Effects of Fibre Treatment on the Properties of Sisal Fibre Reinforced Ternary Concrete

Patrick Oguguo Nwankwo and Emmanuel Achuenu

Abstract
Most of the developing counties are very rich in agricultural and vegetable fibres. The use of vegetable fibres as reinforcing agent in composite matrices (such as cement and polymer) is attracting more attention for various low-cost building products. However, the main draw back in the use of vegetable fibres in composites is the lack of durability. In this work, sisal fibre treated by boiling and washing was used as the reinforcing agent in ordinary Portland cement (OPC) concrete. The cement-based matrix was modified by blending with fly ash (Fa) and calcined waste crushed clay bricks (CWCCB) as pozzolanas. Nine variations of the concrete specimens were prepared. Some specimens were blended with Fa and CWCCB and reinforced with 3% volume fraction of heat treated or untreated sisal fibres, while some specimens were not bended, but reinforced with either 3% volume fraction of heat treated or untreated sisal fibres. The mix ratio was 1:2:4 (one part binder, two parts fine aggregate and four parts coarse aggregate). The OPC was kept constant as 50% of the binders, while Fa and CWCCB were varied in the ratios; 20:30, 25:25 and 30:20 (Fa: CWCCB). The water/binder ratio was 0.6. Treatment of sisal fibres by boiling and washing improved the workability of concrete and enhanced the compressive strength of plain and ternary concrete. The ternary concrete with 25:25 (Fa: CWCCB) blend, reinforced with 3% volume fraction of heat treated sisal fibre gave the highest compressive strength.

Key words: Sisal fibre, Heat treatment, Ternary concrete, Fly ash, Calcined waste crushed clay bricks, Pozzolanas.

1. INTRODUCTION

There is continuous research for cheap alternative construction materials that are durable and sustainable. This search is much more important in developing world, where there is acute shortage of energy and good quality raw materials. The use of vegetal fibres as reinforcing agent in cementitious composites for building and construction industries is attracting new impulse in recent times. Cheaper and more effective treatments to vegetal fibres to prevent degradation and increase the durability are yet incipient and poorly productive.

One of the major problems associated with the use of vegetal fibres in composites is their high moisture sensitivity leading to severe reduction of mechanical properties and delamination. Vegetable fibre cement composites produced with OPC matrices undergo an ageing process in humid environment during which they may suffer reduction in post-cracking strength and toughness. To enhance the load-carrying capacity of vegetal fibres in composites, structural modifications by means of various schemes are essentially based on the economics of the process.

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Pre-treatment to vegetal fibres are broadly classified as physical, chemical and biological treatments according to their principle mode of actions on the substrate. A detailed study of surface modifications of cellulosic fibres has been reported by Belgacem and Gandini (2005) [1]. The authors are of the opinion that the most promising approach of chemical modification seemed to be the one that give rise to continuous covalent bonds between cellulose surface and matrix. They also looked into a novel strategy which did not involve a chemical modification but the formation of a physical sleeve of polymer around the fibres. Tonoli, et al. (2009) [4] evaluated the surface modification of cellulose fibres in order to improve their durability into the fibre-cement composites. The research also investigated the physical and mechanical performance of cement based composite reinforced with surface modified fibres and the durability of these composites assessed by accelerated ageing tests. The procedure used for the surface modification of the cellulose fibres and the choice of the silanes used were based on the studies developed by Abdelmouleh, et al. (2002) [5] and (Delvasto, Botache, Alban, Gutierrez, Perdomo, Segovia, et al, 2004) [6]. The silanes used were methacryloxypropyitri-methoxysilane (MPTS) and aminopropylthri-ethoxcysilane (APTS). They concluded that the surface modification of the fibre showed significant influence on the microstructure of the composite (fibre-matrix interface and mineralization of the fibre lumen). Generally, recent findings report that silane coating of fibres is a good way to improve the durability of vegetal fibre reinforced concrete (Bilba and Arsene, 2008) [7].

Heating cellulosic materials e.g. wood or vegetal fibres result in change of their physical and chemical properties. The properties of the heated materials depend on types and properties of the materials, initial moisture content, surrounding atmosphere, treatment time and temperature (Yildiz, Gezer and Yildiz 20060 [2]. Yildiz, et al. (2006) reported that hemicellulose degraded by heat treatment. Kaewkuk, Sutapun and Jarukumjorn (2009) [3], studied the effect of treatment time and temperature on the mechanical, thermal and morphological properties of sisal fibres. Heat treatment was performed by heating sisal fibre in an oven at

150, 170 and 200ºC with different duration under atmospheric pressure and presence of air. The authors reported that first decomposition peak below 100ºC corresponded to the evaporation of moisture. The second decomposition peak around 150ºC indicated the onset of decomposition of wax and impurities. The third decomposition peak was that of hemicellulose and was observed at around 170ºC. The fourth decomposition peak at 320ºC was the decomposition of the cellulose.

In summary, it seen that to enhance the durability performance of vegetable fibre reinforced cement-based composites, several approaches have been studied including fibre impregnation with blocking agents and water-repellent agents, sealing of matrix pore system, reduction of matrix alkalinity and combination of fibre impregnation and matrix modification (Gram, 1983, Canovas, 1992 and Tolêdo Filho, 1997) [8], [9], [10]. These methods of improvement of the durability of vegetable fibre composites may not be suitable for the development of sustainable and low-cost construction materials, especially in developing world.

In this study, locally sourced and processed sisal fibre was adopted as the reinforcing agent in the modified cement-based composite. The sisal fibre was treated by boiling and washing. Fa and CWCCB are by-products of thermal power plant and of brick factory respectively. These industrial by-products would have been destined for land fill but were beneficially used as pozzolanas for the matrix modification, following work by Nwankwo (2013) [11].

2. MATERIALS AND METHODS

The extraction methods, preparation and properties of sisal fibres, the chemical and physical properties of Fa and CWCCB and other constituent materials of the composite have been characterized and discussed elsewhere (Nwankwo, 2013). The 40mm average length sisal fibre was simply allowed to boil in clean water for 30minutes, it was allowed to cool, then washed and sun dried for 7 days at ambient conditions. The 1:2:4 mix ratios consisting of one part binder, two parts fine aggregate of river sand and four parts coarse aggregate of 19mm crushed granite, coded "4" was adopted for this research. The "BUA" brand 43 grade OPC conforming to BS 12 (1996) and ASTM-C-150 (1994) was kept constant as 50% of the binders, while the remaining binders i.e. Fa and CWCCB were varied in ratios of 20:30, 25:25 and 30:20 respectively. Sisal fibre content was kept constant at 3% volume fraction and water/binder ratio was also kept constant at 0.6. Mixing of the concrete was performed by hand in accordance with the procedure outlined in (Nwankwo, 2013), [11]. Slump tests and compaction factor tests were adopted as a measure of the workability of the fresh concrete mix. Nine variations of sample of the concrete composite were prepared for tests and coded as in Table 2 with interpretations as follows:

i. Control specimen with no sisal fibre and no blends of Fa and CWCCB.(4C)
ii. Specimens with 3% volume fraction of untreated sisal fibre with no blend of Fa and CWCCB (4F).
iii. Specimens with 3% volume fraction of heat treated sisal fibre with no blend of Fa and CWCCB (4FH).
iv. Specimens with 3% volume fraction of untreated sisal fibre with blends of 20%Fa and 30% CWCCB (4F20/30).
v. Specimens with 3% volume fraction of heat treated sisal fibre with blends of 20%Fa and 30% CWCCB (4FH20/30).
vi. Specimens with 3% volume fraction of untreated sisal fibre with blends of 25%Fa and 25% CWCCB (4F25/25).
vii. Specimens with 3% volume fraction of heat treated sisal fibre with blends of 25%Fa and 25% CWCCB (4FH25/25).
viii. Specimens with 3% volume fraction of untreated sisal fibre with blends of 30%Fa and 20% CWCCB (4F30/20).
ix. Specimens with 3% volume fraction of heat treated sisal fibre with blends of 30%Fa and 20% CWCCB (4FH30/20).

The compressive strength test on 150mm cube was adopted as a means of quantifying the performance of the hardened concrete composites. The specimens were cast in 150mm cube steel moulds in accordance with the procedure described in (Nwankwo, 2013) [11] and cured by immersion in clean water. The compressive strength tests were carried out in accordance with BS 1881: Part 116 (1983) at curing ages of 7, 28 and 90 days.

3. RESULTS AND DISCUSSION

3.1 Workability Studies

The rheological properties of fibre reinforced concrete are significant. It was therefore necessary to carry out the slump and compaction factor tests. The results of these tests are shown in Table 1. It is common knowledge that the addition of any type of fibre to plain concrete causes a reduction in the workability. This can be observed from the results in Table 1, which shows that on addition of 3% volume fraction of untreated sisal fibre, the slump for the control mix dropped from 85mm (medium workability) to 30mm (low workability). The large surface areas of fibres tend to restrain flowability and mobility of the mix. The results of the workability tests in Table 1 shows that the slump and compaction factor tests for specimens reinforced with boiled

Table 1 Results of Slump Test and Compaction Factor Test.

Mix Ratio	Treatment to Sisal Fibre	Blend FA: CWCCB (%)	Sisal Fibre ($\%V_f$)	Slump (mm)	Compaction Factor	Degree of Workability
Control	None	None	None	85	0.94	Medium

	None	None	3	30	0.83	Low
	HT	None	3	40	0.85	Low
	None	20:30	3	25	0.84	Low
1:2:4	HT	20:30	3	35	0.83	Low
	None	25:25	3	30	0.85	Low
	HT	25:25	3	35	0.85	Low
	None	30:20	3	30	0.86	Low
	HT	30:20	3	35	0.87	Low

HT: Heat Treated, CF: Compaction Factor.

and washed sisal fibres are higher than those with untreated sisal fibres. It can therefore be inferred that heat treatment of sisal fibres by boiling and washing improved the workability of the fresh concrete mix. A general drop in the slump and compaction factor was observed for specimens with blends of Fa and CWCCB in comparison with control batches. However, an improvement in the workability was observed when the ratio of Fa to CWCCB was greater (30:20 (Fa: CWCCB) blend). The reason for this improvement in workability may be attributed to the physical characteristics of Fa, i.e. the spherical, glossy nature and particle size distribution.

The slump and compaction factors generally reduced with the ternary blend of Fa and CWCCB, and were reduced further as the clay content is increased. The high surface area of CWCCB increases water demand and therefore for a given water/binder ratio, a higher ratio of CWCCB in a ternary blend of Fa and CWCCB, reduced workability. The reduced workability resulting from an increased ratio of CWCCB may also be a consequence of increased amount of silica in CWCCB. The silica-lime reaction requires more water in addition to water required during hydration of cement. While the immediate workability decreases, the adsorbed water might be partially released during the hardening process.

It is generally argued that workability tests based on static conditions, such as slump cone tests are not very effective and can be quite misleading, since the concrete is in fact workable when vibrated. Bentur and Mindess (2001) [12] recommended the use of dynamic tests. However in this research, Fa and CWCCB were blended with OPC. The particles of pozzolanic Fa are spherical and thus improve workability. Their inclusion has the physical effect of modifying the flocculation of cement, with a resulting reduction in water demand. The improvement in workability due to inclusion of these pozzolanas therefore adequately compensated for the loss in workability occasioned by the inclusion of sisal fibres. Thus, both slump and compaction factor tests were adopted for this research as a measure of the workability of the fresh concrete.

3.2 Compressive Strength

Results of the compressive strength tests for control specimens, specimens prepared with untreated and heat treated sisal fibres and ternary blends are shown in Table 2. All values are average of three results. The 7 days compressive strength results of specimens reinforced with untreated sisal fibres increased from 4.2N/mm^2 to 8.5N/mm^2 at 28 days and to 9.1N/mm^2 at 90 days curing ages, indicating 100% strength gain at 90 days. There was remarkable early strength development of about 40% when the specimens were reinforced with heat treated sisal fibres. The increase in the compressive strength of specimens reinforced with boiled and washed sisal fibres, may be attributed to the fact that hot-water solubility of boiled and washed sisal fibres was extremely low when compared with the untreated sisal fibres. All ternary mixtures reinforced with boiled and washed sisal fibres, showed an increased compressive strength. For the 20:30 (Fa: CWCCB) blended specimens, the compressive strength at 28 days curing ages increased from 3.0N/mm^2 for specimens reinforced with untreated sisal fibres, to 3.8N/mm^2 for specimens reinforced with boiled and washed sisal fibres. Specimens blended with 25:25 (Fa: CWCCB) and reinforced with boiled and washed sisal fibres showed remarkable increase in compressive strength compared with specimens reinforced with untreated sisal fibres. At 7, 28 and 90 days curing ages, the compressive strengths were observed to be 6.0N/mm^2, 6.9N/mm^2 and 7.1N/mm^2 respectively. This is an increase of 75%, 64% and 51% respectively over specimens reinforced with untreated sisal fibres. The remarkable improvement in the compressive strength of this category of specimens may be due to the good homogeny and high compaction between the boiled and washed sisal fibres and the blended matrix. This trend was however different with the 30:20 (Fa: CWCCB) blend, where it was observed that the compressive strength of specimens reinforced with untreated sisal fibres at 7, 28 and 90 days curing ages were higher than specimens reinforced with boiled and washed sisal fibres. This result showed that the effects of boiling and washing of sisal fibres on the compressive strength of ternary concrete, is a function of the type and blending ratios of the pozzolanas.

Table 2 Compressive Strength Results for 1:2:4 Mix Ratio and Ternary Mixtures.

Mix Identification	Compressive Strength (N/mm^2)		
	7 Day	28 Day	90 Day
4C	20.3	25.0	25.8
4F	4.2	8.5	9.1
4FH	7.0	8.5	9.4
4F20/30	2.3	3.0	2.3
4FH20/30	3.8	3.8	4.5
4F25/25	1.5	2.5	3.5

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4FH25/25	6.0	6.9	7.1
4F30/20	4.5	6.2	5.6
4FH30/20	3.5	4.5	4.7

4. CONCLUSION

Inclusion of 3% volume fraction of sisal fibres as reinforcing agent in concrete caused a reduction in the workability of the fresh concrete mix. Heat treatment of sisal fibres by boiling with clean water for 30minutes and washing improved the workability of the concrete mix. The compressive strength of concrete increased remarkably when reinforced with boiled and washed sisal fibres. The increase in compressive strength may be attributed to the hot-water solubility of boiled and washed sisal fibres compared with the untreated sisal fibres. The compressive strength of ternary concrete reinforced with heat treated sisal fibres is however a function of the type and blending ratios of the pozzolanas.

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