was observed to be highly reactive and reduces alkalinity of the cement paste down to a pH of 9-10. However, Juarez, Duran, Valdez and Fajardo [10] observed that silica fume is expensive and the reduced alkalinity can pose a corrosion problem for the steel reinforcement. As a result of the observed deficiency of silica fume, obtaining a denser matrix by reducing the water cementitious ratio and adding fly ash (pozzolanas) which is cheaper and less reactive compared with silica fume was recommended. The addition of fly ash to cementitious composite results in a denser matrix while maintaining its alkalinity. Fly ash also reduces the cement requirement for the same concrete strength thereby saving the raw materials such as limestone and coal required for cement manufacture. Less requirement of cement means less emission of carbon dioxide as a result of cement manufacture and reduction in green house gas emission. It results also to saving in the cost of concrete.

Fly ash is presently available in Nigeria as waste product of electricity generation plant in Oji River, Enugu State, Nigeria. This material could be utilized in natural fibre reinforced concrete to improve the durability of the composite and also reduce the cost of concrete and in turn housing production in Nigeria. This study therefore investigates the mechanical properties of banana fibre reinforced concrete when cement is partially replaced with fly ash.

II. EXPERIMENTAL DETAILS

The banana fibres were extracted from the stems of harvested banana plants sourced from farms in Tayu, Sanga Local Government area of Kaduna State Nigeria. “Dangote” brand of 42.5 grade ordinary Portland cement conforming to [11] was used. Standard consistency, initial and final setting time, bulk density and specific gravity were carried out to determine the physical properties of this cement and the results tabulated in Table 1. The fly ash used was sourced from the waste dump of Oji River thermal power station in Enugu State Nigeria. The physical properties and chemical composition of the fly ash were determined in accordance with [12]. The chemical analysis of the sample was carried out at National Metrological Development Centre (NMDC) Jos, Plateau State, Nigeria using Energy Dispersive X-ray Fluorescence Spectrometer (EDXRF). The apparent specific gravity of the fly ash was 2.24, which was less than that obtained for cement. The loose bulk density and cocompacted bulk density of the fly ash were 1300 and 1418 kg/m³ respectively. The chemical composition of the fly ash is presented in Table 2. The result shows that the combined SiO₂, Al₂O₃ and Fe₂O₃ was 90.24% greater than the minimum of 70.00% specified in [12], as such it could be classified as class ‘F’ pozzolana.
The sand used was clean river sand sourced from Gumo in Toro Local Government area of Bauchi State Nigeria. The sieve analysis result shows that the sand fall under zone II as stipulated in [13]. The fineness modulus, specific gravity and water absorption of the fine aggregate were 4.87, 2.62 and 0.72 respectively. The coarse aggregate was sourced from a Satzen quarry Mista Ali, Jos Plateau State, Nigeria. The nominal size of coarse aggregate used in this study was 10mm. The properties of the coarse aggregate were determined by conducting tests in accordance with the provisions of [14]. The specific gravity and water absorption of the coarse aggregate were 2.54 and 0.65 respectively. Clean tap water conforming to recommendation of [15] was used. Conplast SP430 (G), superplasticizer that complies with [16] was used for the study. Banana fibres used in this study were extracted from the stems of harvested banana plants sourced from farms in Tayu, Sanga Local Government area of Kaduna State Nigeria. The specie of banana used in this study was *musa acuminate* (Modern banana). The fibres were extracted by water retting method. Mature banana pseudo-stem obtained from farm were cut to lengths of about 600mm and were totally submerged in clean water fit for drinking for a period of six weeks, after which the stems were removed from the water, loosened and washed in a tank of clean water. The fibres were subsequently sun dried and further loosened by manual combing. This process allows for biodegradation of the banana pseudo-stems that separates the fibres from the pith. The extracted fibres were later chopped to lengths of 30mm ready for the experiments. The properties of banana fibre used in this study were determined and presented in Table 3.

Fly ash concrete of grade 25 was designed according to the specifications of [17] mix design method (British method). Fly ash was used to replace cement at various levels of 0%, 10%, 20%, 30% and 40% by mass of binder. Banana fibres of 30mm length and volume fraction of 0.5% were used in all mixes being the optimum values obtained by Anowai and Job [18] for grade 25 concrete. The mix proportions of different mixes of banana fibre reinforced fly ash concrete are presented in Table 4.

| Parameter                  | Recorded Value | BS 12 Requirement          |
|----------------------------|----------------|---------------------------|
| Initial Setting Time       | 78 minutes     | Minimum of 45 minutes     |
| Final Setting Time         | 306 minutes    | Maximum of 600 minutes    |
| Compacted Bulk density     | 1440           |                           |
| Uncompacted Bulk density   | 1270           |                           |
| Specific Gravity           | 3.15           |                           |
| Standard Consistency       | 31%            | 26%-33%                   |
### Table 2. Chemical Composition of Fly Ash

| Chemical Analysis                     | Class F Fly Ash (%) | ASTM Requirement C 618 (%) |
|---------------------------------------|---------------------|---------------------------|
| Silicon dioxide, SiO₂                 | 57.10               | -                         |
| Aluminium Oxide, Al₂O₃                | 24                  | -                         |
| Ferric Oxide, Fe₂O₃                   | 9.14                | -                         |
| SiO₂ + Al₂O₃ + Fe₂O₃                  | 90.24               | 70.00 minimum             |
| Magnesium Oxide, MgO                  | 0.40                | 5.0 maximum               |
| Vanadium Oxide, V₂O₅                  | 0.15                | -                         |
| Sodium Oxide, Na₂O                    | 0.18                | 1.5 maximum               |
| Potassium Oxide, K₂O                  | 1.23                | -                         |
| Titanium Oxide, TiO₂                  | 3.83                | -                         |
| Sulphur Trioxide, SO₃                 | 2.30                | 5.0 maximum               |
| Chromium Oxide, Cr₂O₃                 | 0.064               | -                         |
| Manganese Oxide, MnO                  | 0.073               | -                         |
| Nickel Oxide, NiO                     | 0.025               | -                         |
| Copper Oxide, CuO                     | 0.11                | -                         |
| Zinc Oxide, ZnO                       | 0.078               | -                         |
| Rubidium Oxide, Rb₂O                  | 0.013               | -                         |
| Strontium Oxide, SrO                  | 0.052               | -                         |
| Yttrium Oxide, Y₂O₃                   | 0.039               | -                         |
| Zirconium dioxide, ZrO₂               | 0.25                | -                         |
| Ruthenium dioxide, RuO₂               | 0.46                | -                         |
| Osmium Oxide, OsO₄                    | 0.009               | -                         |
| Rhenium Oxide, Re₂O₇                  | 0.02                | -                         |
| Lead Oxide, PbO Na₂O₅                 | 0.042               | -                         |
| Loss on Ignition                      | 2.71                | 3.0 maximum               |

### Table 3. Physical, Mechanical and Chemical Properties of Banana Fibre

| Properties                          | Value               |
|-------------------------------------|---------------------|
| Diameter (mm)                       | 14.00 – 26.00       |
| Density (g/cm³)                     | 0.86 – 1.12         |
| Water Absorption                    | 0.41                |
| Tensile Strength (Mpa)              | 385.00 – 655.00     |
| Young’s Modulus (Gpa)               | 24.50 – 36.00       |
| Elongation at break (%)             | 1.80 – 2.60         |
| Cellulose (%)                       | 55.00 – 64.00       |
| Hemicellulose (%)                   | 12.50 – 18.50       |
| Lignin (%)                          | 8.60 – 10.50        |
III. DISCUSSION OF RESULTS

3.1 Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete

The results of the compressive strength of concrete mixtures are presented in Figure 1. The result shows that there are small reductions in compressive strengths of concrete as a result of inclusion of banana fibres. However, there was no record of deterioration as strength increased with age of curing. The compressive strength reduction could be attributed to increasing amount of entrapped air voids due to the presence of fibre, which occurred as a result of difficulty in compaction of fibres reinforced concrete [4]. Nwankwo [22] also reported reduction in compressive strength in a ternary cementitious matrix reinforced with sisal fibre. Figure 1 further shows that Banana fibre reinforced fly ash concrete achieved a slight increase in compressive strength at 90 days of curing due to pozzolanic reactivity of fly ash, which reacts with calcium hydroxide produced in the process of hydration of cement. The pozzolanic reaction produces additional gel, which reduces the amount of voids in the matrix. It was observed that at 90 days of curing, compressive strength (34.57N/mm²) of the mixture with 10% fly ash surpassed that of the control. Specimen containing 10% replacement of cement with fly ash recorded increase in compressive strength of 4.33 and 8.71% over the control specimen at 28 and 90 days of curing respectively. Rewi and Khafagy [4] obtained similar results for sisal fibre reinforced Iraqi bauxite concrete.

![Figure 1. Compressive Strength Development of Banana Fibres Reinforced Concrete with Varying Fly Ash Content](image-url)
3.2 Flexural Strength Test Results

It was physically observed during testing that the plain concrete failed suddenly without warning while banana fibre reinforced concrete specimens (with and without fly ash) failed in ductile manner giving ample warning. The results of the flexural strength of concrete mixtures are presented in Figure 2. The flexural strength results indicates that the specimen containing 0.5% volume fraction of banana fibre and 0% fly ash achieved flexural strengths of 6.5 and 6.9N/mm² at curing ages of 28 and 90 days respectively as against 5.0 and 5.5N/mm² achieved by plain concrete at 28 and 90 days curing ages respectively. This implies that reinforcement of concrete 0.5% volume fraction of banana fibre improved the flexural strength of concrete by 25.0 and 25.5% for 28 days and 90 days of curing respectively over that of the control specimen. The result also shows that replacement of cement with fly ash resulted in lower flexural strength at early curing ages but the strength recovered at 90 days of curing age. Specimens with 10 and 20% replacement of cement with fly ash achieved higher flexural strength than plain concrete at 90 days. It was also observed that at 30 and 40% replacement of cement with fly ash, the flexural strengths were lower than that of plain concrete for all ages of curing. Mohan, Jyabalan and Rajarama [23] showed that the replacement of cement with 25 and 30% fly ash reduced flexural strength of coconut fibre reinforced concrete by 3.80 and 28.2% respectively. Rama, Sadarsana and Sekar [24] also showed that flexural strength of glass fibre reinforced fly ash concrete was reduced with increase in percentage replacement of cement with fly ash. It then follows that high percentage replacement of cement with fly ash adversely affects the flexural strength of banana fibre reinforced concrete.

![Figure 2. Flexural Strength Development of Banana Fibres Reinforced Concrete with Varying Fly Ash Content](image-url)
3.3 Splitting Tensile Strength of Banana Fibre Reinforced Fly Ash Concrete

The results of the splitting tensile strength of the tested concrete specimens are presented in Figure 3. The mix with 10% replacement of cement with fly ash achieved the maximum value of splitting tensile strength of 3.34 and 3.50 N/mm\(^2\) corresponding to 28 and 90 days of curing respectively. This gave 19.29 and 18.24% increase in splitting tensile strength at 28 and 90 days of curing respectively over that of the control plain concrete of the same age. Specimen containing 20% partial replacement of cement with fly ash recorded a slight reduction in splitting tensile strength at 28 days of curing but surpassed that of the control by 9.12% after curing for 90 days. 30 and 40% replacement of cement with fly ash resulted in reduction of splitting tensile strength at all ages of curing. This development agrees with the findings of [22], which showed that the replacement of 20, 25 and 30% of cement with fly ash resulted to the reduction of the splitting tensile strength of coconut fibre reinforced concrete by 18.57, 22.14 and 50% respectively. Siddique and Kadri [25] also showed that increase in percentage replacement of cement with fly ash resulted in reduction of splitting tensile strength of concrete. However, the splitting tensile strength of banana fibre reinforced fly ash concrete increased as curing age increased due to pozzolanic action of fly ash which resulted to more densification of the concrete and development of more effective bond between the banana fibres and concrete. Study by [25] showed the same trend.

![Figure 3. Splitting Tensile Strength Development of Banana Fibres Reinforced Concrete with Varying Fly Ash Content](image)

3.4 Effect of Fly Ash on The Ph of Banana Fibre Reinforced Concrete

The results of pH of Banana fibre reinforced fly ash concrete specimens are presented in Table 5. The results showed that the partial replacement of cement with fly ash by weight resulted to a reduction in the concentration of OH\(^-\) ions, which subsequently led to significant reduction of the pH of the concrete specimens tested. 0%, 10%, 20%, 30% and 40% partial replacement of cement with fly ash resulted to concretes with pH of 12.20, 11.40, 11.40, 11.50 and 11.50 respectively after curing for 90 days. It is expected that further reduction in pH will be recorded with increase in curing age. These results follow the same trend as that obtained by [4], which showed that partial...
replacement of cement with bauxite (pozzolana) at various percentages of replacement of 10%, 20% and 30% resulted to significant reduction of pH values of the concrete. Gram [9] also found that the alkalinity of cement matrices are reduced by partially replacing ordinary Portland cement (OPC) with silica fume, fly ash or completely replacing OPC by high alumina cement.

Table 5. The pH-Level of banana Fibre Reinforced Fly Ash Concrete

| Mix | pH-Level | Curing Age (Days) |
|-----|----------|------------------|
|     |          | 28               | 90               |
| C0  | 12.30    | 12.20            |
| F10 | 12.10    | 11.40            |
| F20 | 12.10    | 11.40            |
| F30 | 11.90    | 11.50            |
| F40 | 11.90    | 11.50            |

3.5 Water Absorption of Banana Fibre Reinforced Fly Ash Concrete

The water absorption test results for all the specimens with and without fly ash are presented Figure 4. It is observed that banana fibre reinforced concrete without fly ash absorbs more water than plane concrete. The introduction of 0.5% volume fraction of banana fibre into the concrete resulted to water absorption of 6.77 % while the water absorption of the control concrete is 5.61% at 28 days. Similarly, [4] found that water absorption of concrete reinforced with 0.5% volume fraction of sisal fibre increased by 16%. This could be as a result of high water absorption of vegetable fibres. However it can be observed that the partial replacement of cement with fly ash resulted in the reduction of water absorption of concrete reinforced by 0.5% banana fibre. Partial replacement of cement with 10%, 20%, 30% and 40% resulted to water absorption of 5.81, 6.55, 7.10 and 7.29% respectively at 28 days. Control specimen recorded water absorption of 6.25% at 90 days while banana fibre reinforced specimens with 10, 20, 30 and 40% partial replacement of cement with fly ash recorded water absorption of 5.52, 4.26, 4.87, 5.86 and 6.12 repectively at 90 days. This development is attributable to increase in density due to the pozzolanic effect of fly ash. Partial replacement of cement with 10% fly ash produced the best result in terms of water absorption of banana fibre reinforced concrete. These results agree with the assertion of [25] which states that partial replacement of cement with pozzolanas result to composites with lower water absorption when compared with composites without pozzolanas. This implies that partial replacement of cement with fly ash has a beneficial effect in banana fibre reinforced concrete with respect to water absorption.

Figure 4. Variations in Water Absorption of Banana Fibre Reinforced Fly Ash Concrete at Different curing Ages
IV. CONCLUSIONS

Based on the experimental results obtained, the following conclusions were drawn;

1. Inclusion of banana fibres into concrete reduced the compressive strength slightly at early age of curing, however at 90 days of curing increase in compressive strength was noticed which was due to the pozzolanic reactivity of fly ash. It was also concluded that specimen containing 10% replacement of cement with fly ash recorded increase in compressive strength of 4.33 and 8.71% over the control specimen at 28 and 90 days of curing respectively.

2. The results show that replacement of cement with fly ash resulted in lower flexural strength at early curing ages but the strength recovered at 90 days of curing age. Specimens with 10 and 20% replacement of cement with fly ash achieved higher flexural strength than the plain concrete.

3. The mix with 10% replacement of cement with fly ash achieved the maximum value of splitting tensile strength of 3.34 and 3.50 N/mm² corresponding to 28 and 90 days of curing periods respectively. This gave 19.29 and 18.24% increase in splitting tensile strength at 28 and 90 days of curing respectively over that of the control plain concrete of the same age. Specimen containing 20% partial replacement of cement with fly ash recorded a slight reduction in splitting tensile strength at 28 days of curing but surpassed that of the control by 9.12% after curing for 90 days.

4. Partial replacement of cement with fly ash by weight resulted to a reduction in the concentration of OH⁻ ions and led to significant reduction of the pH of the concrete specimens tested. 0%, 10%, 20%, 30% and 40% partial replacement of cement with fly ash resulted to concretes with pH of 12.20, 11.40, 11.40, 11.50 and 11.50 respectively after curing for 90 days.

5. Partial replacement of cement with fly ash has a beneficial effect in banana fibre reinforced concrete with respect to water absorption. Partial replacement of cement with 10% fly ash produced the best result in terms of water absorption of banana fibre reinforced concrete.

V. RECOMMENDATION

Based on the findings in this study, it is recommended that cement should be partially replaced with maximum of 20% fly in banana fibre reinforced fly ash concrete in order to improve the durability of banana fibres without underming the mechanical properties of the concrete.

REFERENCES

[1] Rana, A. (2013). Some studies on steel fibre reinforced concrete. International Journal of Emerging Technology and Advanced Engineering 3(1), 120-127.
[2] Chauhan, A. and Chauhan, P. (2013). Natural Fibers Advanced Materials. Journal of Chemical Engineering and Process Technology. http://dx.doi.org/10.41/2157-7049.56.003. Retrieved on March, 2014.
[3] Rai, A and Jha, C.N. (2014). Natural Fibre Composites and its Potential as Building Materials.http://besharp.archidev.org/IMG/doc. Retrieved on 10th April, 2014.
[4] Rewi, K.H.A, and Khafagy, M.A.S.A. (2011). Effects of adding Sisal Fiber and Iraqi Bauxite on Some Properties of Concrete. AL-TAQANI, 24 (2), 58-73.
[5] Mukhopadhyay, S., Fangueiro R., Arpac Y. and Senturk U. (2008). Banana Fibre-Variability and Fracture Behaviour. Journal of Engineered Fibres and Fabrics. 3 (2), 39-45.
[6] Awad E., Mabsout M., Hamad B., & Khatib K. (2011). Preliminary studies on the use of natural fibres in sustainable concrete. Lebanese Science Journal, 12(1), 106-117.
[7] Aziz, M.A., Paramasivam, P. and Lee, S.L. (1981). Prospects of Natural Fibre Reinforced Concretes in Construction. International Journal of Cement Composites and Lightweight Concrete, 3 (2), 123-132.
[8] Ghavami, K. (1995). Ultimate Load Behaviour of Bamboo Reinforced Lightweight Concrete Beams. Journal of Cement and Composites. 17(4), 281-288.
[9] Gram, H.E. (1988). Durability of Natural Fibre in Concrete. Concrete Technology and Design. Blackie and Sons Ltd. London 5, 143-172.
[10] Juarez, C., Duran, A., Valdez P. and Fajardo, G. (2007). Performance of “Ageve Lecheuguilla” Natural Fibre in Portland Cement Composites Exposed to Severe Environmental Conditions. Building and Environment, 42, 1151-1157.
[11] British Standards Institution (1991). BS 12. Specification for Portland Cements. London, England.
[12] American Society for Testing and Materials (2000). ASTM C618. Specifications for Pozzolanas. ASTM International, USA.

[13] British Standards Institution (1992). BS 882. Specification for Aggregates from Natural Sources for Concrete. London, England.

[14] British Standards Institution (1975). BS 812: Part 2. Method of Sampling and Testing of Mineral Aggregates, Sands and Fillers. London, England.

[15] British Standards Institution (1980). BS 3148. Methods of Tests for Water for Making Concrete. London, England.

[16] British Standards Institution (1985). BS 5075 - 3. Concrete Admixtures. Specification for Superplasticizing Admixtures. London, England.

[17] Department of Environment (1992). Design of Normal Concrete Mixes. Building Research Establishment, UK.

[18] Anowai, S.I. and Job, O.F. (2017). Influence of Lengths and Volume Fractions of Fibre on Mechanical Properties of Banana Fibre Reinforced Concrete. *International Journal of Recent Innovations in Engineering and Research*, 2 (6), 49-58.

[19] British Standards Institution (1983). BS 1881 – 116. Testing Concrete – Method for Determination of Compressive Strength. London, England.

[20] British Standards Institution (1983). BS 1881 – 117. Testing Concrete – Method for Determination of Tensile Splitting Strength. London, England.

[21] British Standards Institution (1983). BS 1881 – 118. Testing Concrete – Method for Determination of Flexural Strength. London, England.

[22] Nwankwo, P.O. (2013) Performance Evaluation of a Ternary Cementitious Matrix Reinforced with Sisal Fibre. Unpublished Doctoral thesis, University of Jos, Nigeria.

[23] Mohan, S.R., Jayabal, P. and Rajaraman, A. (2012). Properties of fly ash based coconut fibre Composite. *American Journal of Engineering and Applied Sciences*. 5(1): 29-34.

[24] Rama, M.R., Sudarsana, R.H., & Sekar, S.K. (2010). Effect of glass fibres on fly ash based concrete. *International Journal of Civil and Structural Engineering*. 1(3), 606-612.

[25] Siddique, R. and Kadri, E.H. (2012). Properties of high-volume fly ash concrete reinforced with natural fibres. *Leonardo Journal of Sciences*. 21 (11), 83-98.

[26] Soroshian, P. and Won, J.P. (1995). Statistical evaluation of mechanical and physical properties of cellulose fibre reinforced cement composite. *ACI Material Journal*, 172-180.