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ESTIMATING THE SHEAR STRENGTH OF SISAL FIBRE REINFORCED CONCRETE

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ABSTRACT
This research examines the shear strength of Sisal Fibre Reinforced Concrete (SSFRC).Sisal Fibre (SSF) addition was at 1% by weight of dry constituents, this is considered the upper limit for workable mixes in the absence of water reducing agents. Beams of various grades of concrete (20N/mm^2 to 40N/mm^2) were tested and they all failed in shear. Experimental results of beams were compared with modified versions of the BS 8110 formula for shear strength in concrete, to determine the best fit. The inclusion of SSF at 1% addition increased the compressive strength of the concrete mix by an average of 16.9% and the shear strength by 16%. However, the shear strengths of the SFRC are only greater than those of normal concrete of corresponding compressive strengths by 9.5%. The equation proposed may be used to estimate the shear strength of SSF reinforced concrete at this level of fibre addition.

Keywords: *Compressive strength, Reinforced concrete, Shear strength, Sisal fibre.*

1. INTRODUCTION

There are different modes of shear failures in concrete structures. These different modes arise from different types of deformation around the critical diagonal or inclined crack formed from the interaction of moment and shear forces across the section. These deformations include sliding, rotation and disintegration which gives rise to corresponding failure modes such as diagonal tension, shear compression and web crushing. Shear failure, especially without shear reinforcement is brittle being initiated by tensile cracks and needs to be avoided, Since shear failure is initiated or precipitated by tensile cracks, any process which can delay the formation or propagation of the critical crack after formation will be expected to result in an increase in the shear strength of reinforced concrete elements. Fibre reinforcement has been used to toughen soils, bricks and pottery since ancient time [1-3]. However, it has become a viable option in recent time for toughening brittle matrix and materials.

Extensive research and development have been conducted into the production, properties and applications of Fibre Reinforced Concrete (FRC) and reported all over the world. Since 1973, the American Concrete Institution (ACI) has been publishing "State of the Art Reports" on the use of FRC [4, 5]. Furthermore, other studies have been reported elsewhere such that the behaviour and principle of fibre reinforcement in concrete and other brittle materials are fairly understood. Short and randomly distributed fibres in concrete have been shown to improve its tensile strength, flexural strength, toughness, impact strength and durability [6 – 8]. In their study [8] reported that the inclusion of fibres can slightly increase the cracking strength of the matrix, though the cracking strain of the matrix remains unchanged. The most beneficial part of fibre reinforcement characteristics is post cracking behaviour; it has been discovered that though the fibres may not increase the cracking strength significantly, the rapid propagation or widening of the

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crack is arrested as the high modulus fibres bridge the gap between the two surfaces of the crack allowing more contact and preventing sliding or rotational movement, thereby increasing the rupture strength and other properties such as permeability and abrasion [9 – 11]. Fibres suitable for reinforcing concrete have been produced from steel, glass, carbon, and polymers. Naturally occurring fibres such as sisal, sugar cane bagasse and jute are also used for reinforcement [4, 5].

Investigations on shear failure of FRC beams have shown that an adequate amount of appropriately shaped fibres can significantly increase the shear resistance of concrete beams [12 – 15].For many of these studies, especially those done in developed countries, research and developments have concentrated on metallic and polymer fibres because they are stronger, durable and more effective. [14] **c**arried out an experimental study to predict the shear strength of steel fibre reinforced concrete beams based on existing experimental results, they used a large database containing 222 shear strength tests of Steel Fibre Reinforced Concrete beams without stirrups and developed equations for predicting the shear strengths of different groups of such beams by linear and non-linear regression analysis. A statistical analysis was then performed to compare their proposed equations to those developed by other previous researchers. Overall, it was observed that the linear regression equations developed from their study could accurately predict the shear strength compared to the other previously proposed models. Likewise, [16] carried out an experimental research on the prediction of shear strength of steel fibre reinforced concrete beams without web reinforcement in which standard beams made of steel fibre reinforced concrete with different amount of fibres (ranging from 0.0% to 1.5.0% by volume) were tested under direct shear. They observed that the ultimate shear strength of matrix increases significantly by adding fibres to the matrix and proposed an equation for the ultimate shear strength of such beams. They observed that the optimum content of fibre is about 0.75% volumetric percentage.

However, in developing countries such as Nigeria, metallic and synthetic fibres are not readily available, they are therefore very expensive and this has not encouraged the popular usage of FRC. The alternatives to metallic and polymer fibres are natural fibres which are easily produced and whose production can be sustained in developing countries. Sisal fibre produced from the leaves of the plant *Agavesisalana* is one of the most promising natural fibre reinforcement for use in composites such as concrete, on the account of its low cost, low density, high specific strength, high modulus, no health risk and easy availability [17]**.** In Australia, sisal fibres have been successfully used for making gypsum plaster sheets. A considerable amount of research has been carried out in Sweden for developing good quality concrete products reinforced with sisal fibres. These fibres are stronger than most of the other natural fibres [4].

Many studies have been reported on the properties and strengths of SSFRC [11, 18 – 23]. Most of these studies have concentrated on the effect of fibre length and percentages on compressive and tensile strengths or the effect on durability and flexural strength but few studies have been conducted on shear strength.

Therefore, this study aims to extend the knowledge of the use of Sisal fibre reinforcement by investigating the effect of Sisal fibre reinforcement on the shear strength of beams without web reinforcement, with the fibre content near recommended optimum value without the use of water reducing agents. The objectives were:

i) To produce ordinary reinforced concrete and sisal fibre concrete of compressive strengths between 20N/mm^2 and 40N/mm^2.
ii) To determine the wet and hardened state properties of the concrete (workability, compressive strengths and density).
iii) To determine and compare the shear strength of the different types of concrete, using a beam test.
iv) To determine the relationship between the shear strength and compressive strength of sisal fibre reinforced concrete.

2. MATERIALS AND METHODS

2.1 Materials

The following materials were used in the research work:

a) ***Cement:*** - Grade 42.5 Portland Cement conforming to Nigeria Standard which was sourced from a local Supplier in Kaduna, Nigeria.
b) ***Fine and coarse aggregate:***- Locally available sharp river sand was used as fine aggregate while crushed granite chippings of 20mm maximum aggregate size was used as coarse aggregate respectively. They were sourced from local Suppliers at Tudun Wada, Kaduna. Preliminary

material tests showed that they were suitable for concrete work as recommended by BS 882 [24].

c) ***Steel reinforcement****:* - 12mm diameter reinforcement was sourced from a local Supplier at Panteka Market, Kaduna and was tested to confirm conformity with BS 4449 [25] standards (Test set up shown in Figure 1)

d) ***Sisal fibre:*** **-** Sisal fibre, shown below in Figure 2 was sourced from the Panteka Market in Kaduna and its properties as previously determined by [26] are presented in Table 1.

2.2 Methods

2.2.1 Concrete Mixes

Normal concrete mixes to were designed to produce concrete of compressive strength between 20N/mm^2 and 40N/mm^{2}at steps of 5N/mm^2. The final concrete mixes adopted were obtained through adjustments by series of trial mixes. The mix ratios adopted for 20, 25, 30, 35 and 40N/mm^2 were 1:2:3.5, 1:2:3, 1:1.5:2, 1.1:2, and 1:1:1 respectively. Water to cement ratio used for the mixes were 0.6, 0.6, 0.5, 0.4 and 0.36 respectively. To these mixes were added Sisal fibres at 1% by weight of dry constituent of the concrete. All mixes were hand mixed until consistent mixture was obtained and 150mm cubes were produced in accordance with [27]. The Cubes were demoulded after 24hours and cured in water at ambient temperature until compressive strength test at 28 days.

2.2.2 Beam Specimen Production

Test beam samples measuring 110mm x 200mm x 1200mm (see Figure 4) were produced, three for each grade and type of concrete. Casting was in wooden moulds shown in Figure 3 with compaction by tamping rod method. Samples were cured in water at ambient temperature for 28 days before testing. All beams were reinforced with 2No. 12mm diameter bars as main reinforcement and 8mm diameter stirrups at the two ends to hold the main reinforcement in place as shown in Figures 4

Figure 1: Setup for Testing of Steel Reinforcement

Table 1: Properties of the Sisal fibre

Property	Value
Natural humidity	14.48%
Average diameter	0.13mm
Water absorption	340%
Specific gravity	0.22g/cm^3
Tensile Strength for One strand	10.60N/mm^2
Tensile Strength for Two strands	24.45N/mm^2
Tensile Strength for Three strands	30.60N/mm^2
Elongation at break,	5.58mm
Colour	Shiny white

Figure 2: Sisal fibre

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Figure 3: Wooden Formwork, Cast Beams and Cubes

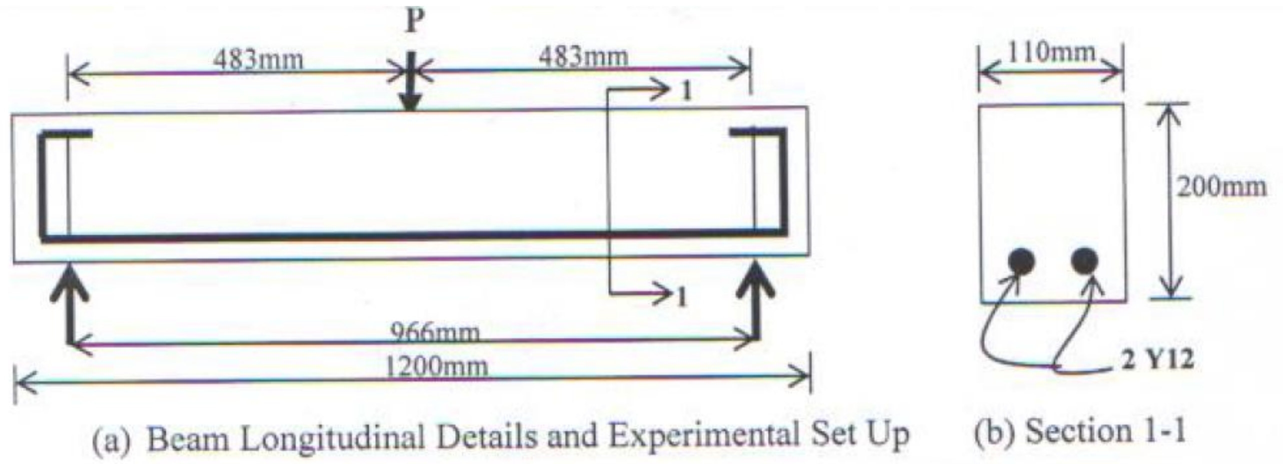

Fig 4: Beam Details and Test Setup

Figure 5: Slump Test to Determine Mix Workability

2.2.3 Workability:
Slump test was adopted to determine the workability of the wet concrete and was carried out according to [28] as shown in Figure 5.

2.2.4 Density and Compressive Strength Test:
The density and compressive strength of both normal and fibre reinforced concrete mixes were determined at 28 days in accordance with [29, 30]. See Figure 6 for the crushing machine and testing.

2.2.5 Beam Shear Test:
Beam samples were tested at 28 days for shear strength under 3-point loading arrangement as shown in Figure 4 and Figure 7. The 3-point loading arrangement was adopted because of the limitation of the machine and the need to maintain a shear span/effective depth ratio of 3. The test was conducted with a 3000kNCapacity SEIDNER Universal Testing Machine (see Figure 7)

Figure 6: Compressive Strength Tests on Cubes at 28 Days

Figure 7: Beam Test Set Up and Tested Beams

Table 2: Slump Test Value for Normal and Sisal Fibre Concrete

Grade Target (fcu)	G20	G25	G30	G35	G40
Slump values(0% Sisal fibre) mm	50	35	45	35	55
Slump values(1% Sisal fibre) mm	12	15	25	32	38

3. RESULTS AND DISCUSSION

3.1 Reinforcement Properties

The Yield Strength of the main reinforcement (Y12) was 527N/mm^2 while the Ultimate Strength was 571N/mm^{2}and these were obtained from five (5) samples taking randomly from suppliers from the local market in Kaduna.

3.2 Workability

The results of the slump test for all the concrete mixes are presented in Table 2. As may be observed from Table 2, the workability decreased with the inclusion of Sisal fibre for every mix, though in general, workability ranged between low to medium for both normal and Sisal Fibre Concrete.

3.3 Concrete Density

The results of the density test of all the mixes are presented in Table 3. The average density of normal concrete was 2423kg/m^3 for all mixes, while that of Sisal fibre reinforced concrete was 2401kg/m^3. In general the density of Sisal fibre reinforced concrete was lower for the same mix, this implies that the inclusion of 1% sisal fibre reduced the density of concrete by 0.91%.It could be observed that, the addition of sisal fibre did not reduce the density significantly, since this is still within the range for normal concrete weight, which is between 2300 and 2500kg/m^3 for concrete produced from granite chippings.

Table 3: Density of Concrete for Normal and Sisal Fibre Concrete

S/N	Concrete Target Grade	Density 0% Sisal fibre (kg/m^3)	Density 1% Sisal fibre (kg/m^3)	Percentage differences in Density between normal and SFRC (%)
1.	G20	2413	2387	-1.08
2.	G25	2428	2403	-1.03
3.	G30	2452	2404	-1.96
4.	G35	2415	2422	0.29
5.	G40	2408	2389	-0.79
Average		2423	2401	-0.91

3.4 Compressive Strength Test Results

The results of the compressive strength test are presented in Table 4. Table 4 shows that the sisal fibre reinforced concrete had higher compressive strengths than their normal concrete counterparts. The difference ranged from 11.5% to 22.3% with an average of 16.9%.

Table 4: Compressive Strength of Concrete, fcu (N/mm²)

S/N	Target Concrete Grade	Compressive. Strength 0% Sisal fibre A (N/mm²)	Compressive. Strength 1% Sisal fibre B (N/mm²)	Ratio of Compressive Strength B/A
1.	G20	21.82	25.48	1.168
2.	G25	26.77	29.84	1.115
3.	G30	28.22	34.52	1.223
4.	G35	34.99	40.68	1.163
5.	G40	39.94	47.03	1.178
		Average		1.169

3.5 Beam Test Results

3.5.1 Cracking Behaviour and Failure Modes

All the beams tested failed in shear after the formation of a diagonal tension/shear crack (See Figure 8). However, there was slight difference in the behaviour of normal concrete and Sisal fibre reinforced concrete beams. For normal concrete, eventual failure occurred almost immediately after the formation of the diagonal tension crack. Whereas, for the fibre reinforced concrete beams, failure was delayed or prolonged as the fibres formed a bridge of resistance and slowed down crack growth. It was observed that the normal reinforced concrete beam failed by diagonal tension as diagonal tension crack which appeared grew up and down the beam depth with little resistance and very small increase in load after the formation of the diagonal crack. On the other hand, the Sisal fibre reinforced concrete beams developed other smaller cracks after the formation of the critical diagonal crack because of the presence of the fibre reinforcement which slowed down the propagation. The fibre reinforced concrete beam failed generally in the shear compression mode with the crushing of the small compression zone at the head of the critical diagonal crack.

3.5.2 Shear strength results

Presented in Table 5 is the shear strength of all beams tested with the corresponding concrete strength. These data has been plotted in Figure 9 to show the trend of the shear strength with compressive strength of concrete for the two types of concrete. Figure 9 shows that shear strength of sisal fibre reinforced concrete is higher than that of normal concrete of similar strength and the trend lines are almost parallel. The shear strengths of the sisal fibre concrete mixes were on the average 16% higher than those of the corresponding normal concrete mixes.

Figure 8: Shear Failures in Beam Test

Table 5: Shear strength of Concrete Beams

S/N	Beam I.D	Compressive Strength of Concrete f_{cu} (N/mm^2)	Shear Strength of Beam v_c (N/mm^2)
1.	**G**20	22.01	1.55
2.	**G**25	26.79	1.64
3.	**G**30	29.36	1.69
4.	**G**35	34.65	1.75
5.	**G**40	39.67	1.84
6.	**FG**20	25.48	1.78
7.	**FG**25	29.84	1.85
8.	**FG**30	34.52	1.96
9.	**FG**35	40.68	2.06
10.	**FG**40	47.03	2.14

G – Normal Concrete and **FG** – 1% Fibre Reinforced Concrete

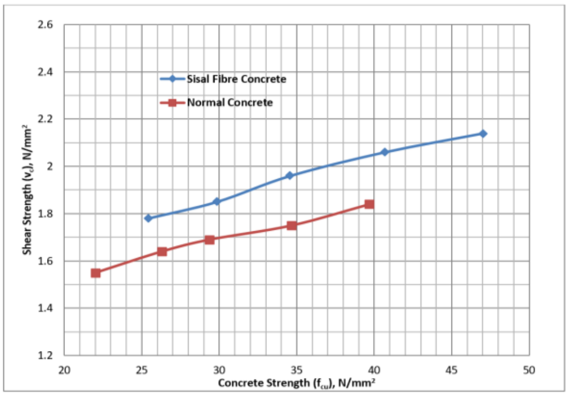

Figure 9: Relationship between Shear Strength and Compressive Strength for normal and Sisal fibre reinforced concrete

4. ANALYSIS OF RESULTS

4.1 Equation for the Shear Strength of Sisal Fibre Reinforced Concrete

It is generally accepted that the mechanism of shear resistance is too complex to be represented by a single theory of failure or for shear failure to be represented by a single theoretical formula. However, elements contributing to the shear resistance have been identified and these include dowel action, aggregate interlock and compressive strength of the concrete. Though the contributory actors are known, the interactions between them are not completely known or understood. Therefore, shear strength of reinforced concrete elements unreinforced in shear are normally calculated using empirical formulas derived from a combination of dimensional analysis and statistical analysis on observed experimental results. Such a formula is that of BS 8110-1:1997[31] which has the form given in Equation (i). In BS 8110, $\mathbf{k_1}$= 0.67.

$$\vartheta_c = k_1 \left(\frac{100A_s}{b_v d}\right)^{\frac{1}{3}} \left(\frac{400}{d}\right)^{\frac{1}{4}} \left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} \qquad (1)$$

Where:

v_c = Concrete shear strength; k_1 = Empirical constant; A_s = Area of main reinforcement

b_v = Shear breadth; d = effective depth of main reinforcement; f_{cu} = Characteristic cube strength of concrete

In this study, only the compressive strength of the concrete has been varied. If it is therefore assumed that all other terms retain their form and other forms of the concrete strength term which have been suggested are explored, the best formula which fits best the observed result may be adopted. Other forms of Equation (1) explored are given in Equations (2) and (3).

$$\vartheta_c = k_2 \left(\frac{100A_s}{b_v d}\right)^{\frac{1}{3}} \left(\frac{400}{d}\right)^{\frac{1}{4}} \left(\frac{f_{cu}}{25}\right)^{\frac{1}{2}} \qquad (2)$$

$$\vartheta_c = k_3 \left(\frac{100A_s}{b_v d}\right)^{\frac{1}{3}} \left(\frac{400}{d}\right)^{\frac{1}{4}} \left(\frac{f_{cu}}{25}\right)^{\frac{2}{3}} \qquad (3)$$

The forms of Equations (1) to (3) have been compared to the experimental results in Figures 10 –12.Analysis of the SSFRC beam result with Equation (1) gave an average value of 1.285 for k_1, with Standard deviation of 0.011and hence an acceptable coefficient of variation (COV) of 0.8 %.From Figure 10, the regression line follows the experimental curve closely and tends to represent the trend of the results obtained. Analysis of the SSFRC beam result with Equation (2) gave an average value of 1.218 for the empirical constant k_2 with Standard deviation of 0.058 with a Coefficient of variation (COV) of 4.8%. However as shown in Figure 11, the line of the equation (2) is steeper than that of the experimental result. The equation gave lower values of shear strength at compressive strengths lower than 35N/mm^2 but higher shear strength values for compressive strengths higher than this value. Therefore, Equation (2) cannot be said to represent the trend of the experimental result obtained. Analysis of the SSFRC beam result with Equation (3) gave an average value of 1.156 for the empirical constant k_3, the data gave Standard deviation of 0.102 and the Coefficient of Variation (COV) was 8.8%. As plotted in Figure 12, the line of the Equation (3) fails to represent the trend of the experimental result and is similar in characteristics to that of Equation (2). From the analysis, the Equation

(1) best fits the result of this study and may be used to estimate the shear strength of Sisal Fibre Reinforced Concrete at this level of fibre reinforcement. This equation is represented complete as Equation (4):

$$v_c = 1.285\left(\frac{100A_s}{b_v d}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} \quad (4)$$

Analysis of the normal concrete results gave:

$$v_c = 1.173\left(\frac{100A_s}{b_v d}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} \quad (5)$$

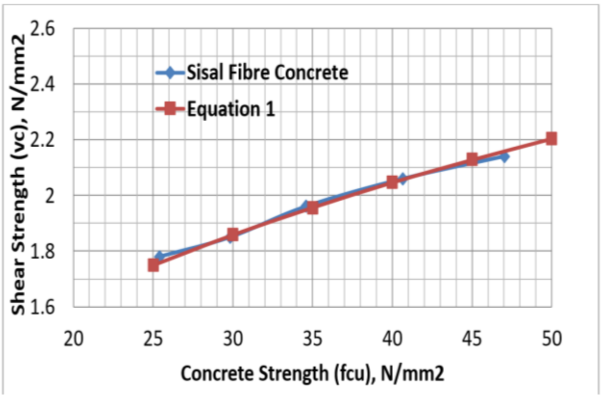

Fig 10: Comparison of Equation (1) and the Shear Strength of Sisal Fibre Reinforced Concrete

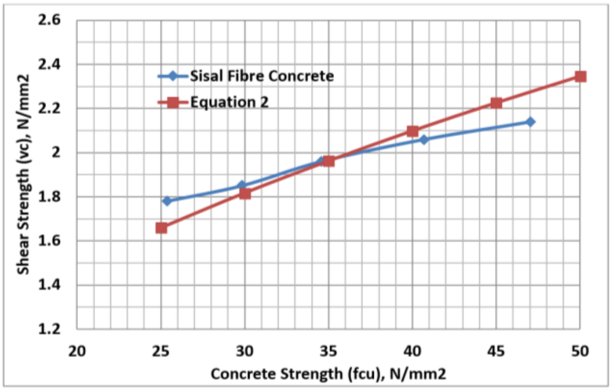

Fig 11: Comparison of Equation (2) and the Shear Strength of Sisal Fibre Reinforced Concrete

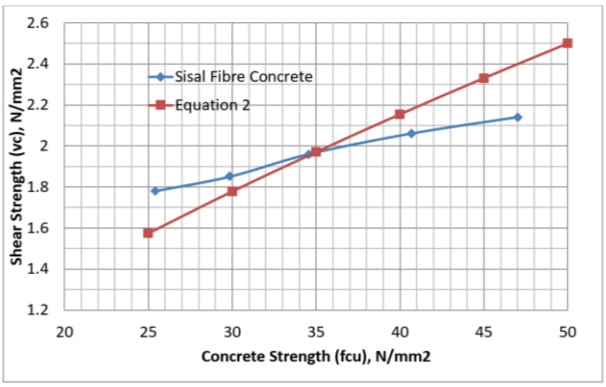

Fig 12: Comparison of Equation (3) and the Shear Strength of Sisal Fibre Reinforced Concrete

Therefore, inclusion of the sisal fibre only increased the shear strength of the concrete of corresponding strength by only 9.5%.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

a) The inclusion of sisal fibre at about 1% content decreases the workability of normal concrete to the low range of workability; water reducing agents will be required for workable mixes at higher fibre content.

b) At 1% sisal fibre content addition to normal concrete mixture, the density of the resulting concrete is still within the normal concrete weight range.

c) The inclusion of sisal fibre at 1% content by weight increased the compressive strength of concrete mix by 16.9% and the shear strength of the concrete mix by 16%.

d) The inclusion of Sisal fibre reinforcement increased resistance to cracking and crack propagation.

e) The shear strength of Sisal Fibre Reinforced Concrete at 1% Sisal Fibre addition is 9.5% higher than that of normal concrete of similar compressive strength.

5.2 Recommendation

Sisal fibre reinforcement is recommended for use in the production of concrete to the level of 1% weight addition when water reducing agent is not used and the shear strength of the resulting concrete may be predicted from the modified BS 8110 equation proposed.

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