DURABILITY PROPERTIES OF BANANA FIBRE REINFORCED FLY ASH CONCRETE

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Abstract – *This study investigates the durability properties of banana fibre reinforced fly ash concrete. Grade 25 concrete incorporating 0, 10, 20, 30 and 40% fly ash were designed and reinforced with 0.5% volume fraction banana fibres of 30mm long. The specimens were cast, cured in water upto 90 days and the compressive strength determined. After curing in water for 90 days, some of the samples were immersed in 5% sulphuric acid, magnesium sulphate and sodium chloride solutions for 28 days. The residual mass and compressive strengths after exposure to these media were determined and compared with the compressive strength obtained after curing in water for 90 days. Some samples were also exposed to temperatures of 200, 400 and 600°C and their residual compressive strengths determined. The results showed that partial replacement of cement with fly ash improved the acid resistance of banana fibre reinforced concrete by reducing the losses in mass and compressive strength. Partial replacement of cement with fly ash improved the resistance of banana fibre reinforced concrete to sulphate attack with the specimens containing 20% replacement of cement with fly ash recording the lowest loss in compressive strength compared to its 90 days compressive strength. The results also showed that partially replacing cement with 10 and 20% fly ash improved the resistance of banana fibre reinforced concrete to chloride attack. Fire resistance of banana fibre reinforced concrete was also improved by partial replacement of cement with fly ash. This implies that a 20% fly ash blended concrete reinforced with 0.5% volume fraction of 30mm long banana fibres can be used for construction purposes in a chemically aggresive environment.*

Key Words: Banana fibre, Fly ash, Concrete, Acid resistance, Sulphate resistance, Chloride resistance, Fire resistance

1.INTRODUCTION

Fibres are broadly classified into man-made and natural fibres. Man-made fibres are made from synthetic materials, steel and natural polymers while natural fibres originate from vegetable, animal and mineral sources. The use of natural fibres in composites is preferred over man-made fibres due to their numerous advantages. Due to light weight, high strength to weight ratio, corrosion resistance and other advantages such as low cost and wide spread availability, natural fibre based composites are becoming important composite materials in building and civil engineering fields [1]. Synthetic and steel fibre based composites despite their usefulness in service are difficult to recycle after their designed service life and are generally more expensive than natural fibres. Al-Tuhami and Seleem [2] gave the possible advantages of natural fibre to include lower pollution level during production, lower energy necessary for fibre production than that of synthetic fibres like glass or carbon, lower cost, healthier in use due to their natural origins and less abrasion to the processing equipment. As a result of its numerous merits, natural fibre based composite matrices are attracting more attention for various low-cost building products [1]. Natural fibres are classified into animal fibres, mineral fibres and plant fibres.

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 [3]. The results of these investigations showed encouraging commercial prospects for application of natural fibres in low cost housing construction.

Banana fibre is a plant fibre categorized as skin fibre. Skin fibres are collected from the skin or bast surrounding the stem of the plant. Skin fibres have higher tensile strength than other fibres and are therefore used for durable yarn, fabric, packaging, and paper [4]. Awward, Mabsout, Hamad and Khatib [5] and Vejje and Murthy [6] established that banana fibre can be used as reinforcement in concrete. However the internal and external durability of concrete reinforced with banana fibres were not investigated.

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired properties. Inadequate durability manifests itself by deterioration, which can be due either to external factors or to internal causes within the concrete itself [7]. Vegetable fibre cement composites produced with OPC matrices undergo an aging process in humid environments in which they may suffer a reduction in post cracking strength and toughness. This durability problem is associated with an increase in fibre fracture due to fibre mineralization. According to Silva, Mobasher, and Diasde Toledo Filho (2009) as cited by [8], this mineralization process is a result of migration of hydration products (mainly $CaOH_2$) to the fibre structure. Durability of vegetable fibre reinforced concrete is related to the ability to resist both external (temperature and humidity variations, sulphate or chloride attack e.t.c.) and internal damage due to compartibility problem between fibres and cement matrix and volumetric changes [8]. The performance of natural fibres in concrete and other cementitious matrices 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 [9]. The degradation of natural fibres immersed in Portland cement is due to the high alkaline environment, which dissolves the lignin and hemi-cellulose phases thus weakening the fibre structure. Banana fibre being a natural fibre is likely to degrade in an alkaline environment of concrete. To improve the durability of natural fibre reinforced concrete, two main approaches may be adopted. The first approach is the modification of the fibre, which involves coating natural fibres to avoid absorption of water and free alkalis. According to Ghavami [10] fibre modification is beneficial for the durability of natural fibre reinforced concrete using water repellent agents or fibre impregnation with sodium silicate, sodium sulphite, or magnesium sulphate. The second approach is modification of the fibre reinforced 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). Juarez, Duran, Valdez and Fajardo [11] recommended partial replacement of cement with fly ash, which will result to a denser matrix as solution to internal degradation of plant fibres in concrete. Anowai and Job [12] confirmed that partially replacing cement with fly ash reduced the alkalinity of banana fibre reinforced concrete.

Fly ash 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 carbondioxide as a result of cement manufacture and reduction in green house gas emission. It results also to saving in the cost of concrete. Anowai and Job [12] showed that up to 20% of cement could be replaced with fly ash in banana fibre reinforced concrete.

There is need to ascertain the performance of natural fibre reinforced concrete when exposed to aggressive environment such as fire or elevated temperature since human safety in case of fire is one of the major considerations in the design of buildings [13]. Mundel [14] asserts that subjecting concrete to high temperatures can cause the development of cracks and like any other crack propagation may eventually cause loss of structural integrity and shortening of service life. It is found that a number of fibres can improve the residual properties of concrete after exposure to elevated temperatures [15]. The inclusion of steel fibres in concrete affects the spread of cracking and potentially improves the performance of concrete after exposure to high temperatures [16]. Ravikumar and Thandavamoorthy [17] showed that glass fibre reinforced concrete performed better than plain concrete in terms of fire resistance.

This study therefore investigates the performance of banana fibre reinforced concrete with and without fly ash as percentage replacement of cement when exposed to aggressive environments such acid, sulphate, chloride and fire attacks.

2. EXPERIMENTAL DETAILS

The cement used for this study was "Dangote" brand of 42.5 grade ordinary Portland cement conforming to [18]. Standard consistency, initial setting time, final setting time and specific gravity the cement were 31%, 78 minutes, 306 minutes and 3.15 respectively. The fly ash used in this study was sourced from Oji River thermal power station in Enugu State, Nigeria. Chemical analysis of the fly ash indicates that the sum of the constituents; SiO_2, Al_2O_3 and Fe_2O_3 was 90.24% which is greater than the minimum of 70.00% specified in [19]. This implies that the fly ash is Class F fly ash. The apparent specific gravity of the fly ash was 2.24.

The sand used for this study was clean river sand, which satisfied the requirements stipulated in [20] for zone 2 fine aggregates. Specific gravity of the fine aggregates was 2.62. This value falls with in the range of 2.6-2.7 given by [21] for natural aggregates. Coarse aggregate used in this study was crushed granite having nominal size of 10mm. The specific gravity, water absorption, aggregate impact value and aggregate crushing value of the coarse aggregates used were 2.62, 0.65%, 10.85% and 22.95% respectively. The water used in this study is in compliance to the recommendations of [22]. The superplasticizer used in this study was Conplast SP430 (G), which complied with the requirements of [23].

The banana fibres were extracted by water retting technique from the stems of banana plants (*musa acuminate*) sourced from farms in Tayu, Sanga Local Government area of Kaduna State, Nigeria. Fly ash concrete of grade 25 was designed following the specifications of [24] mix design method. Fly ash was used to replace cement at 0%, 10%, 20%, 30% and 40% by mass of binder. Banana fibres of 30mm length and volume fraction of 0.5%, which were the optimum values obtained by [25] for grade 25 concrete reinforced with banana fibre were used for the all mixes. The mix proportions of different mixes of banana fibre reinforced fly ash concrete are presented in Table 1.

Batching, mixing and casting were done following standard procedures. For mixtures in which Portland cement were partially replaced with fly ash, the fly ash and cement were mixed dry to uniform colour separately. The required dosage of super plasticizers were added in steps, and then the whole constituents mixed for proper time until uniform dispersion of fibres was achieved. The mixtures were filled into oiled moulds and vibrated using table vibrator. After setting for 24 hours, the specimens were demoulded and cured in water up to 90 days. The compressive strengths of the specimens were determined at 7, 28 and 90 days curing periods. After curing in water for 90 days the specimens were subjected to fire resistance, acid resistance, sulphate resistance and chloride resistance tests.

Acid resistance of control concrete and banana fibre reinforced fly ash concrete specimens was evaluated by measuring the residual compressive strength and change in mass after exposure in acid environment. Three 100 x 100 x 100mm cubes of each of the test specimens were immersed in acid solution after initial curing period of 90 days in water. The weight of each specimen was measured before and after immersion in acid solution. Sulphuric acid (H_2SO_4) solution with 5% concentration was used as the standard exposure solution.

Sulphate resistance of control concrete and banana fibre reinforced fly ash concrete specimens was evaluated by measuring the residual compressive strength and change in mass after sulphate exposure. Three 100 x 100 x 100mm cubes of each of the test specimens were immersed in sulphate solution after initial curing period of 90 days in water. The weight of each specimen was measured before and after immersion in sulphate solution. Magnesium sulphate ($MgSO_4$) solution with 5% concentration was used as the standard exposure solution.

The chloride resistance of control concrete and banana fibre reinforced fly ash concrete specimens was evaluated by measuring the residual compressive strength and change in mass after exposure in chloride environment. Three 100 x 100 x 100mm cubes of each of the test specimens were immersed in chloride solution after initial curing period of 90 days in water. The weight of each specimen was measured before and after immersion in chloride solution. Sodium chloride (NaCl) solution with 5% concentration was used as the standard exposure solution.

Fire resistance tests were conducted after initial curing in water for a period of 90 days. The specimens were air dried and heated in a furnance to the set temperature until it reaches a uniform value. The samples were exposed to temperatures of 200, 400 and 600°C. The temperature was held constant for a period of 2 hours after which the samples were air-cooled to room temperature. After cooling the residual compressive strengths were determined in accordance with the provisions of [26].

Table 1. Concrete Mix Proportions of Banana Fibre Reinforced Fly Ash Concrete

MIX ID	C0	F0	F10	F20	F30	F40
CEMENT (Kg/m^3)	375	373	336	299	261	224
FLY ASH (%)	0	0	10	20	30	40
FLY ASH (Kg/m^3)	0	0	37	75	112	149
BANANA FIBRE (%)	0	0.50	0.50	0.50	0.50	0.50
FIBRE LENGTH (mm)	0	30	30	30	30	30
WATER (Kg/m^3)	215	214	203	193	171	160
SUPERPLASTISIZER ($Litre/m^3$)	0	1.25	1.25	1.25	1.25	1.25
FINE AGGREGATE (Kg/m^3)	675	672	672	672	672	672
COARSE AGGREGATE (Kg/m^3)	1100	1095	1095	1095	1095	1095

3. RESULTS AND DISCUSSION

3.1 Acid Resistance of Banana Fibre Reinforced Fly Ash Concrete

The results of compressive strength of specimens and percentage loss in compressive strength after exposure to acid environment are shown in Table 2 while the losses mass are presented in Figure 1. From the results presented, the acid resistance of control concrete is greater than that of Banana fibre reinforced concrete (without fly ash). However, the partial replacement of cement with fly ash improved the resistance of banana fibre reinforced fly ash concrete by reducing the weight loss and loss in compressive strength. This could be due to pozzolanic reaction of cement with fly ash. Study by Johnsirani and Jagannathan [27] also showed that concrete made by partially replacing cement with fly ash showed better acid resistance than normal concrete, with 20% replacement giving the best resistance. The results of percentage change in mass of specimens after acid exposure are shown in Figure 1. The results show that Banana fibre reinforced fly ash concrete specimens showed lesser loss in mass after acid exposure. From the results, the loss in mass of concrete reduced as the percentage replacement of cement with fly ash increases. The improved resistance of specimen with fly ash to acid attack could be due to reduction of $Ca(OH)_2$ available for reaction with acid by pozzolanic reaction.

Table 2. Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Sulphuric Acid

Specimen ID	90 days Compressive Strength (N/mm²)	Compressive Strength after Exposure (N/mm²)	Loss in Compressive strength (%)
C0	29.01	22.50	22.44
F0	27.16	18.52	31.59
F10	31.48	23.46	25.48
F20	28.40	21.60	23.94
F30	23.46	20.99	10.53
F40	20.99	19.75	8.81

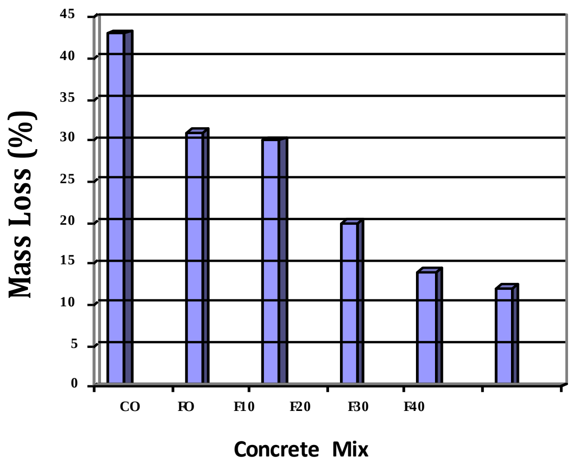

Figure 1. Loss in Mass of Banana Fibre Reinforced Fly Ash Concrete after Exposure in Sulphuric Acid.

3.2 Sulphate Resistance of Banana Fibre Reinforced Fly Ash Concrete

The sulphate resistance was evaluated by measuring the weight loss and compressive strength loss of specimens after exposure in sulphate medium. The results for the compressive strength before and after exposure in magnesium sulphate solution are presented in Table 3 while losses in mass as a result of the exposure to sulphate environment are presented in Figure 2. The control specimen recorded a loss of 5.55% in compressive strength while banana fibre reinforced specimens with 0, 10, 20, 30 and 40% replacement of cement with fly ash recorded losses of 5.81, 4.38, 4.05, 3.24 and 3.53% in compressive strength respectively after curing in magnesium sulphate solution for 28 days. Specimens containing fly ash recorded the lower losses in compressive strength compared to their 90 days compressive strengths. This development could be as a result of continous pozzolanic activity between the fly ash and free calcium hydroxide in the mix. The results show that partial replacement of cement with fly ash improved the resistance of banana fibre reinforced fly ash concrete to sulphate attack. Putting the design strength of the concrete into consideration, 20% replacement of cement with fly ash gave the best result. Johnsirani and Jagannathan [27] also showed that concrete made by partially replacing of cement with fly ash showed better sulphate resistance than normal concrete with 20% replacement giving the best resistance. All the specimes recorded slight loss in mass after exposure to sulphate solution. The results show that banana fibre reinforced concrete containing 0% fly ash recorded the highest loss in mass and compressive strength.

Table 3. Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Magnesium Sulphate

Specimen ID	90 days Compressive Strength (N/mm²)	Compressive Strength after Exposure (N/mm²)	Loss in Compressive Strength (%)
C0	29.01	27.40	5.55
F0	27.16	25.58	5.81
F10	31.48	30.10	4.38
F20	28.40	27.25	4.05
F30	23.46	22.70	3.24
F40	20.99	20.25	3.53

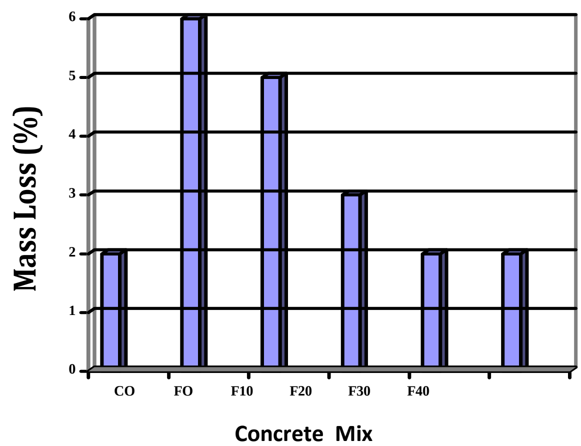

Figure 2. Loss in Mass of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Magnesium Sulphate.

3.3 Resistance of Banana Fibre Reinforced Fly Ash Concrete to Chloride Attack

The chloride attack resistance was evaluated by measuring the weight loss and compressive strength loss of specimens after exposure in Sodium chloride (NaCl) solution. The results are presented in Tables 4 and 5. The results show that partial replacement of cement with fly ash improved the resistance of banana fibre reinforced concrete to chloride attack. The control specimen performed better than all the mixes reinforced with banana fibres in terms of resistance to chloride attack. The control specimen recorded only 1.76% loss in compressive strength as against 4.46% loss in compressive strength for banana fibre reinforced concrete specimen containing no fly ash. Specimens containing 10% and 20% replacement of cement with fly ash recorded loss in compressive strength of 2.70% and 3.31% respectively while specimen with 30% and 40% replacement of cement with fly ash recorded loss in compressive strength of 5.29% and 5.91%. This implies that partially replacing cement with 10 and 20% fly ash improved the resistance of banana fibre reinforced concrete to chloride attack.

Johnsirani and Jagannathan [27] also showed that concrete made by partially replacing cement with fly ash showed better chloride attack resistance than normal concrete with 20% replacement giving the best resistance. Results presented in Table 5 show that there is no significant loss in mass of all the specimens after exposure to sodium chloride environment.

Table 4. Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Sodium Chloride

Specimen ID	Mass before Exposure (g)	Mass after Exposure (g)	Gain in Mass (%)
C0	2494	2501	0.28
F0	2649	2652	0.11
F10	2411	2416	0.21
F20	2274	2277	0.13
F30	2275	2281	0.26
F40	2395	2400	0.21

Table 5. Change in Mass of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Sodium Chloride

Specimen ID	90 days Compressive Strength (N/mm^2)	Compressive Strength after Exposure (N/mm^2)	Loss in Compressive Strength (%)
C0	29.01	28.50	1.76
F0	27.16	25.93	4.46
F10	31.48	30.63	2.70
F20	28.40	27.46	3.31
F30	23.46	22.22	5.29
F40	20.99	19.75	5.91

3.4 Effects of High Temperatures on Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete

The compressive strength results of the concrete specimens subjected to fire tests are presented in Table 6 while the losses in compressive strength are shown in Figure 3. The results show that the control concrete recorded 17.25%, 28.87% and 35.21% losses in compressive strength at temperatures of 200, 400 and 600°C respectively. It is also observed from the results that banana fibre reinforced concrete without fly ash recorded 17.15%, 20.55% and 74.23% losses in compressive strength at temperatures of 200, 400 and 600°C respectively. The results show that banana fibre reinforced concrete performed better than plain concrete at temperatures of 200 and 400°C in terms of losses in compressive strength. However control concrete performed better than Banana fibre reinforced concrete at the temperature of 600°C. Banana fibre reinforced concrete lost 74.23% of its compressive strength at 600°C. This could be as a result of thermal degradation of banana fibres. This development agrees with the assertion of [28] that natural fibres degrade at low temperatures. However, the partial replacement of cement with fly ash resulted to improved performance of banana fibre reinforced concrete. Partial replacement of cement with 10%, 20%, 30% and 40% fly ash resulted in 8.71%, 7.95%, 3.28% and 6.33% losses in compressive strength at temperatures of 200°C, 15.63%, 15.31%, 10.03% and 13.92% losses in compressive at 400°C and 49.21%, 37.22%, 43.77% and 59.49% losses in compressive at 600°C respectively. The improved performance of Banana fibre reinforced fly ash concrete specimens is due to the pozzolanic reaction between fly ash and calcium hydroxide liberated as a result of hydration of cement. This result agrees with the results of [29] which showed that partial replacement of cement with pozzolana in concrete resulted to better performance of concrete at high temperatures.

Table 6. Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Elevated Temperatures

MIX	Compressive Strength (N/mm²) Exposure Temperatures (°C)			
	Ambient	200	400	600
C0	28.40	23.50	20.20	18.30
F0	27.16	22.50	20.55	07.00
F10	29.63	27.05	25.00	15.05
F20	27.16	25.00	23.00	17.05
F30	22.23	21.50	20.00	12.5
F40	19.75	18.50	17.00	08.00

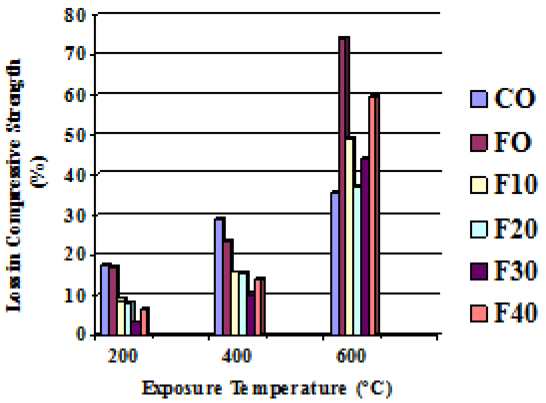

Figure 3. Loss in Compressive Strength of Banana Fibre Reinforced Fly Ash Concrete after Exposure to Elevated Temperatures

4. CONCLUSIONS

Based on the results of experimental investigations on the effects of fly ash on the durability properties of banana fibre reinforced concrete exposed to aggressive environments, the following conclusions can be drawn;

1. Partial replacement of cement with fly ash improved the resistance of banana fibre reinforced fly ash concrete by reducing the weight loss and loss in compressive strength. Specimen with 10% replacement of cement with fly ash produced the best result. However, the 20% fly ash replacement is also good. The results show that Banana fibre reinforced fly ash concrete specimens showed lesser loss in mass after acid exposure.
2. Partial replacement of cement with fly ash improved the resistance of banana fibre reinforced concrete to sulphate attack. Specimens containing 20% replacement of cement with fly ash recorded the lowest loss in compressive strength compared to its 90 days compressive strength.
3. Partially replacing cement with 10 and 20% fly ash improved the resistance of banana fibre reinforced concrete to chloride attack.
4. Partial replacement of cement with fly ash resulted to improved fire resistance of banana fibre reinforced concrete.

5. RECOMMENDATION

Based on the findings in this study, it is recommended that cement should be partially replaced with 20% fly in banana fibre reinforced concrete in order to improve the external durability of banana fibres reinforced concrete in aggressive environments.

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