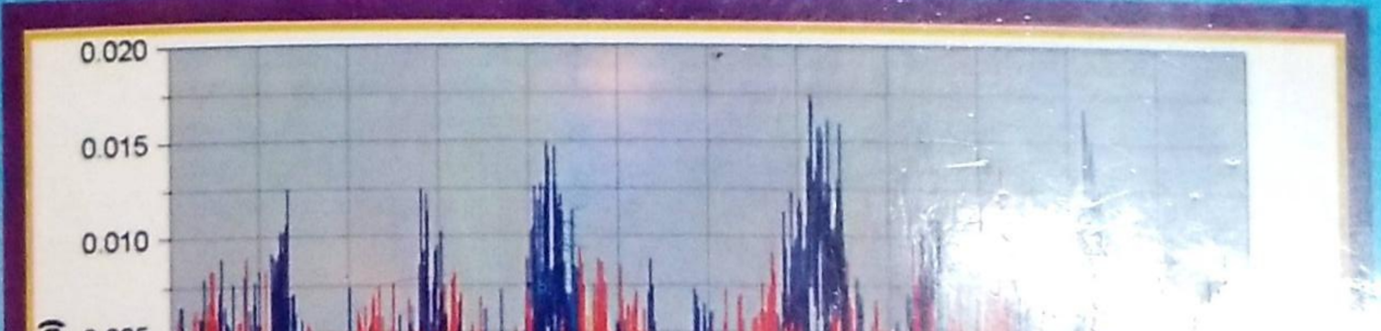
Environmental Technology & Science Journal (ETSJ)

Volume 3 No. 2 NOV., 2008 ISSN-2006-0459



PUBLISHED BY:
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Assessment of the Mechanical Properties of Sisal Fibre Reinforced Concrete Slab

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Abstract
The mechanical properties of sisal fibre reinforced concrete slab were examined using the central point bending test and the impact strength test. The sisal fibre reinforcement was hand laid in the form of mat or fabric with 0%, 2%, 4%, and 6% by weight of cement in a slab. Sisal fibre reinforcement was shown to improve some of the mechanical properties investigated. The flexural strength as well as impact strength was seen to increase as the fibre content increases from 0% to 6%. In contrast, the compressive strength reduces with a corresponding decrease in weight of the slabs as fibre content increases from 2% to 6% .The mix proportion used was 1:2:4 with water/cement ratio of 0.6 and cured for 28 days. The modulus of rupture for the slab was found to be 0.0039, 0.0078, 0.011 and 0.056 N/mm^2 respectively for 0%, 2%, 4%, and 6% of sisal fibre. For the impact strength, the number of blows to no rebound for the various percentages of fibre was 42, 36, 32 and 27. The maximum deflections at rupture were 6.00, 7.00, 9.00 and 12.00 mm for the various fibre content. The result shows that the slab reinforced with sisal fibre can be used in structural elements where high energy absorption may be required. The sisal fibre reinforced slab was also able to sustain some load even when cracks had developed.

Keywords: Sisal Fibre, Reinforced Concrete, Slab, Mechanical Properties, Compressive Strength

Introduction

Fibre reinforced concrete (FRC) is a kind of concrete to which various fibres of very small diameter and short lengths (for example, steel fibres 10 to 20 microns in diameter and 10 to 50mm length) are added to make a concrete. This material has increase tensile strength, resilience, flexibility and other qualities. The fibre may be steel, glass, polymer, carbon, or even natural fibres like coconut fibre. As glass reacts with cement, special care should be taken while using them. Fibre reinforced concrete has been used as overlays for pavements in airports, bridges and over industrial floors. It can also be used in structures where increased resistance to cracking is needed. (Varghese, 2006)

According to ACI 544.1R-82, fibre reinforced concrete is defined as concrete made with hydraulic cement, containing fine or fine and coarse aggregate and discontinuous discrete fibres. The fibres can be made from natural materials (e.g. asbestos, sisal, cellulose) or are a manufactured product such as glass, steel, carbon, and polymer (e.g. polypropylene, Kevlar). Neville, (2002) explained that both hydraulic cement paste and concrete exhibit somewhat brittle nature and this lead to the purpose of reinforcing the cement- base matrix with fibres are to increase the tensile strength by delaying the growth of cracks, and to increase the toughness (total energy absorbed or impact strength) by transmitting stress across a cracked section so that much larger deformation is possible beyond the peak stress than without fibre reinforcement. Fibre reinforcement improves the impact strength and fatigue strength, and also reduces shrinkage. The quantity of fibres used is small, typically 1 to 5 per cent by volume, and to render them effective as reinforcement the tensile strength, elongation at failure and modulus of elasticity of the fibre need to be substantially higher than the corresponding properties of the matrix.

Sisal Fibre

Sisal hemp (Agave Sisalana) belongs to the species of Agave cultivated for fibre. It is also known as true sisal because it is the chief source of structural fibre (Kochlar, 1981). Also Microsoft Encarta Dictionary,(2006) describe Sisal as a strong white fibre obtained from the leaves of an agave plant. Agaves in general are well adapted to arid environment, but sisal is capable of withstanding even desert conditions where other species cannot survive. Sisal thrives best on dry permeable sandy – loam soil with some lime but can grow on well drained black cotton soil. For good growth, sisal requires a high temperature and evenly distributed rainfall of 100 to 125cm^3. Sisal plants lives for 10 to 14 years, and during its life span, each plant produce 5 to 7 Kg of fibre (Skat, 1986). The leaves can be harvested mechanically or manually. Fibres can be extracted manually by beating the leaves or by allowing the leaves to rot. Manual extraction by beating is done by placing the cut leaves on hard surface and is continuously hit with an object made of wood or rubber until the leaves become very flexible and starts to foam. The sisal is then washed by allowing water to flow over it leaving the white strand or fibre.

Properties of Sisal Fibre

Fibre strands generally termed as fibre are rather coarse, nearly white or pale-yellow in colour, about 0.9 to 1.5m in length. Properly cleaned fibres are strong, fairly durable and resistance to the decaying action of micro-organism found in salt water. Sisal leaves contains 86% water, 4% fibre and 11% of other residues (I.L.O publication, 1992). Sisal fibre has a high percentage of cellulose (72%) and relatively high proportion of lignin (14.5%) (Kochlar, 1981).

Table 1.0 Physical Properties of Sisal Fibre

Properties	Values
Length (mm)	1000-1300
Diameter (mm)	0.2-0.3
Young modulus (N/mm^2)	26
Density (kg/m^3)	1450
Tensile strength (N/mm^2)	570
Elongation at break (%)	3
Water absorption (%)	60 – 70

Source: Ilo publication, (1992) and Kochlar, (1981).

Natural Fibre Reinforced Concrete

In cement based matrices, the two major role played by the fibre are to improve the toughness and the post cracking performance of the matrices. There are also some changes created to the pre-cracking behaviour of the hardened matrix, which help to define the composite action. Fibre content (% by volume), ratio of fibre modules to the matrix modules and the ratio of fibre strength to the matrix strength all influence the performance of the composite before and after cracking (Toledo et al, 1999). In a well designed composite, the fibres can serve two functions in the post cracking zone (Benture and Mindess, 1990. These functions are:

(i) To increase the strength of the composite over that at the matrix by providing a means of transferring stresses and Loads across the crack and

(ii)To increase the toughness of the composites by providing energy absorbing mechanism related to the rebounding and pull-out processes of the fibres bridging the cracks.

From the work of Swift and Smith (1978) respectively the result of flexural static strength (Table 1.0) and toughness of beams made of cement based fibre reinforced matrices, it was indicated that a remarkable high strengths can be achieved using suitable mixing and casting techniques with optimum fibre volume fraction. Although in Table 2.0, the modulus of rupture is found for different ages. They also observed that impact resistance can be improved by the addition of sisal fibres.

Table 2.0 Modulus of Rupture of Sisal Fibre Reinforced Concrete.

Mix proportion Cement:sand:coarse agg(w/c)	Fibre content (%)	Fibre length (mm)	Curing period (days)	Specimen size (mm)	Modulus of rupture (N/mm^2)
1:1.8:2.4(0.57)	3	50	28	100x100x500	3.70
1:1.8:2.4(0.57)	2	50	35	100x100x500	3.80
1:1.78:1.82(0.36)	5	50	14	100x100x500	4.80
1:3:0(0.50)	2	50	7	80X80X300	3.70
1:3:0(0.50)	1	50	28	80X80X300	3.30

Source: Swift and Smith, (1978,)

When fibres in the matrix material are placed vertically and horizontally, the greatest stiffness and strength is developed in the direction of the fibre. The properties of the composite will depend upon the fibre volume fraction, the mechanical properties of the components parts, assuming a linear elastic behaviour. For effective stress transfer to the fibre, the elastic modulus of the matrix must be very much lower than that of the fibre (Swift and Smith, 1979). It therefore follows that, there is a minimum modular Ratio, E (fibre)/ E (matrix) below which improvement in the mechanical strength properties of the composite maynot be obtained. High strength and high modulus fibres impact strength and stiffness to the composite whereas low modules, high elongation fibres would result to large energy absorption characteristic and impact toughness' and resistance to impact and explosive loading (Swift and Smith, 1979).

Theoretical Considerations

Mechanical Properties of Sisal Fibre Reinforced Concrete

Reinforcement of brittle matrices with fibre of different kinds has been shown to improve the mechanical properties of the composite material (Mutua et al, 1996).

3.0 The Mechanical Properties of Sisal Fibre.

Properties	Values
Tensile strength * (KN/m^2)	347.0
Modulus of elasticity * (KN/m^2)	14.0
Elongation of failure * (%)	5.0
Tensile strength * (KN/m^2)	325.0
Modulus of elasticity * (KN/m^2)	7.0
Elongation to failure * (%)	8.0
Specific gravity	0.7 to 1.0
Cross sectional area (mean, m^2) (10^{-4})	5
Cross sectional area (range, m^2) (10^{-4})	2 - 10

Source: Mutual et al (1996)

* Natural atmospheric conditions, 25°C, 60% relative humidity

* After soaking in water for 24 hours

Abrasion resistance

Resistance to abrasion may bear some relationship to crushing strength and in general, it is safe to assume that the concrete having the highest crushing strength has the greatest resistance to abrasion. Durability of the natural fibre is related to its resistance to deterioration (wear and tear) which is a result of external causes such as the effect of interaction between constituent materials such as alkali-fibre reaction, volume changes, due to permeability and absorption e.t.c. The effect of alkali on the fibre is severe as it dissolves the fibre content so that they become decomposed and loose their reinforcing properties. However, Gram (1980) suggested that the best way of contracting the embrittlement of these fibres is to reduce the alkalinity of the pore water, which is achieved when 40 to 50 % of cement is reduced. The information on the resistance of concrete to abrasion can be obtained with a dense concrete that has a low w/c ratio and a minimum of fine aggregate compatible with good workability and that has been properly placed and cured. The abrasion resistance increases roughly as does that compressive strength up to about 6,000 N/mm^2 (George, 1974).

Materials and Methods

The cement used in this experiment was finely grounded powder, which was a brand of Dangote Ordinary Portland cement produced in Obajana factory, Kogi State, Nigeria and conformed to BS EN 197-2000, and the mixing water was pipe borne water fit for drinking. The fine aggregate for this research work was obtained from a river around Bida environment. The sand was sieved to remove particle passing 5.00mm sieve and those retained on a 75μm sieve. The coarse aggregate used was crushed stone that passed through 20mm and retained on 4.75mm sieve. Sisal fiber used in accordance to the provision of BS 882 1983 as reinforcement for these research was obtained from building materials market at Dei-Dei, Abuja. The fibres were well stored and they contain minimum unwanted materials. The fibres were stuck together and had to be separated into strands before use. A standard mix of 1:2:4 with water/ cement ratio of 0.60 was used. A total of 12 number slab of dimension 460 x 460 x 50 mm was produce with 0%, 2%, 4% and 5% of the weight of cement replaced with fibre in the specimen. Mixing of the composite to achieve homogeneity was performed manually in the laboratory. The materials were measured and emptied on a clean plastic surface. It was then thoroughly dry mixed before a measured quantity of water was added, the mixing of the materials continues until a homogenous mix was achieved.

Presentation of Test Results and Analysis

Table 4, presents the results of the physical properties of the aggregates. The sand used for this work has a specific gravity of 2.63, a bulk density of 1686.20 kg/m^3, moisture content of 3.67%, a fineness modulus value of 2.43, a Coefficient of Uniformity (C_u) of 8.00 and a Coefficient of Curvature (C_c) of 1.02, the sand used is of Zone 1. These results reflect that the sand sample is well graded. The crushed stone sample has a specific gravity of 2.62, bulk density of 1682.50 kg/m^3, a C_u of 1.44 and a C_c Of 0.90, reflecting a uniform sample. All the aggregates conformed to the BS 812 (1985).

Table 4: Summary of Physical Properties of Constituent Material

Parameter	Sand	Crushed Stone
Specific Gravity	2.63	2.62
Bulk Density(kg/m^3)		
Uncompacted	1534.80	1564.41
Compacted	1686.20	1682.50
% Void	9.87	7.55
Moisture Content	3.67	
Sieve Analysis		
Fineness Modulus (F.M.)	2.43	
Coefficient of Uniformity	8.00	1.44
Coefficient of Curvature	1.02	0.90

Tests to determine slump, density and comprehensive strength were carried out in this study.

For the comprehensive strength tests, 460 x 460 x 50mm slab specimens were used. A total of 48 specimens were cast and cured in water at room temperature in the laboratory for 7, 14, 21 and 28 days. At the end of each curing period three specimens of each mixture were tested for compressive strength and the average was recorded. The results of the various test carried out on the aggregates, sisal fibre as well as the reinforced concrete made with this material indicates uniformity in the sample taken. The fine aggregate and coarse aggregate used falls within the grading limit stipulated in BS 882. (1983). The sand corresponds to the requirements of the nominal size of graded aggregate of size 5mm to 75μm; while the crushed stone corresponds to the requirements of the nominal size of graded aggregate size of 20mm to 5mm. The result for modulus of rupture at 28 days of curing and percentage of fibre reinforcement is presented in Table 5.

Table 5: Modulus of Rupture Results

% Sisal fibre	Maximum load (N)	Maximum deflection (mm)	Modulus of rupture (N/mm^2)
Plain concrete (0%)	10	6.00	0.0039
2%	20	7.00	0.0078
4%	30	9.00	0.011
6%	40	12.00	0.056

Table 5 shows that the modulus of rupture for the sisal fibre reinforced concrete is higher than that of the plain concrete thus showing that there is a general improvement in the bending strength of the sisal fibre reinforced concrete slab. A graph showing the variation of fibre percentage to the modulus of rupture is plotted in figure 1. Figure 2 described the variation of deflection with load.

Table 6: Compressive Strength Results

% Sisal fibre	Weight (kg)	Compressive strength (N/mm^2)
Plain concrete (0%)	24.00	20.50
2%	23.50	15.60
4%	22.60	17.05
6%	23.80	15.73

The compressive strength was determined through the use of the rebound hammer test. The result in Table 6 shows that the inclusion of the fibre has brought about a reduction in the compressive strength of the slab i.e. an increase in fibre content results to a corresponding decrease in the compressive strength compared to the compressive strength of the plain unreinforced concrete slab. Even though the rebound hammer is not an acceptable test, it is useful as a measure of uniformity and relative quality of concrete (Neville and Brooks, 2003). An increase in fibre content also gives a corresponding decrease in the weight of the slabs.

Table 7: Impact Strength Result

% Sisal fibre	Number of blows to no-rebound	Compressive strength (N/mm^2)	Weight (kg)
Plain concrete (0%)	42	18.70	24.00
2%	36	17.90	23.50
4%	32	16.90	22.60
6%	27	15.73	23.80

The impact strength is assessed in terms of the ability of the specimen to withstand repeated blow and to absorb energy. Hence the impact strength and total energy absorbed by the concrete increase with its static compressive strength

The hammer was placed on the slab and the number of blows which the slab can withstand before reaching the "no rebound" was taken. The "no-rebound" state indicates a definite state of damage.

It was observed that the higher the compressive strength, the lower the energy absorbed before cracking, and the greater the number of blows of reaching no-rebound.

Therefore, the sisal fibre reinforced concrete slab shows a significant improvement when subjected to impact loading and hence, has a higher energy absorption capacity when compared to the plain concrete slab. Fig.3 shows the relationship between numbers of blow to "no – rebound" and compressive strength.

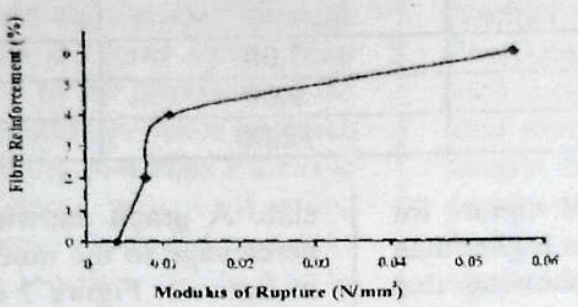

Fig 1.0: Variation Of Fibre Reinforcement (%) to Modulus of Rupture.

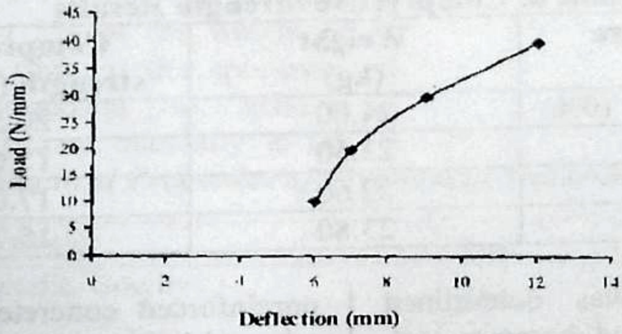

Fig 2.0: Variation of Deflection with Load

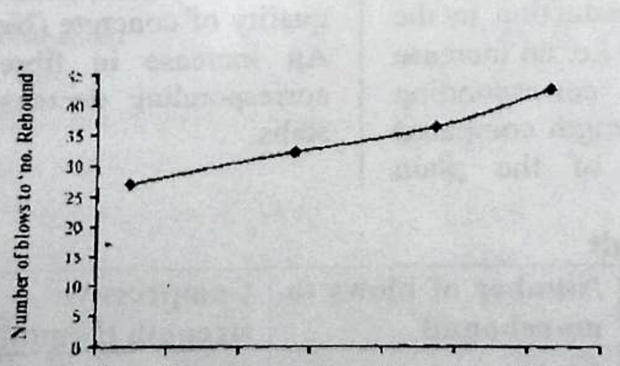

Fig 3.0: Relation Between Numbers of blow to 'no. Rebound' and Compressive Strength.

Conclusions and Recommendation

From the results of the research conducted, the following conclusions are drawn.

There is a significant impact of the fibre on the Bending Strength at 2% and 4% and 6% fibre content compared to the plain concrete slab of same section. The inclusion of fibre produced concrete with low compressive strength and high energy absorption capacity i.e. impact strength. The result also shows that the higher the fibre content, the higher the failure loads. It is thereby recommended that Sisal fibre could be used as reinforcement in concrete where high energy absorption is required.

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