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Predicting the engineering properties of concrete using acanthus montanus fibre

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ABSTRACT: *Acanthus montanus (Natural Sponge) fibre is abundant in Ghanaian forest. The Density, Compressive, Tensile strengths and Toughness of concrete reinforced with Acanthus montanus fibre were evaluated. A basic mix ratio of 1:1.5:3.0/0.5 (cement: sand: stones/wc) was used for the concrete with/without fibre. Fibre weight fraction of 0.25%, 0.50%, and 0.75% was added to concrete with varying wc ratios of 0.45, 0.50 and 0.55. The specimens were prepared, cured and tested in accordance with BS1881: 1982. Specimen with 0.75% fibre and 0.50 wc ratio had tensile strength of 4.09N/mm^2, 18% over the plain concrete. There was improvement of toughness by about 6% over the plain concrete with 0.75% fibre addition and 0.5 wc ratio. However, the addition of fibre did not improve the compressive strength. The specimen with 0.25% of fibre content and w/c of 0.5 had the highest compressive strength of 38 N/mm^2, among the fibre enhanced concrete, which is 5% lower than the plain concrete. The results of the study support the conclusion that addition of Natural Sponge fibre up to 0.75% (by weight of cement) is suitable enhancement of concrete where the Tensile strength and ductility of the concrete is emphasized for engineering purposes.*

Keywords: *Acanthus montanus, fibre, Natural, sponge, strength.*

I. Introduction

The overall development of a country relies on its infrastructural development. Accommodation has become a pressing challenge in Ghana and many parts of Africa.

Ghana Statistical Service (2012) reported that Ghana housing deficit stands 1.7 million. Affordable housing system has been a concern for rural and urban population in Ghana and other part of the world, due to the prohibitive costs of both construction and building materials. Scientist and Engineers are looking out for the use of alternative building materials which are renewable, readily available, cheap and environmental friendly local construction materials.

The building materials, constitutes the largest single input in construction of building. Adedeji, 2010 (as cited in Adedeji & Fa, 2012) reported that about sixty percent (60%) of the total housing expenditure goes for the purchase of building materials. Hence the need for local building materials to replace the expensive conventional building materials.

Natural reinforcing materials have a very important role in the alleviation of the housing problem due to its low cost and low levels of energy using local extraction. They are also in abundance, conserved scarce resources, and protect human and environment. The use of natural reinforcing materials as concrete enhancer is as a results of the expensive conventional building materials, which are mostly imported. Natural Sponge fibre, scientifically called Acanthus montanus fibre (AMF) (Dressler et al., 2014) has been successfully blended with Cocos nucifera (coir) fibre used as reinforcement for ceiling materials (Oladele et al., 2012).

Mass concrete is good in compression but weak in tension and tends to be brittle; engineers try to find an alternate way of solving the weakness in tension by using conventional steel bars and wire mesh reinforcement and inclusion of a sufficient volume of certain artificial fibres. Fibres in cement matrix composite improved toughness of the concrete after cracked. The used of Acanthus montanus fibre as concrete enhancer has not been detailed investigated.

The researcher's aim is to investigate the potential use of Sponge fibre as enhancement of the engineering properties of concrete.

II. Experimental study

The experimental investigation was carried out on test specimens using one basic mix proportion with three variations of water cement ratio (w/c), one fibre aspect ratio and different weight fraction (0.00%, 0.25%, 0.5%, and 0.75%) of Sponge fibre.

2.1 Materials

Ordinary Portland Cement conforming to BS12 (1996) operating on ISO 14000 from GHACEM was used. The fine aggregate was natural sand, passing through 20 mm and retained on 4.75 mm sieve size conforming to BS 882 (1975), while the coarse aggregate was crushed granite having a maximum size of 10mm. Sponge fibres with average diameter 0.40mm and average length 40mm was used. Portable water from Ghana Water Company was used.

2.2 Preparation of Acanthus montanus fibre (AMF)

The tread like sponge plant was soak in water for two weeks, beat with sticks to loosen the bark from the fibre. The twin sponge without the bark was then immersed in a 10% concentration of NaOH solution for thirty (30) minutes to dissolve the lignin and hemicelluloses of fibres to facilitate its extraction (Yalley & Kwan, 2009). The fibres after extraction were immersed in Acetic acid solution for 15 minutes to neutralise the NaOH solution. The fibres were further rinsed thoroughly in drinkable water to remove any chemicals that might be present.

The fibres were properly shaped and digital micrometer screw gauge was used to measure the diameters so as to determine the average diameter of the fibre. An aspect ratio of 100 was employed.

A: Fibre from forest **B:** Beating of fibre after soaking in water to loose the bark **C:** Fibre from NaOH solution

D:Fibre from Acetic acid solution **E:** Fibre from water **F:** Cutting Fibre after drying

Plate 1: Extraction of Acanthus montanus fibres

2.3 Preparation and testing methods

Ten batches with each batch of 10 cubes of side 150mm and 10 cylindrical specimens of 150 mm diameter and 300mm height. In all, a total of 200 specimens were prepared. A concrete strength of 30N/mm^2 was targeted. Try mix was conducted and mix proportion of 1:1.5:3 and wc ratio of 0.50 were arrived at (BS1881-108:193). Based on the results of the trial mixes mix proportion of 1:1.5:3 and three different wc ratio of 0.45, 0.50, and 0.55 were used. They were denoted by A as control specimen and batches with certain percentage of fibre addition as Bij; as specimens with "i%" fibre content and "j" water cement ratio. The concrete was hand mixed to ensure that the Fibres were uniform dispersed.

Mixing was done per BS1881-125:1986. To avoid balling of fibres, firstly, aggregates and cement were thoroughly mixed until a uniform grey colour was achieved. Secondly, the Fibres were gradually uniformly dispersed by hand, while mixing till all the fibres are found evenly distributed in the mix. Water was then gradually added while mixing. The same procedure for the mixing was used for the control mix but this time AMF was not added.

Cleaned and oiled moulds were then positioned, filled with the mixes in three layers. Each layer placed on compaction table and the top surface of the mould was levelled after the third compaction.

The specimens were stripped from the moulds 24 hours after casting and then submerged in water for 28 days until testing for strength (BS1881-111:1983). The cubes were subjected to compression test while the cylinders were subjected to splitting tensile test.

2.4 Test methods

The compressive testing machine used has model of 50-C46 G2 of maximum capacity of 200kN. Hundred cubes and hundred cylinders from each mix were tested for compression and splitting tensile strength respectively, at day 28 age in accordance with BS1881 (Plate 2 & 3).

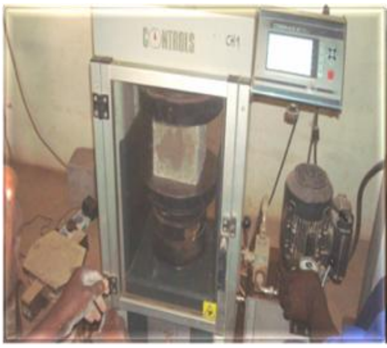

Plate 2: Compressive test

Plate 3: Splitting tensile test

III. Analysis of results

The analysis of the results from the laboratory experiments is in this section.

3.1 Density of the concrete

An average density for both the cubes and cylinders were used. The plain concrete had a density of 1677.20 kN/m^3 (See Table 1). The addition of AMF decreased the density from 1677.20 to 1527.10 kN/m^3 when 0.75% of fibre weight fraction was added. Within the fibre enhanced concrete the specimen with fibre content of 0.25% and water cement ratio of 0.50 had the highest density of 1637.37 kN/m^3, which is 2.4% lower than the plain concrete.

At the same wc ratio, increased in the fibre content decreased the Density of the concrete. In the same vein keeping constant fibre content, specimens with 0.50 water cement ratio had the highest density than those of w/c of 0.45 and 0.55. From literature, Lertwattanaruk and Suntijitto (2014) reported that increasing the percentage replacement of natural fibres tends to reduce the density of the composites.

Table 1 Results showing the properties of density for AMFC

Specimens	Fibre Content (%)	Water cement Ratio	Density (Kg/m^3)
A0.00/0.50	0.00	0.50	1677.20
B0.25/0.45	0.25	0.45	1560.60
B0.25/0.50	0.25	0.50	1637.78
B0.25/0.55	0.25	0.55	1567.35
C0.50/0.45	0.50	0.45	1556.40
C0.50/0.50	0.50	0.50	1588.30
C0.50/0.55	0.50	0.55	1558.10
D0.75/0.45	0.75	0.45	1548.08
D0.75/0.50	0.75	0.50	1579.60
D0.75/0.55	0.75	0.55	1527.10

Source: Author, 2016

From (1), both the fibre content (FC) and water cement ratio (w/c) are negatively correlated to density. When the fibre content is increased by 1% and keeping wc constant, the density will decrease by about 128kg/m^3. Likewise the density will decrease by 42kg/m^3 when wc is increased by one unit and keeping fibre content constant.

With R^2(adj.) = 0.7 explained that about 70% of the variations in density is influenced by fibre content (FC) and water cement ratio (w/c), with fibre content being the main contributing variable (t-value = -7.82).

$$\textbf{Density (kg/m}^3\textbf{) = 1677.20 - 127.87fc(\%) - 42w/c} \quad \textbf{(1)}$$

This would suggest that the present regression model is a good predictor of density. It would appear that the fibre content explained the bulk of the variance in the density (t=- 7.82, p=0.016).

Table 2 Regression Analysis: Density versus fibre content, water cement ratio

Term	Coef	R-square	R-sq(adj)	F-Value	t-value	P-Vlaue
Constant	1677.20	83.34%	70.01%		11.50	0.000
Fibre content (%)	-127.20				-7.82	0.016
Water cement ratio	-42				-1.15	0.0888
Regression				4.00		0.069

Source: Author, 2016

3.2 Compressive strength

The addition of AMF did not increase the compressive strength (Table 3). This result confirms Oladele et al., 2012 and Ozerkan et al., 2014 saying compressive strength decreased with inclusion of fibre content.
At the same wc ratio specimen with 0.25% fibre content against 0.50 water cement ratio recorded the maximum compressive strength which is about 5% less than the plain concrete of 40.09 N/mm^2. In general there was 16% reduction in the compressive strength when 0.75% of fibre was added to the concrete.

Table 3 Compressive strength AMFC

Specimens	Fibre Content (%)	Water cement Ratio	Compressive Strength (N/mm^2)
A0.00/0.50	0.00	0.50	40.09
B0.25/0.45	0.25	0.45	37.58
B0.25/0.50	0.25	0.50	38.09
B0.25/0.55	0.25	0.55	34.55
C0.50/0.45	0.50	0.45	35.70
C0.50/0.50	0.50	0.50	37.22
C0.50/0.55	0.50	0.55	33.78
D0.75/0.45	0.75	0.45	35.42
D0.75/0.50	0.75	0.50	36.10
D0.75/0.55	0.75	0.55	33.66

Source: Author, 2016

The predicted equation for compressive strength is

$$\textbf{CS (N/mm}^2\textbf{) = 40.09 - 5.33 fc (\%) – 22.4 w/c} \quad \textbf{(2)}$$

Fibre content and Water cement ratio are negatively related to Compressive Strength. The R^2 adjusted explained that about 65% of the variations in the compressive strength are influenced by the fibre content and water cement ratio. From (2) a percentage increased in fibre content decreased the compressive strength of about 5.33N/mm^2 at a content wc ratio.

This would suggest that the present regression model is a good predictor of compressive strength. It would appear that the fibre content and wc ratio both explained the bulk of the variance in the compressive strength (t=- 5.01, p=0.019; t= -4.01, p=0.085). The F-value (6.59) suggests that all the factors have significant impact on the compressive strength since p-value is 0.025 at 5% significant level.

Table 4 Regression Analysis: Compressive strength versus fibre content, water cement ratio

Term	Coef	R-square	R-sq(adj)	F-Value	t-value	P-Vlaue
Constant	40.09	75.32%	65.41%		8.83	0.000
Fibre content (%)	-5.33				-5.02	0.019
Water cement ratio	-22.4				-4.01	0.085
Regression				6.59		0.025

Source: Author, 2016

3.3 Split tensile strength

AMF content (%) in the cement matrix enhanced concrete. Within the concrete enhanced with AMF, table 5, at the same fibre content specimen with water cement ratio 0.50 as against fibre content of 0.75% recorded the highest tensile strength which is 18% more than the cement matrix. It was noted that the highest properties were obtained at optimum fibre weight fraction of 0.75% with water cement ratio of 0.50 compare with the concrete in the absence of AMF.

Table 5 Split tensile of concrete specimens with AMF

Specimens	Fibre Content (%)	Water cement Ratio	Tensile split Strength (N/mm^2)
A0.00/0.50	0.00	0.50	3.46
B0.25/0.45	0.25	0.45	3.55
B0.25/0.50	0.25	0.50	3.51
B0.25/0.55	0.25	0.55	3.51
C0.50/0.45	0.50	0.45	3.58
C0.50/0.50	0.50	0.50	3.73
C0.50/0.55	0.50	0.55	3.51
D0.75/0.45	0.75	0.45	3.83
D0.75/0.50	0.75	0.50	4.09
D0.75/0.55	0.75	0.55	3.53

Source: Author, 2016

From (3) Fibre content is a positively related while Water cement ratio is negatively related to Split Tensile Strength. The R^2 adjusted is 70.34%, explained that about 38% of the variations in the Split Tensile Strength are influenced by Fibre content & Water cement ratio. Yalley & Kwan 2009 and Domke, 2012 said concrete enhanced with Fibre content were held together even after failure. Again, a percentage increased in fibre content increased the Split Tensile Strength by a margin of $0.509N/mm^2$.

$$\textbf{TS }(N/mm^2) = 3.46+0.509fc\ (\%)-1.37w/c \qquad (3)$$

It would appear that the fibre content explained the bulk of the variance in the Tensile strength ($t=3.53$, $p<0.039$). The F-value (3.80) suggests the overall factors have no significant impact on the Tensile strength at 5% significant level.

Table 6 Regression Analysis: Split tensile strength versus water cement ratio, fibre content

Term	Coef	R-sq	R-sq(adj)	F-Value	t-value	P-Vlaue
Constant	3.46	82.04%	70.34%		6.35	0.000
Fibre content (%)	0.509				3.53	0.039
Water cement ratio	-1.37				-1.08	0.318
Regression				3.80		0.076

Source: Author, 2016

3.4 Toughness

Within all the fibre enhance concretes toughness was better than the control with the exception of 0.25%/0.45 specimens. The optimum specimens of 0.75%/0.50 resulted in the highest value of energy absorption, about 6% more than the control. Bantie, 2010; and Udoeyo and Adetifa (2012) are in support of the result. The energy absorption capacity (toughness) of the AMF concrete, which express ductility; was measured by the area under stress-strain curve, as displayed in Fig. 1.

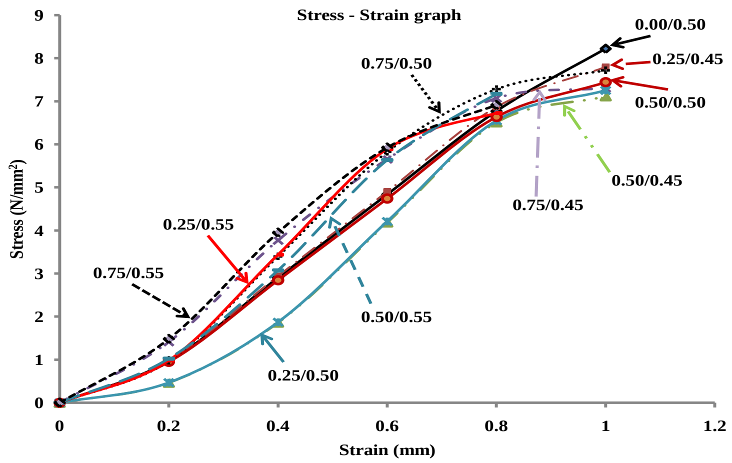

Figure 1: stress-strain curve

The toughness has multiple regression equation of

$$\mathbf{T = 23.7 + 2.70fc(\%) + 55.4\ w/c} \qquad \textbf{(4)}$$

Where T = toughness, FC = fibre content, and W/C = water cement ratio

From (5), both variables are positively related. If endogenous variables are considered constant, the Toughness is 23.7N/mm^2. Holding fibre content constant if water cement ratio is increase by 1unit, the Toughness will increase by 55.4 N/mm^2 and is significant at 5% level for t-value (2.80) and p-value of 0.027, it has impact on the Toughness. Again if water cement ratio is held constant thereby increasing fibre content by 1%, the Toughness will go up by 2.70N/mm^2. With t-value (7.86) and p-value of 0. 018 show that it is significant and it implies that the fibre content is the main predictor of Toughness at 5% level. The R^2 -(adj.) explained that 72.17% of the variation in toughness is explained by the independent variables. The F-value (4.28) suggests that the overall factors have no significant (0.061) influence on Toughness at 5% level.

Table 4.7 Regression Analysis: Toughness versus water cement ratio, fibre content

Term	Coef	R-sq(adj)	R-sq(adj)	F-Value	t-value	P-Vlaue
Constant	23.7	55.02%	72.17%		-0.76	0.472
Fibre content (%)	2.7				7.86	0. 018
Water cement ratio	55.4				2.80	0.027
Regression				4.28		0.061

Source: Author, 2015

IV. Conclusions

Out of the experimental investigations on the strength characteristics of concrete reinforced with AMF's, the following conclusions can be derived out of the findings.

- The presence of fibres in concrete alerts the decrease of the concrete. It is found that the density of the concrete decreases of about 2.4%. It is as a result of the presence of light weight fibre content which has lighter weight and has replaced some of the cement matrix. The optimum density satisfies the light weight concrete requirement of 300-1850kg/m^3.
- Compressive strength was affected with the introduction of fibres. The strength is about 5% lower than the cement matrix, as a result of increase in fibre content associated with voids due to difficulties in compaction. Although the presence of fibre decreased the compressive strength, the value is more than the range of 17 - 28 N/mm^2 as concrete compressive strength requirement for residential building.

- There was improvement of the Splitting Tensile Strength and Toughness of concrete with fibre addition. This may be due to increase in bonding between AMF and the cement matrix.
- The proposed models were able to predict the test results accurately.

V. Acknowledgements

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VI. Recommendation

I recommend long term durability be conducted on Sponge fibre in concrete and mortar mix.
Silt test be conducted on the sand before use in the RC concrete and further research should be done beyond Sponge fibre concrete content of 0.75%.

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APPENDIX B
Processes of the test experiment

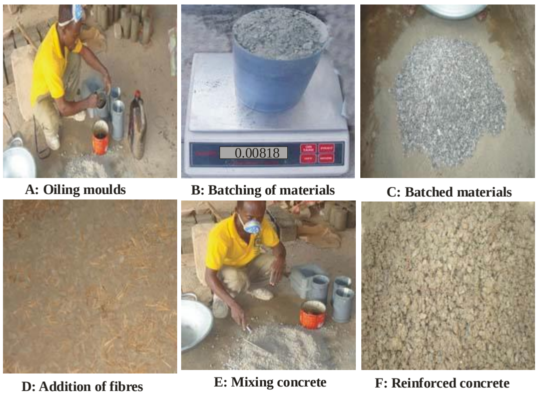

Plate B 3a Preparation of reinforced concrete

Plate B 3b Casting of moulds and curing

Plate B 3c Distractive cubes

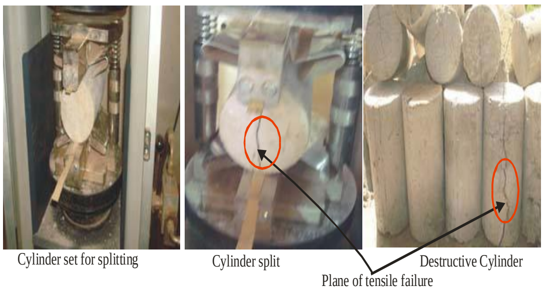

Plate B 3d Destructive cylinders