Experimental Study on Strength and Durability Properties of Sisal Fiber Reinforced Concrete (SFRC)

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Abstract— Concrete is the most widely used material throughout the world. Concrete is a brittle material which is good in compression but it is weak in tension, this leads to the formation of cracks, these cracks extend and reach the compression phase and finally the member breaks. It becomes necessary to find a best method to improve the strength of concrete by replacing cement with some natural material. A technique of introducing of natural fibers in concrete can be done. The influence of sisal fibers on the strength of concrete is taken as the main objective of this experimental study. The fiber diameter was first observed through micrometer gauge and was seen to be average 0.3mm. The sisal fibers were added with aspect ratio of 100 and the varying percentages of 0%, 0.5%, 1%, 1.5% and 2% in M25 grade of concrete and the mechanical properties such as compression, and split tensile were tested. Then the optimum fiber volume fraction for compressive strength was found. From the obtained optimum volume, the durability tests were conducted. The test results indicated that the sisal fibers were effective in improving the strength and durability of concrete.

Keywords: Compressive strength, Split tensile strength, Sisal fiber, Optimum volume, Aspect ratio

I. INTRODUCTION

Concrete is a composite material composed of gravels (coarse aggregates), sand (fine aggregates) and hydrated cement (binder). Concrete is the most commonly used material for civil engineering construction. The infrastructure needs of our country are increasing day by day and it is necessary to enhance its characteristics by means of strength and durability. The significance of concrete has been developed and the limitations of concrete have been slowly but surely eliminated which increases the durability of concrete allowing high performance value to be achieved. However, concrete is strong in compression and weak in tension. To overcome this weakness in concrete, natural fibers are used as reinforcement is utilized to carry the tensile forces and prevent the cracks formed in the concrete.

The introduction of sisal fibers was brought in as an alternative to developing concrete in view of enhancing its compressive and tensile strengths. The basic governing principles between conventional concrete and fiber reinforced concrete having several characteristic variations; such as – fibers are generally short, closely spaced, and dispersed throughout a given cross section. The present investigation deals with the study on sisal fiber reinforced concrete, used for improving the properties of concrete. The usage of these natural fibers can improve the sustainability of cement composites by being renewable and are considerably less costly.

II. FIBER REINFORCED CONCRETE

A homogeneous mixture of cement, aggregate, water and discontinuous discrete fibers is known as Fiber Reinforced Concrete (FRC). In FRC, thousands of small fibers are randomly distributed in the concrete during mixing, and thus improve concrete properties in all directions. Fibers present in the concrete mix resist the formation of cracks in the concrete and also it is necessary to enhance so many mechanical properties such as toughness, ductility, compressive as well as tensile strength. Two important parameters employed in describing fibers are aspect ratio and volume fraction. Aspect ratio is the ratio of fiber length to its diameter (l/d). Typical aspect ratio (A.R) ranges from 30 to150 and it plays a crucial role in improving the properties of concrete. Volume fraction is the volume of fiber in the concrete matrix. The principle reason for incorporating fibers into a cement matrix is to increase the toughness, tensile strength and improving the cracking deformation characteristics of the resultant composite.

III. ADVANTAGES OF FIBRE REINFORCED CONCRETE

- Fiber reinforced concrete has started to find its place in many areas of civil infrastructure applications, where the need for repairing, increased durability arises also avoid the corrosion at the maximum.
- The advantages of natural fiber materials are strength, durability, reduce cost of environmental compatibility and bio degradability. It is a hard and tough fiber. In components such as slabs and pavements, fiber is added to control cracking induced by temperature variation.
- Fiber reinforced concrete is better suited to minimize cavitation erosion damage in structures such as sluice-ways, navigational locks and bridge piers where high velocity flows are encountered also avoid catastrophic failures in bridges.
- Also in the quake prone areas the use of fiber reinforced concrete would certainly minimize the human casualties.

IV. OBJECTIVES OF THE STUDY

- To study the effect of percentage of fiber added in to the concrete.
- To study the effect of fiber on different mix design.
- To analyze the mechanical properties such as compressive strength, split tensile strength of sisal fiber reinforced concrete.
- To analyze the optimum volume fraction of fiber based on the result of compressive strength.
- To study the durability properties of sisal fiber reinforced concrete.

V. MATERIALS USED

A. *Cement*

Ordinary Portland cement of 53 grade is used. The physical properties of the cement are given in the Table I.

Physical Properties	Results
Fineness	1.51
Standard Consistency	34%
Initial setting time	More than 1 hr
Specific gravity	3.15
Soundness	1mm
Compressive strength of cement for 7 days	26.59MPa

Table 1: Properties of Cement

B. *Coarse Aggregate*

The coarse aggregates used are crushed stone predominately retained on 4.75 mm sieve. The maximum size of aggregate used is 20mm.

C. *Fine Aggregate*

Aggregates used ae those passing through 4.75 mm sieve and predominately retained on 75µ sieve. M sand or manufactured sand is used in this thesis. The test conducted according to IS 2386:1963. From gradation curve it was found that the fine aggregate is of zone 2. The physical properties of aggregates are given in Table II.

Physical Properties	Results	
	Coarse Aggregate	*Fine Aggregate*
Bulk Density	1.75	1.74
Specific Gravity	2.88	2.65
Void Ratio	0.65	0.53
Fineness Modulus	8.114	3.402
Uniformity Coefficient	1.76	5.55
Coefficient of Curvature	0.822	0.68

Table 2: Properties of Aggregates

D. *Sisal Fiber*

Sisal fibers can be added to cement based matrices as reinforcement. Fibers work as primary reinforcement in thin products in which conventional reinforcing bars cannot be used. It can be used with an aspect ratio of 100 having fiber diameter of 0.3mm and fiber length of 30mm..

Fig. 5.1: Sisal Fiber

Here sisal fibers are added as 0%, 0.5%, 1%, 1.5% and 2% by weight of concrete to determine the compressive and split tensile strength.

E. *Water*

In the concrete mix portable water that is free from oils and other impurities is used. The water used has no acidic or alkaline content in it.

VI. METHODOLOGY

Based on the objectives, a methodology for present thesis work has been adopted.

- Preliminary tests of materials were done.
- Mix design of M25 and SFRC with fibers added in varying percentage of 0%, 0.5%, 1%, 1.5% and 2% were prepared.
- Compressive strength and split tensile strength of 5 different mixes of M25 grade namely A_0, A_1, A_2, A_3 and A_4.
- Compressive strength and split tensile strength of A_0, A_1, A_2, A_3 and A_4 are tested for 28 days were found out.
- From the test result of compressive strength, the optimum volume fraction of fiber was found, while the split tensile strength improved with increase in volume fraction.
- From the obtained optimum volume of fiber, the durability test was conducted. Durability tests are as follows:
  - Acid attack test
  - Chloride attack test
  - Sulphate attack test
  - Oven dried test

VII. CONCRETE MIX DESIGN

The mix design for M25 grade is done according to IS 10262: 2009 and the conventional concrete with 0% sisal fiber can be represented by the letter A_0. A1 represents the mix where 0.5% sisal fiber is added. A2 represents the mix containing 1% of sisal fiber. A3 represents the mix containing 1.5% of sisal fiber. And A4 represents the mix containing 2% of sisal fiber. In all the mixes the amount of water used is kept constant.

Sl.no	Mix	Cement content (kg)	F. A Content (kg)	C.A Content (kg)	Water content (liters)	Sisal fiber Content (kg)
1	A_0– SF 0%	16.02	28.84	49.6	8.1	0
2	A_1- SF 0.5 %	16.02	28.84	49.6	8.1	0.52
3	A_2- SF 1%	16.02	28.84	49.6	8.1	1.03
4	A_3- SF 1.5 %	16.02	28.84	49.6	8.1	1.54
5	A_4- SF	16.02	28.84	49.6	8.1	2.05

	2%					

Table 3: Mix Design

VIII. EXPERIMENTAL TESTS

A. *Casting of specimens*

The materials required for SFRC specimens were calculated based on the adopted mix design. In this thesis work, fibers are added 0%, 0.5%, 1%, 1.5% and 2% by weight of concrete to the concrete mix. For the present thesis work, 30 cubes and 15 cylinders of SFRC specimens were casted in aspect ratio of 100. After casting SFRC cubes and cylinders, the specimens were removed from the corresponding moulds after storing the specimens in a room temperature of 24 hours. Then the specimens are submerged in clean water for providing proper curing conditions. In the present work, the SFRC specimens were also tested for 7 days and 28 days curing. After casting the conventional concrete (A_0-0% SF) and SFRC specimens, these specimens are tested for compressive strength and split tensile strength properties.

B. *Compressive strength test*

Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied. A total of 30 cubes of dimension 150 mm x 150 mm x 150 mm were casted with an addition of 0%, 0.5%, 1%, 1.5% and 2% sisal fibers of aspect ratio of 100. Specimens were tested after curing for 7days and 28 days. The specimens were tested for cube compression. Specimens are placed in Compression testing machine of capacity 100 tones without eccentricity and at uniform rate of 140 kg/cm^2. Loads were applied till the cubes failed. The maximum load was noted and cube compressive strength of 7 days and 28 days were calculated in MPa.

Fig. 8.1: Compression testing machine with sample

C. *Split tensile strength test*

A standard cylinder of size 150 x 300mm was used here. The load was applied on the surface of the cylinder diametrically and uniformly. The compression testing machine is used in this case also. Assuming that concrete is an elastic body the lateral tensile stress is determined using this method. The split tensile strength determined using this method is usually in the range 1/8 to 1/12 of compressive strength of concrete. .

Fig. 8.2: Split tensile strength test on SFRC specimen

A total of 15 cylinders of dimension 150 mm x 300 mm were casted with an addition of 0%, 0.5%, 1%, 1.5% and 2% sisal fibers of aspect ratio of 100. Specimens were tested after curing for 7days and 28 days under CTM.

D. *Durability tests*

To determine the durability of obtained volume of SFRC and conventional concrete of 0% sisal fiber, various tests such as acid attack, sulphate attack, chloride attack and water absorption test were conducted.

1) *Acid attack test*

The concrete cube of size 150 x 150 x 150 mm of 1% dosages of sisal fiber and 0% sisal fiber of M25 grade of concrete were casted and cured in mould for 24 hrs, after 24 hrs, all the specimens are demoulded and kept in curing tank for 28 days. After 28 days, all the specimens are kept in atmosphere for 2 days for constant weight. Then the specimens are weighed and immersed in 5% sulphuric acid (H_2SO_4) solution of pH value 0.3 for 56 days. After 56 days of immersing in acid solution, the specimens are taken out and were washed in running water and kept in atmosphere for 2 days for constant weight. Then the specimens are weighed and the resistance of concrete to acid attack was found by calculating the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in acid water. For this test, totally 6cubes were casted. From that, 3 cubes are of 1% SFRC and 3 cubes are conventional concrete of 0% sisal fiber.

2) *Sulphate attack test*

The concrete cube of size 150 x 150 x 150 mm of 1% dosages of sisal fiber and 0% sisal fiber of each grade of concrete were casted and cured in mould for 24 hrs, after 24 hrs, all the specimens are demoulded and kept in curing tank for 28 days. After 28 days, all the specimens are kept in atmosphere for 2 days for constant weight. Then the specimens are weighed and immersed in 5% Sodium sulphate (Na_2SO_4) solution for 56 days. After 56 days of immersing in sulphate solution, the specimens are taken out and were washed in running water and kept in atmosphere for 2 days for constant weight. Then the specimens are weighed and the resistance of concrete to sulphate attack was found by calculating the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in Sodium sulphate solution. For this test, totally 6cubes were casted. From that, 3 cubes are of 1% SFRC and 3 cubes are conventional concrete of 0% sisal fiber.

3) Chloride attack test

The concrete cube of size 150 x 150 x 150 mm of 1% dosages of sisal fiber and 0% sisal fiber of M25grade of concrete were casted and cured in mould for 24 hrs, after 24 hrs, all the specimens are demoulded and kept in curing tank for 28 days. After 28 days, all the specimens are kept in atmosphere for 2 days for constant weight. Then the specimens are weighed and immersed in 5% Sodium chloride (NaCl) solution for 56 days. After 56 days of immersing in chloride solution, the specimens are taken out and were washed in running water and kept in atmosphere for 2 days for constant weight. Then the specimens are weighed and the resistance of concrete to chloride attack was found by calculating the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in Sodium chloride solution. For this test, totally 6cubes were casted. From that, 3 cubes are of 1% SFRC and 3 cubes are conventional concrete of 0% sisal fiber.

4) Water absorption test

The cubes of size 150 x150 x 150 mm were casted and tested after 28 days curing. The specimens were taken out and oven dried at a temperature of 100°C to 110°C for not less than 24 hours. Each specimen removed from the oven was cooled to 20°C to 25°C using dry air and the dry weight was determined. Then the specimens were immersed in water. The wet weights were recorded after 48 hours. Here, the water absorption test is carried on 1% of SFRC with conventional concrete of 0% sisal fiber. Therefore, totally 6 cubes were casted. From that, 3 cubes are of 1% SFRC and 3 cubes are conventional concrete of 0% sisal fiber.

IX. RESULTS AND DISCUSSIONS

The results obtained from experimental tests conducted on SFRC with varying percentages of 0%, 0.5%, 1%, 1.5% and 2% are given below.

A. Compressive strength

It was observed that there was a considerable increase in compressive strength due to the addition of sisal fibers when tested for 7 and 28 days of curing. The compressive strength values for after 7 days and 28 days curing of the SFRC specimens with varying percentages are given in a table and the strength comparison of compressive strength with curing will be plotted in a graph also shown below.

Mix	Average compressive strength for 7 days (N/mm²)	Average compressive strength for 28 days (N/mm²)
A_0 – SF 0%	18.36	30.36
A_1 -SF 0.5 %	19.64	35.20
A_2 – SF 1%	20.77	39.18
A_3 – SF 1.5%	20.30	36.51
A_4 – SF 2%	18.49	32.12

Table 4: Compressive Strength Values

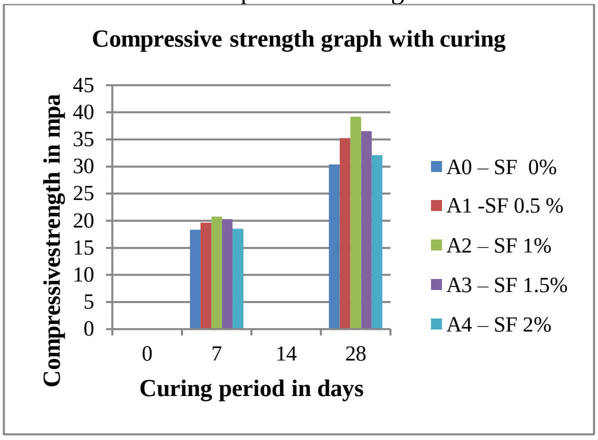

Fig. 9.1**:** Graph showing compressive strength with curing

B. Split tensile strength

It was observed that there was a considerable increase in split tensile strength due to the addition of sisal fibers when tested for 7 and 28 days of curing. The split tensile strength values for after7 days and 28 days curing of the SFRC specimens with varying percentages are given in a table and the strength comparison of split tensile strength with curing will be plotted in a graph also shown below.

Mix	Average split tensile strength for 7 days (N/mm²)	Average split tensile strength for 28 days (N/mm²)
A_0 – SF 0%	1.91	3.06
A_1 -SF 0.5 %	2.25	3.89
A_2 – SF 1%	2.53	4.88
A_3 – SF 1.5%	2.35	4.32
A_4 – SF 2%	1.97	3.48

Table 5: Split Tensile Strength Values

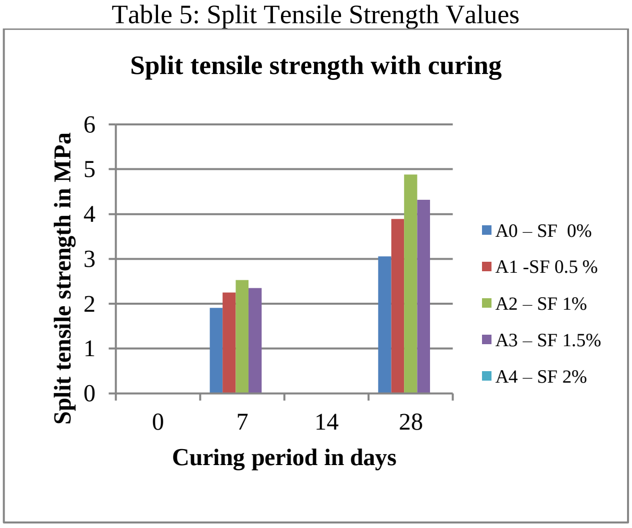

Fig. 9.2: Graph showing split tensile strength with curing

C. Durability tests results

1) Acid attack test

From the experimental test result, it is observed that, when compared to conventional concrete the sisal fiber reinforced concrete was more resistant to acid attack, leading to less loss of weight and compressive strength for concrete with addition of sisal fibers. Therefore, 1% SFRC by weight of its concrete is more resistant to the acid attack. From the results of acid attack test, loss in weight of cube specimen after immersion in Hydrochloric acid solution and loss in compressive strength of cube specimen after immersion in Hydrochloric acid solution of concrete can be represented in table given below.

Percentage of sisal fiber	% Mass reduction	
	Initial weight after 28 days curing	Final weight after 56 days immersing in H_2SO_4 solution
A_0 - 0% SF	7.58	6.43
A_2 - 1% SF	8.79	7.68

Table 6: Loss in Weight after Immersion in H_2SO_4 Solution

Percentage of sisal fiber	Strength reduction	
	28th day compressive strength	56th day compressive strength
A_0 - 0% SF	30.36	23.47
A_2 - 1% SF	39.18	31.24

Table 7: Loss in Strength after Immersion in H_2SO_4 Solution

2) Sulphate attack test

From the experimental test results, it is observed that, when compared to conventional concrete the sisal fiber reinforced concrete was more resistant to sulphate attack, leading to less loss in weight for concrete with addition of sisal fibers. Therefore, 1% SFRC by weight of its concrete is more resistant to the sulphate attack. From the results of Sulphate attack test, loss in weight of cube specimen after immersion in Sodium sulphate solution and loss in compressive strength of cube specimen after immersion in Sodium sulphate solution of concrete can be represented in table given below.

Percentage of sisal fiber	% Mass reduction	
	Initial weight after 28 days curing	Final weight after 56 days immersing in Na_2SO_4 solution
A_0 - 0% SF	7.43	6.67
A_2 - 1% SF	8.58	7.98

Table 8: Loss in Weight After Immersion in Na_2SO_4 Solution

Percentage of sisal fiber	Strength reduction	
	28th day compressive strength	56th day compressive strength
A_0 - 0% SF	30.36	24.89
A_2 - 1% SF	39.18	35.74

Table 9: Loss in Strength After Immersion in Na_2SO_4 Solution

3) Chloride attack test

From the experimental test results, it is observed that, when compared to conventional concrete the sisal fiber reinforced concrete was more resistant to Chloride attack, leading to less loss in weight for concrete with addition of sisal fibers. Therefore, 1% SFRC by weight of its concrete is more resistant to the chloride attack. From the results of Chloride attack test, loss in weight of cube specimen after immersion in Sodium chloride solution and loss in compressive strength of cube specimen after immersion in Sodium chloride solution of concrete can be represented in table given below.

Percentage of sisal fiber	% Mass reduction	
	Initial weight after 28 days curing	Final weight after 56 days immersing in NaCl solution
A_0 - 0% SF	7.75	6.81
A_2 - 1% SF	8.28	7.19

Table 10: Loss in Weight After Immersion in NaCl Solution

Percentage of sisal fiber	Strength reduction	
	28th day compressive strength	56th day compressive strength
A_0 - 0% SF	30.36	23.71
A_2 - 1% SF	39.18	31.39

Table 11: Loss in Strength After Immersion in NaCl Solution

4) Water absorption test

From the experimental test results, it is observed that water absorption value increases in 1% of fiber dosage than conventional concrete of 0% sisal fiber in each grade of concrete. It reveals that the fiber added into the concrete, the pores are increased the amount of water absorption also increased. The water absorption test result of concrete can be represented in a table given below.

Mix	Sample 1		Sample 2		Sample 3	
	Initial(kg)	Final (kg)	Initial(kg)	Final (kg)	Initial(kg)	Final (kg)
A_0	8.58	8.32	8.72	8.44	8.67	8.41
A_2	8.69	8.24	9.25	8.87	9.14	8.73

Table 12: Water Absorption Test Sample Values

Mix	Sample 1	Sample 2	Sample 3
	W.A (%)	W.A (%)	W.A (%)
A_0– 0% SF	3.13	3.32	3.09
A_2 - 1% SF	5.46	4.28	4.69

Table 13: Water Absorption Test Result

X. SUMMARY AND CONCLUSIONS

On studying the SFRC with varying percentages of adding sisal fibers by weight of cement, it can be concluded that,

- The addition of sisal fiber into the concrete significantly increases the strength properties of the concrete.
- It was observed that the addition of fibers increased the compressive strength of concrete for varying dosages of 0.5%, 1%, 1.5% and 2% and was found to be 19%, 36%, 25% and 7% more than that of conventional concrete of 0% sisal fiber. The maximum percentage increase in compressive strength was achieved at 1% of fiber dosage.
- It was observed that the addition of fibers increased the split tensile strength of concrete for varying dosages of 0.5%, 1%, 1.5% and 2% and was found to be 32.6%, 72.6%, 50.4% and 16.6% more than that of conventional concrete of 0% sisal fiber. The maximum percentage increase in split tensile strength was achieved at 1% of fiber dosage.
- SFRC is more resistant to acid attack, sulphate attack, and chloride attack when compared to conventional

concrete of 0% sisal fiber. In all cases the maximum resistance was observed in case of SFRC with 1% of fiber dosage.

- It was also observed that water absorption value increases in 1% of fiber dosage than conventional concrete of 0% sisal fiber in each grade of concrete. It reveals that the fiber added into the concrete, the pores are increased the amount of water absorption also increased.
- From the above experimental study, it can be concluded that addition 1% of sisal fibers by weight of concrete enhances its strength and durability considerably.

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