Strength Development Ratio Of Untreated And Heat Treated Sisal Fibre Reinforced Medium Strength Ternary Concrete

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***Abstract*—The strength development ratio (F_c) of plain concrete and ternary concrete containing three blends of fly ash (FA) and calcined waste crushed clay bricks (CWCCB) as pozzolanas and incorporating 3% volume fraction (V_f) of 40mm average length of untreated and heat treated sisal fibre have been investigated. In this investigation, nine variations of concrete and ternary concrete samples were prepared and cast in 150mmx150mmx150mm mould comprising: (1) Plain concrete of 1:2:4 mix ratio, as control specimens (i.e. one part of ordinary Portland cement (OPC) as binder, two parts of river sand as fine aggregate, and four parts of 19mm crushed granite as coarse aggregate), designated as (4C). (2) Concrete specimens of 1:2:4 mix ratio, reinforced with 3% V_f of untreated sisal fibre (4F). (3) Concrete specimens of 1:2:4 mix ratio, reinforced with 3% V_f of heat treated sisal fibre (4FH). (4) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio consisting of 50% OPC + 20% FA + 30% CWCCB and reinforced with 3% V_f of untreated sisal fibre (4F20/30). (5) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio as in (4) and reinforced with 3% V_f of heat treated sisal fibre (4FH20/30). (6) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio of 50% OPC + 25% FA + 25% CWCCB and reinforced with 3% V_f of untreated sisal fibre (4F25/25). (7) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio as in (6) and reinforced with 3% V_f of heat treated sisal fibre (4FH25/25). (8) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio of 50% OPC + 30% FA + 20% CWCCB and reinforced with 3% V_f of untreated sisal fibre (4F30/20). (9) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio as in (8) and reinforced with 3% V_f of heat treated sisal fibre (4FH30/20). Water/binder ratio was kept constant at 0.6 for all specimens. The cube specimens were cured by immersion in clean water and tested at 7, 28 and 90 days curing ages. Plain concrete specimens incorporating 3% V_f of untreated sisal fibre enhanced the strength development ratio by 65%. Heat treatment of sisal fibre caused an overall reduction of the strength development ratio.**

Keywords—Sisal fibre, Ternary concrete, Compressive strength, Fly ash, Calcined waste crushed clay bricks.

I. INTRODUCTION

Concrete constitutes the oldest and most widely used construction material in today's world. Concrete is cheap, strong and durable and easily obtainable. However the concrete industry continues to be one of the main consumers of energy in construction. The estimated annual concrete production is 11 billion metric tons [1]: 70-75% of the number being aggregates; 15% is water; and 10-15% is cement as the binder. The grater percentage of cement used for concrete is based on Portland cement clinker which is an energy-intensive process. Two prominent compounds present in OPC, such as C_3S and C_2S are known to react with water to form calcium silicate hydrates $(C-S-H)$ and calcium hydroxide $C_a(OH_2)$ [2].Ordinary Portland cement, if fully hydrated, produces approximately 70% $C-S-H$ 20% $C_a(OH_2)$ (in fully matured concrete), 7% sulfoaluminate, and 3% secondary phases all of its own weight [3]. It is reported that in the year 2005 the global cement production was 2.3 billion tons constituting almost four times the quantity in 1970 [4]. One ton of cement production translates to one ton of CO_2 emission: half of the CO_2 is from chemical process of clinker production, 40% from burning fuel, and 10% shared between electricity used and transportation [5].

It is evident from the foregoing statistics of the CO_2 emission from the cement/concrete industry the significant negative impact on the environment. There has therefore been global concern on environmental degradation caused either by CO_2 emission and large energy consumption in the manufacture of cement and by extraction of raw materials. The need to address these problems together with the economic advantage necessitated the urgent need to reduce cement consumption while replacing cement with supplementary materials. The common supplementary materials, used as substitute in cement are in the form of pozzolanas. Pozzolana is a siliceous or aluminous material which, in itself possesses little or no cementitious value but will, in finely divided form and in the presence of water, reacts chemically with calcium hydroxide $C_a(OH_2)$ to form compounds that possess hydraulic cementitious properties. Pozzolanas are classified as either Natural or Artificial [6]. Natural pozzolanas require no further treatment or processing other than grinding to obtain fine particles, therefore not much energy is expended in obtaining natural pozzolanas. On the other hand, artificial pozzolanas results from chemical and/or structural modifications of materials originally having no or only pozzolanic properties. Fly ash and calcined waste crushed clay bricks as industrial waste products, are both inorganic artificial pozzolanas and are covered by this definition. These pozzolanic materials can be used as an inexpensive substitute for cement and concrete mixtures. The research of the economic binder by using the industrial by-products (fly ash, blast furnace slag, silica fume) and the natural resources (natural pozzolanas, limestone) is a major concern to reduce the deficit recorded during the manufacture of Portland cement [7].

Nigeria has large deposit of coal and clay. Fly ash is a by-product of thermal power plant. Coal firing power stations are therefore envisaged to be the main source of power generation in the country in the near future. Fly ash is produced by the injection of finely ground coal at high speed with a stream of hot air (about 1500ºC) into the furnace at electricity generating stations. The carbonaceous content is burnt instantaneously, and the remaining matter (comprising silica, alumina and iron oxide) melts in suspension, forming fine spherical particles on rapid cooling while being carried out by flue gases. Fly ashes are characterised by C_aO content rather than ASTM sum of oxides. Class F ash has up to 15% of C_aO. Class C ash has 15-20% C_aO. Class CH ash has grater than 20% C_aO. Fly ash react with any free lime left after hydration to form calcium silicate hydrates, which is similar to the tricalcium and dicalcium silicates formed in cement curing.

Clay consists of a variety of phyllosilicate minerals rich in silicon and aluminium oxides and hydroxides, which include variable amounts of structural water. Clay materials are characterised by its layered shape, tendency towards high plasticity, small particle size distribution, and affinity for water [8]. Calcinations of clay (waste bricks) which is an artificial pozzolana, is also an essential process in the development of satisfactory pozzolanic properties since it can hydrate in the presence of $C_a(OH_2)$: The formation of cementitious material by the reaction of free lime (C_aO) with the pozzolan admixture (AlO_3, SiO_2, Fe_2O_3) in the presence of water is known as hydration.

Calcinations results principally from transformation of aluminium silicate [$Al_2(Si_2O_5)(OH)_4$] clay minerals. The rupturing of crystalline structure of kaolinite minerals releases siliceous and aluminous compounds, thereby making the clay very unstable and chemically active. This transformation occurs between 600 and 900ºC, depending on the clay mineral present [9] [10].

There is growing global interest in the research and development of fibre reinforced concrete, due to the high cost of steel reinforced concrete. Tropical countries like Nigeria are known to be the domain of vegetable fibre. Sisal fibre *(Agave Sisalana)* has been widely reported as one of the strongest vegetable fibres, with high cellulose content, and elastic modulus, increased impact strength, moderate tensile and flexural capacity compared to other vegetable fibres [11] [12].

Sisal is a perennial hardy plant, which unlike the other fibres is not a seasonal crop. It can establish and easily grow in almost all states of Nigeria covering sub humid to arid and semiarid regions of Nigeria. It can also survive in almost all soil types and its input costs are least for its survival, regeneration and maintenance on sustainable basis. Sisal tolerates prolonged droughts and high temperatures also. It yields parallel hard fibres.

The extraction of sisal fibre is traditionally by retting, a biodegradation process involving microbial decomposition of sisal leaves, which separates the fibre from pith. The other methods available for the extraction of fibre are the chemical and mechanical extraction. Studies have shown that simple heat treatment of sisal fibre by boiling and washing increased the crystalinity of the cellulose, a marginal improvement in the workability of the fresh concrete mix and an increase in the density and strength of the composite [13].

Extensive studies have revealed that fly ash and calcined waste crushed clay bricks can be used as supplementary cementitious materials as binary blends [14] [15] [16] [17]. Benefits of using high-reactivity metakaolin in ternary systems with ground granulated blast-furnace slag and fly ash have been reported [18]. Reference [19] reports that mixtures with 8 to 12% metakaolin replacement at 0.4 to 0.3 water-cementitious materials ratio greatly improved the compressive strength at all ages. Reference [19] showed that high-reactivity metakaolin enhanced resistance to chloride ingress. However the reactivity of fly ash and calcined waste crushed clay bricks in a ternary blend in concrete incorporating untreated and heat treated vegetable fibre as reinforcing agent is rarely seen in literature. This paper presents an investigation of the strength development and the pozzolanic reactivity of untreated and heat treated sisal fibre reinforced medium strength ternary concrete.

II. MATERIALS AND METHODS

A. Materials

The "BUA" brand 43 grade ordinary Portland cement conforming to B.S. 12 (1996) [20] and ASTM - C – 150 (1994) [21] was used as the main binder material. The cement has a specific gravity of 3.15 and a specific surface area of 320m^2/kg, percentage retained on mesh 325 (45μm) is 22.0. The fly ash was procured from a waste dump at Oji River thermal power plant in Enugu State, Nigeria. The fly ash was sieved and the percentage retained on mesh 325 (45μm) is 8.4. The calcined waste clay bricks were ground with the aid of porcelain ball mill for 90 minutes. The percentage retained on mesh 325 (45μm) after sieving was 35.0.The specific gravity, the retention on sieve no. 325 and the specific surface area (Blaine fineness) were tested in accordance with ASTM C 188, C 430 and C 204 respectively. Table 1 shows the chemical characteristics of the fly ash, calcined waste crushed clay bricks and OPC, which were carried out using X-Ray fluorescent spectroscopy.

The fine aggregate used was river sand and was sourced from river Gumo in Bauchi State, Nigeria. The coarse aggregate is of 19mm crushed granite. Sisal fibres were sourced and prepared locally through the traditional method of biodegradation process involving microbial decomposition of the sisal leaves. The sisal fibres were cut to average length of 40mm. Detail of method of extraction of sisal fibre, preparation and characterisation has been carried out elsewhere [22]. The heat treatment of sisal fibre was achieved by simply allowing the sisal fibre to boil in clean water for 30 minutes, it was allowed to cool, and then washed with clean water and sun dried for 7 days at ambient conditions.

B. Methods

The strength development activity of sisal fibre reinforced ternary concrete has been determined by mechanical method in accordance with ASTM C 311 [23], with modification**.** In this investigation the modified mechanical method consists of the evaluation of the compressive strength of 150mmx150mmx150mm concrete cube samples. Nine variations of concrete and ternary concrete samples were prepared comprising: (1) Plain concrete of 1:2:4 mix ratio, as control specimens (i.e. one part of ordinary Portland cement (OPC) as binder, two parts of river sand as fine aggregate, and four parts of 19mm crushed granite as coarse aggregate), designated as (4C). (2) Concrete specimens of 1:2:4 mix ratio, reinforced with 3% V_f untreated sisal fibre (4F). (3) Concrete specimens of 1:2:4 mix ratio, reinforced with 3% V_f of heat treated sisal fibre (4FH). (4) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio consisting of 50% OPC + 20% FA + 30% CWCCB, reinforced with 3% V_f of untreated sisal fibre, (4F20/30). (5) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio as in (4) and reinforced with 3% V_f of heat treated sisal fibre (4FH20/30). (6) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio of 50% OPC + 25% FA + 25% CWCCB and reinforced with 3% V_f of untreated sisal fibre (4F25/25). (7) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio as in (6) and reinforced with 3% V_f of heat treated sisal fibre (4FH25/25). (8) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio of 50% OPC + 30% FA + 20% CWCCB and reinforced with 3% V_f of untreated sisal fibre (4F30/20). (9) Ternary concrete specimens of 1:2:4 mix ratio, with binder ratio as in (8) and reinforced with 3% V_f of heat treated sisal fibre (4FH30/20). The materials for the concrete and ternary concrete were hand mixed with the water/binder ratio kept constant at 0.6 for all specimens. The concrete cubes, for the purpose of evaluating the compressive strength, were cast and compacted with a tamping rod, in 150mm cube mould in accordance with the requirements of B.S. 1881: Part 116 (1983). After casting, samples were covered with moist jute bags and maintained at 23 ±2ºC for 24 hours. The cube samples were de-moulded after 24 hours and cured by complete immersion in a tank filled with clean water kept at 20ºC. The compressive strength was determined from the average of three specimens at 7, 28 and 90 day curing ages. The cube samples were tested in an electronically operated testing machine shown in Plate 1 and housed in the Materials and Concrete Testing Laboratory of the Department of Building, University of Jos.

Plate 1. *Determination of compressive strength of concrete with testing machine.*

TABLE I. CHARACTERISTICS OF POZZOLANIC MATERIALS AND OPC USED FOR THE STUDY.

Chemical Properties	Percentage Composition		
	Fly Ash	CWCCB	OPC
Silicon Oxide SiO_2	57.1	60.80	19.92
Calcium Oxide CaO	0.93	2.30	61.65
Aluminum Oxide Al_2O_3	24.00	19.00	4.26
Ferric Oxide Fe_2O_3	9.14	11.97	2.88
Magnesium Oxide MgO	0.40	0.04	3.10
Vanadium Oxide V_2O_5	0.15	0.057	-
Sodium Oxide Na_2O	0.18	Traces	0.13
Potassium Oxide K_2O	1.23	3.38	0.88
Titanium Oxide TiO_2	3.83	1.15	-
Sulphur Trioxide SO_3	2.30	-	2.80
Carbon Dioxide CO_2	-	-	1.93
Chromium Oxide Cr_2O_3	0.064	0.047	0.031
Manganese Oxide MnO	0.073	0.17	0.11
Nikel Oxide NiO	0.025	0.01	-
Copper Oxide CuO	0.11	0.082	0.063
Zinc Oxide ZnO	0.078	0.018	-
Rubidium Oxide Rb_2O	0.013	0.037	-
Strontium Oxide SrO	0.052	0.035	0.14
Yttrium Oxide Y_2O_3	0.039	0.038	0.023
Zirconium Oxide ZrO_2	0.25	0.12	0.031
Ruthenium Dioxide RuO_2	0.46	0.42	0.23
Osmium Oxide OsO_4	0.009	-	-
Rhenium Oxide Re_2O_7	0.02	0.02	-
Lead Oxide PbO	0.042	-	-
Equivalent Alkali Na_2O_3	-	-	-
Insoluble Residue	-	Traces	1.17
Ignition Loss	2.71	-	2.98
% Retained on Mesh 325 $(45\mu m)$	8.4	35.0	22.0
Specific Surface Area ($m^2/kg)$	200-600	-	200-500

III. RESULTS AND DISCUSSION

The 7, 28, and 90 days compressive strength for all specimens are shown in Table 2. The strength development, $^{28}/_{7}$ day F_c ratios are also given in Table 2. F_c ratios that are either greater than 1.67 or less than 1.25 are undesirable [24]. Figures 1, 2 and 3 show the relationship between compressive strength and curing age indicating the rate of strength development of concrete compared with the various ternary mixtures. The compressive strength of the control specimen increased from 20.3N/mm^2 at 7 days curing age to 25.0N/mm^2 and 25.8N/mm^2 at 28 days and 90 days curing age respectively, indicating about 19% increase. The strength development (F_c) ratio was obtained as 1.23 which is slightly lower than the desirable ratio of 1.25. This slightly lower (F_c) value may be attributed to the slow formation of calcium silicate hydrates (C-S-H) between 7 and 28 day curing age.

Results of the compressive strength for specimens prepared with 3% V_f of untreated and heat treated sisal fibres are presented in Table 2. Figures 1, 2 and 3 show the relationship between the compressive strength and the curing age. All compressive strength values are average of three readings from the result of compressive strength test on three specimens. There is tendency of fibres to decrease the compressive strength of concrete. In this investigation, the reduction is from 25N/mm^2 to 8.5N/mm^2 at 28 days curing age, for untreated sisal fibre. This reduction is associated with the low modulus of sisal fibre employed, and the additional porosity resulting from their inclusion. The incorporation of 3% volume fraction of sisal fibre in the concrete matrix can be regarded as high fibre content and this could have created more voids in the concrete due to lack of free rearrangement of the concrete matrix as a result of the poor workability and balling effect during casting and compaction of the specimens. The addition of fibres in concrete increased the void volume and therefore decreased the density. The effect of voids can be beneficial in promoting ductility in fibre reinforced composites [25], but has a negative effect on the compressive strength as demonstrated by the results in Table 2. In addition, the high alkalinity of conventional cement-based composite caused the hydrolysis of cellulose chains and/or the dissolution of amorphous constituents of the sisal fibre.

It was observed that the 7 days compressive strength of the specimens with untreated sisal fibre increased from 4.2N/mm^2 to 8.5N/mm^2 at 28 days and 9.1N/mm^2 at 90 days curing ages, indicating 100% strength gain. There was a remarkable early strength gain of about 40% when the specimens contained 3% V_f of heat treated sisal fibres. This increase in compressive strength of specimens containing heat treated sisal fibres may be attributed to the fact that hot-water solubility of boiled and washed sisal fibre was extremely low when compared with untreated sisal fibre as shown in Table 2. Boiling the sisal fibre in water removed part of the deleterious components such as inorganic compounds tannins, gum, sugars, colouring matter and starches (TAPPI) that may have significant effect on the formation of cement-cement bond and fibre-cement bond [26]. It was observed during the cube crushing that the failure of the specimen incorporating sisal fibre was gradual, and in spite of the occurrence of excessive vertical cracks, the specimens still did not break into pieces (non-explosive failure), as shown in Plate 2 when compared with the control specimens with no fibre.

IV. CONCLUSIONS

From the outcome of the experimental studies presented in the paper, the following conclusions can be drawn:

1. The incorporation of 3% volume fraction of 40mm average length of untreated sisal fibre increased the strength development ratio of unblended composite by about 65%.
2. Heat treatment of sisal fibres reduced the strength development ratio of ternary blended concrete by 30% for 20%FA + 30%CWCCB blend, 45% for 25%FA + 25%CWCCB and 6.2% for 30%FA + 20%CWCCB.
3. The very early strength enhancement exhibited by the ternary blend of 30%FA + 20%CWCCB, incorporating 3% volume fraction of untreated sisal fibre is due to a combination of filler effect of the pozzolanas and accelerated cement hydration [27]. Subsequent enhancement is due to the reaction between fly ash and calcined waste crushed clay bricks with calcium hydroxide $C_a(OH_2)$ produced by the hydration of the cement.

Plate 2. *Ductile (non explosive) failure of sisal fibre reinforced concrete cube specimen.*

TABLE II. COMPRESSIVE STRENGTH RESULTS FOR 1:2:4 MIX RATIO AND TERNARY MIXTURES.

Mix Identification	Compressive Strength (N/mm^2)			Strength Development Ratio (F_c)
	7 Day	*28 Day*	*90 Day*	
4C	20.3	25.0	25.8	1.23
4F	4.2	8.5	9.1	2.02
4FH	7.0	8.5	9.4	1.21
4F20/30	2.3	3.0	2.3	1.30
4FH20/30	3.8	3.8	4.5	1.00
4F25/25	1.5	2.5	3.5	1.67
4FH25/25	6.0	6.9	7.1	1.15
4F30/20	4.5	6.2	5.6	1.37
4FH30/20	3.5	4.5	4.7	1.29

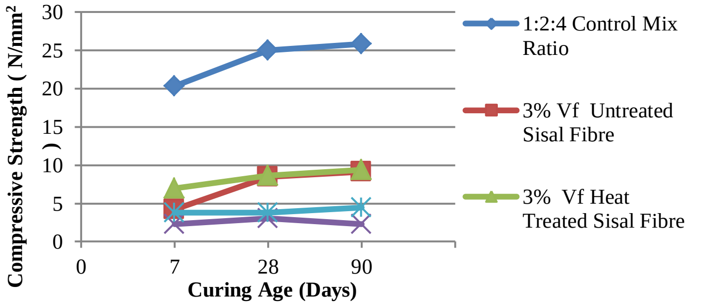

Fig. 1. *Compressive strength for 20/30 ternary blend of FA/CWCCB at 7, 28 and 90 days curing age (1:2:4 mix ratio)*

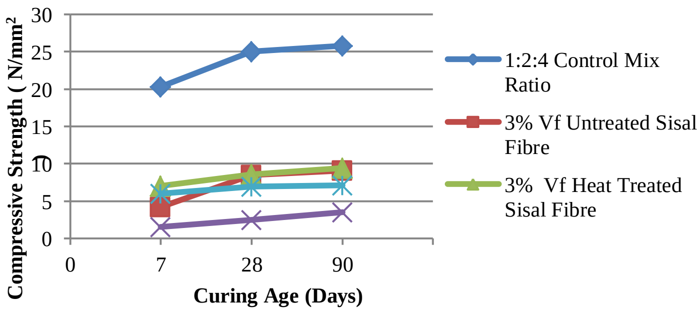

Fig. 2. *Compressive strength for 25/25 ternary blend of FA/CWCCB at 7, 28 and 90 days curing age (1:2:4 mix ratio)*

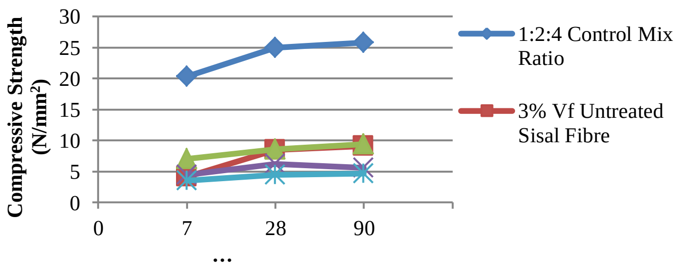

Fig. 3. *Compressive strength for 30/20 ternary blend of FA/CWCCB at 7, 28 and 90 days curing age (1:2:4 mix ratio)*

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