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Performance Evaluation of Sisal Fibre as Reinforcing Agent in Medium Strength Ternary Concrete

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ABSTRACT

There is growing trend worldwide in the research and development of sustainable low-cost, atoxic, renewable and durable construction materials. Tropical countries like Nigeria are known to be the domain of vegetable fibres and other non-pyroprocessed industrial by-products that possess cementing properties (pozzolanas). Sisal fibre has emerged as reinforcing material in polymers used in civil industries and other products and has the potential to be cultivated in luxurious abundance in Nigeria. This paper reports the experimental study on use of locally sourced and processed sisal fibre as reinforcing agent in ternary of fly ash (Fa) and calcined waste crushed clay bricks (CWCCB), normal strength, OPC concrete. In this work, the physical and chemical characteristics of sisal fibre, Fa and CWCCB are obtained. The amount of OPC in the ternary mixtures was fixed at 50%, while the ratio of fine to coarse aggregate was fixed at 1:2. The mechanical performance of concrete samples in three ternary blends of Fa and CWCCB in the ratios of 20/30, 25/25 and 30/20, incorporating 3% volume fraction of 40mm average length of sisal fibres as reinforcing agent were evaluated. It was shown that concrete samples incorporating 3% volume fraction of sisal fibre and containing 30%Fa + 20%CWCCB(4F30/20), gave the best mechanical performance.

Keywords: Sisal Fibre, Ternary Concrete, Fly Ash, Calcined Waste Crushed Clay Bricks.

1. INTRODUCTION

Cement and steel reinforcement constitute the primary conventional building materials, and owing to the inflationary trend of the world economy are beyond the reach of majority of world population. Despite the high cost of these materials, the construction industry continues to be the main unnecessary consumer of energy and materials. Cement for example, is reported to account for 83% of total energy use in the processing of non-metallic minerals and 94% of CO_2 emissions (International Energy Agency (IEA), 2008). In view of these disturbing statistics on CO_2 emission and the rising environmental concern towards making the world 'green' , the pursuit of sustainable developments as defined in the Brundtland Report, (1987), becomes a major issue when trying to meet the challenge in providing adequate housing for the ever increasing populations. The research and development of low-cost construction materials which are environmentally friendly, structurally safe with elevated durability and acceptable mechanical performance, therefore becomes a real challenge facing researchers and engineers of the 21st century.

In this study, an attempt is made to investigate cementitious composite system with low cement contents, and material of high ductility that will act as reinforcing agent, with capacity to endure the multidirectional stress resulting from service load that may consequently, partially or completely replace steel reinforcement. To achieve these, two propositions are advanced: one involved the use of locally sourced and processed vegetal fibre as reinforcing agent for concrete composites. The other proposition involved the use of non pyroprocessed industrial by-products that possess cementing properties (pozzolanas).

Sisal fibre (*Agave Sisalana*), as reported by Joseph et al., (1999), is one of the strongest vegetable fibres with high cellulose content, and elastic modulus, increased impact strength, moderate tensile and flexural strength and inexpensive when compared to other vegetable fibres. However, the main draw back in the use of sisal and other vegetable fibres in the reinforcement of cementitious composites made with ordinary Portland cement (OPC) is the lack of durability of the composites. The key mechanism of deterioration of the fibres is believed to be due to migration of hydration products (mainly, calcium hydroxide ($Ca(OH)_2$)). This is associated with the modification of the reaction and hydration velocity of cement particles to the fibre structure. Consequently, the hydrolysis of the cellulose chain and/or the dissolution of amorphous constituents of the fibre- results.

Blends in the form of pozzolanas (Supplemental Cementitious Material, (SCM)) in cement are divided into two categories, binary and ternary. Binary is a mixture of two products (i.e. Portland and one pozzolana), whereas the ternary blend is a mixture of three products (i.e. Portland and two pozzolanas). Cement blended with additives such as fly ash, silica fume etc have been used as binary, to minimize chemical interactions between the fibres and the cementitious matrices, hence improve the

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durability of the composite. Most often, these additives are expensive and contribute to CO_2 emission. The ternary blend of fly ash (Fa), a waste product generated by thermal power plant, and calcined waste crushed clay bricks (CWCCB), also a waste product of brick factory, with OPC, is rarely seen in literature. The choice of the two blends of Fa and CWCCB in this research is predicated on the fact that they are industrial wastes which would have been destined for land fills. Also their availability could negate the need to produce more Portland cement and beneficially uses the energy already expended in their manufacturing process.

This research characterized the locally sourced and processed sisal fibre and evaluated the effects of the ternary blend of Fa and CWCCB as pozzolanas on the mechanical properties of cementitious composites with the sisal fibre as the reinforcing agent.

2. MATERIALS AND METHODS

The concrete composite was cast by addition of sisal fibre sourced from permanent site of the University of Jos in Nigeria, and processed by retting. The sisal leaves were cut and buried in a pit containing stagnant mud water for 21 days at ambient conditions. The process allows microbial decomposition of the sisal leaves, which separates the fibre from the pith. On the 21st day, the fibres were washed with sufficient quantity of clean water till pulp was detached from fibre, then sun dried for 7 days at ambient conditions. The sisal fibres were chopped to an average length of 40mm. The important properties needed for the use of sisal fibre to its highest potentials were determined and tabulated in Table 1.

The "BUA" brand 43 grade OPC conforming to BS 12 (1996) and ASTM-C-150 (1994) was used. Fly ash was procured from a waste dump at the thermal power plant located in Oji River, in Enugu State of Nigeria. Calcined waste crushed clay bricks burned at 850^{o}C was procured from a brick manufacturing industry located in Minna, in Niger State of Nigeria. The calcined waste bricks were ground with the aid of porcelain ball mill for 90 minutes. River sand was used as the fine aggregates, while 19mm crushed granite was used as the coarse aggregates. The physical and chemical properties of OPC, Fa and CWCCB are shown in Table 2.

TABLE 1

PHYSICAL, MECHANICAL AND CHEMICAL PROPERTIES OF SISAL FIBRE.

Property Determined	Value			CV (%)	Standard Deviation
	Lower	Upper	Mean		
Diameter (mm)	0.07	0.26	0.17	22.3	-
Density (kg/m^3)	730	1050	890	8.2	-
Natural Moisture Content (%)	12.8	15.3	14.1	8.7	-
Water Absorption after 5 minutes Under Water (%)	61.0	89.2	75.1	12.9	-
Water Absorption to Saturation (%)	195.0	272.0	233.5	16.0	-
Specific Gravity	0.91	1.09	1.00	5.0	-
Tensile Strength (N/mm^2)	292	603	448	41.32	102.0
Modules of Elasticity (N/mm^2)	15.0	28.0	21.5	29.5	3.0
Extension (mm)	20.2	20.6	20.4	-	-
Elongation to Failure (%)*	4.6	6.4	5.0	-	1.0
Elongation to Failure (%) **	8.0	14.8	11.4	-	-
Strain at Failure (%)	2.05	4.16	3.10	29.15	-
Cellulose	48.79	57.91	53.35	-	-
Hemicellulose	15.35	29.03	22.19	-	-
Lignin	15.95	19.95	17.95	-	-
Ash	1.08	2.10	1.59	-	-

* *Normal Atmospheric Condition and Ambient Temperature.*
** *After Soaking in Water for 48 hours.*
\- *Not Determined/Applicable.*
CV *Coefficient of Variation.*

TABLE 2

PHYSICAL AND CHEMICAL PROPERTIES OF MATERIALS

Properties	OPC	Fa	CWCCB
Physical Properties			
Blain specific surface area (m^2/kg)	340	200-600	-
% retained on mesh 325 (45µm)	22.0	8.4	35.0
Specific gravity	3.15	2.25	2.26
Bulk density (kg/m^3)	1440		
Loose bulk density (kg/m^3)	-	1306	1157
Compacted bulk density (kg/m^3)	-	1414	1371
Chemical Properties	***wt%***	***wt%***	***wt%***
CaO	61.65	0.93	2.30
SiO_2	19.92	57.10	60.80
Al_2O_3	4.26	24.00	19.00
Fe_2O_3	2.88	19.14	11.97
MgO	3.10	0.46	0.04
SO_3	2.80	2.30	-
K_2O	0.88	1.23	3.38
TiO_2	0.21	3.83	1.15
Na_2O	0.13	0.18	Traces
Ignition lose	2.98	2.71	-

2.1 Batching of Materials

It is assumed in the batch computation that the volume of compacted concrete is equivalent to the sum of the absolute volume of the materials that make up the materials i.e.:

$$Absolute\ volume = \frac{weight\ of\ material}{specific\ gravity\ of\ material}$$

The mix proportion considered in this study was 1:2:4 mix ratio (i.e. one part binders, two parts fine aggregate and four parts coarse aggregate) and referred to as "normal" (Ternary) concrete. Addition of 3% volume fraction of sisal fibre will reduce the workability of the concrete. In order to make the mix workable, a constant water binder ratio of 0.6 was adopted. Table 3 shows the mass of constituent materials per cubic metre of concrete.

Hand mixing was adopted for this study and was carried out on a clean, hard non-absorbent surface. To avoid balling of fibres and segregation, the following procedure was adopted in mixing of the concrete. Fine aggregate, cement and pozzolanas were thoroughly mixed four times. The required amount of sisal fibres were uniformly dispersed by hand throughout the mass with slow increments. Dry mixing continued until homogeneity was achieved, followed by addition of the required quantity of water. The mixing is continued until a good blend of concrete was achieved.

The mechanical strengths of the composites were evaluated by compressive strength test on 150mm concrete cubes. The 150mm cube steel moulds were thoroughly cleaned and oiled with mould oil before casting fresh concrete to ensure easy de-moulding and smooth surface finish of the hardened concrete. The wet mixture was cast into mould and vibrated using electrically operated vibrating table. Specimens were de-moulded after 24hours and subjected to curing by complete immersion in a tank filled with clean tap water for the specified number of curing ages. Specimens were referenced for ease of identification as follows:

Code	Interpretation
4	1:2:4 Plain concrete mix ratios.
C	Control specimen
F	Specimen contains 3% volume fraction of sisal fibre.
Fa	Specimen contains fly ash.
CWCCB	Specimen contains calcined waste crushed clay bricks and 50% ordinary Portland cement.
20/30	Specimen contains 20% fly ash, 30% calcined waste crushed clay bricks and 50% ordinary Portland cement.
25/25	Specimen contains 25% fly ash, 25% calcined waste crushed clay bricks and 50% ordinary Portland cement.
30/20	Specimen contains 30% fly ash, 20% calcined waste crushed clay bricks and 50% ordinary Portland cement.

The compressive strength tests were carried out on 150mm hardened concrete cubes comprising three replacement ratios as proposed by Nwankwo, (2013) at curing ages of 7, 28 and 90 days. The tests were carried out in accordance with BS 1881: Part 116 (1983). An electrically operated universal testing machine was used to determine the failure load.

TABLE 3
MASS OF CONSTITUENT MATERIALS PER CUBIC METER OF CONCRETE (kg.).

Material	Mix Ratio 1:2:4
Cement (Control Mix)	321
Cement(With 3% Fibre)	312
Cement (50%)	156
Fine Aggregate	696
Coarse Aggregate	1331
Sisal Fibre (3% V_f)	27
Water (litres)	250
20FA + 30CWCCB	62.2 + 93.3
25FA + 25CWCCB	77.75 + 77.75
30FA + 20CWCCB	93.3 + 62.2

3. RESULTS AND DISCUSSION

Table 4 shows the results for the compressive strength for the control specimen and the other ternary blends for 7, 28 and 90 days curing ages. The results showed a tendency of sisal fibres to decrease the compressive strength of concrete. In this study, the reduction is from 25N/mm² to 8.5N/mm² at 28 days curing age. This reduction is associated with the low modulus of sisal fibre employed, and the additional porosity resulting from their inclusion. Addition of 3% volume fraction of sisal fibre which may be regarded as high fibre content could have created more voids volume in 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 with consequent decrease in density. All specimens with sisal fibre had ductile (gradual) mode of failure in contrast to the brittle (explosive) mode of failure for specimens without sisal fibres. This confirms that the effect of voids can be beneficial in promoting ductility in fibre reinforced composites (Yang et al., 2007), but has negative effect on the compressive strength as demonstrated by the results in Table 3. In addition, the high alkalinity of conventional cement-based composite may have caused the hydrolysis of cellulose chains and/or the dissolution of amorphous constituents of the sisal fibre.

The 7 days compressive strength of specimens incorporating sisal fibre with no blend of Fa and CWCCB, (4F), increased from 4.2N/mm² to 8.5N/mm² at 28 days and to 9.1N/mm² at 90 days curing age, indicating 100% strength gain. It has been shown by (Tolêdo Filho et al., 2003), that deleterious components such as inorganic compounds tannins, gum, colouring matter and starches (TAPPI) in fibres, may have significant effect on the formation of cement-cement bond and fibre-cement bond. The author will in subsequent work study the effects of the removal by boiling and washing the sisal fibres, of part of these deleterious inorganic compounds, on the mechanical strength of sisal fibre reinforced concrete. It can be seen that the ternary concrete with a blend of 30%Fa + 20%CWCCB (4F30/20) attained maximum compressive strength at 7, 28 and 90 days curing ages. It can also be observed that at early curing age of 7 days, the ternary concrete containing 30%Fa + 20%CWCCB developed a slightly higher compressive strength (4.5N/mm²) over the specimen with no blend (4F) (4.2N/mm²). This trend is in conformity with observations of other researchers (Bui, (2005), Wong, (2005), Mazloom, (2006) and Almusallam, (2004)). However at latter curing age of 90 days, specimens with no blend (4F) attained higher compressive strength of 9.1N/mm² compared to 5.6N/mm² for 30%Fa + 20%CWCCB blend. The increase in early strength for ternary concrete containing higher percentage of Fa may be attributed to higher pozzolanic reactivity of Fa compared to CWCCB.

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

Mix Identification	Compressive Strength (N/mm²)		
	7 Day	28 Day	90 Day
4C	20.3	25.0	25.8
4F	4.2	8.5	9.1
4F20/30	2.3	3.0	2.3
4F25/25	1.5	2.5	3.5
4F30/20	4.5	6.2	5.6

4. CONCLUSION

Water absorption for locally sourced and processed sisal fibre was observed to be critical for the first 15 minutes, the mean tensile strength was 448kN/mm², a value considered high compared to results from other researchers. The ternary blend of fly ash and calcined waste crushed clay bricks resulted in more densified concrete with 1.6% - 0.4% increase over control specimen. The increase in density may be as a result of the reduction of diffusion rates of gases and ions, which may subsequently lead to improved durability of concrete. Among the three ternary blends of Fa and CWCCB concrete incorporating 3% volume fraction of sisal fibres, the 30%Fa + 20%CWCCB (4F30/20) blend gave the best mechanical performance. Thus the use of 3% volume fraction of sisal fibre as reinforcing agent and the optimum ternary blend of Fa and CWCCB in cementitious concrete composites could significantly contribute to sustainable development of low-cost construction materials in the nearest future.

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