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An Investigation on Effects of Sisal Fiber Reinforced Concrete on Concrete Properties

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Abstract: One of the additional materials for sustainability and strength of concrete is Fiber Reinforced Concrete. Hence, the researcher is attempting to use sisal fiber as an effective and sustainable additive to produce good quality fiber reinforced concrete. This study aimed to examine the effects sisal fiber on the compressive and flexural strength of concrete. As well as it recommends the optimum percentage of sisal fiber percentage. Sisal fibers were brushed, lined up, and cut to obtain a 5cm length of the fiber. To produce a well-mixed fresh concrete, the fiber was added after mixing all concrete ingredients. The compressive strength was tested at the ages of 7, 14, and 28 days of curing. Flexural strength was tested at ages 7 and 28 days curing. A total 45 of 150 x 150 x 150mm concrete test cubes and 30 of 50mm x 100mm x 100mm beams were cast using a mix proportion of 1:1.93:3, with water-cement ratio of 0.5. The results showed that the compressive and flexural strength increased as the sisal fiber percentage increased up to 1.5%. The optimum values of compressive and flexural strength come from concrete containing 1.5% sisal fiber. Based on the test results, the compressive strength at 0.5%, 1.0%, and 1.5% gained 4.53%, 16.56%, and 29.69% of the average compressive strength respectively. At 2% addition of fiber, concrete lost 35.31% of strength at 28 days curing. The flexural strength at 0.5%, 1.0%, and 1.5% sisal fiber gained 9.23%, 12.1% and 9% of strength respectively, while at 2% the addition of sisal fibber lost 15% of strength at 28 days curing. Therefore, the addition of sisal plant fiber increased both compressive and flexural strength up to 1.5% fiber by weight of cement compared to the control group of concrete 1.5% of sisal fiber is recommended.

Keywords: Compressive Strength, Flexural Strength, Proportion, Sisal Fiber

1. Introduction

1.1. Background

Natural fibers are economically and locally available in many countries. Fibers are line-like materials used for different purposes. The use of it reduces the weight by 10% and lowers the energy needed for production by 80%, while the cost of the component is 5% lower than the comparable fiber glass-reinforced component [1]. The improvement of an economical, sustainable, safe, and secure shelter is an inherent global problem and numerous challenges remain to produce environmentally safe, durables. In recent years, a great deal of interest has been created worldwide on the potential applications of natural fiber reinforced cement-based composites [11]. Therefore, sisal plant fiber is included as some natural fibers that are available and easily cultivated in many countries.

Sisal fiber is obtained from the leaves of the plant agave sisalana and is produced in tropical regions such as Mexico, Brazil, Tanzania, Kenya, Madagascar and China. It is mainly used in the manufacturing of natural ropes, twine, sacking, carpet making, and textile materials like nets, mats, and automobile floor mats. And sisal fiber can be used as reinforcement production as composites materials [2]. According to Sabarinathan, Sisal fiber is a material that was chosen to improve the various strength, durability, reduce the cost of environmental compatibility, and reduce hazardous properties of a structure to obtain sustainability and better quality structure [3]. However, sisal fiber is more attractive than other because; easily available, renewability, low density, economical and acceptable mechanical properties.

As well as artificial fibers and fabricated fibers used for the manufacturing of composites and natural fibers used composites materials and environmental friendly [4, 14]. In addition, sisal plant short fibres delay restrained plastic shrinkage controlling crack development at early ages and sisal plant fiber is important for well resistant to moist and it has good tension resistance or tensile strength [12].

Generally, the maximum flexural and compressive strength values were verified for reinforcement with 50 mm fibers and 0.35% fiber content by weight. In this study, compared to the unreinforced specimens, specimens reinforced with 50 mm fibers at 0.35% by weight, were 94% and 77% higher, in terms of flexural and compressive strength, respectively. [13].

Ethiopia stands at eleventh in worldwide countries in sisal fiber production, but Ethiopia cannot use different materials [4, 14]. Generally, it is easily cultivated and reusable recourse as well as the one of the most widely used natural fibers. This sisal fiber is a local name known as *'kacha tekile'*. In Ethiopia mostly used for rope and carpet and found everywhere it grown wild in the hinge fields used as a fence. However, we know the thank for concrete technology, sisal fiber is important for improving concrete properties used as fiber reinforced concrete. Sisal fiber which has the capacity to surface crack distributor for gradual concrete failure and used for compression and flexural, tension and splitting tensile stress.

1.2. Problem Statements

It is known that conventional concrete is weak in tensile strength and strong in compressive strength. Steel reinforcement is being provided in order to overcome this weakness. However, steel is a cost and uses nonrenewable resources. Because of the unsustainably use of steel, it needs improvements for sustainability without affecting strength. According to different researchers, fiber reinforced is essential with additional energy and absorbing capability to transform a brittle into ductile material. There is a different type of fiber reinforced concrete which are man-made fibers such as poly-propylene, asbestos, and steel fibers. They are expensive and nonrenewable fiber material and steel fiber is attacked by corrosion [5]. Natural fibers used as polymer composites and highly fascinated for several advantages such as; low cost, low consumption of energy used for production, it is locally available, renewable, it is easily produced, and environment friendly [4]. The researcher encouraged to choice sisal fiber is one of the natural fibers used as concrete construction material. Sisal fiber is locally available, renewable and easily produced, no need of season and environmental conditions to grow. In Ethiopia there is limited knowledge on the importance of sisal fiber is used as different construction materials. However, sometimes the sisal fiber is used as rope, carpet, and fence. Therefore, sisal fiber is important to improve the properties of concrete.

1.3. Objectives of the Study

The aim of this research was to investigate the effect of sisal fiber on the properties of concrete with the specific objectives of:

1. To investigate the compressive strength of sisal fiber reinforced concrete at different percentage.
2. To investigate the flexural strength of sisal fiber reinforced concrete at different percentage.
3. To identify the optimum mix proportion of sisal fiber reinforced concrete based on strength properties.

2. Material and Methods

2.1. Research Design

The research design was conducted by using both experimental and analytical methods. Therefore, the methodology used in the study was a laboratory experimental procedure, a sample of data were collected which available in Jimma, Ethiopia. Researchers performed a laboratory tests to check the effects of sisal fiber on improve the properties of concrete.

The results presented based on ASTM, ACI and ES standards. The researchers were prepared to create a baseline for the laboratory test schedule with an effective data samples and specification of materials for the laboratory test schedule such as; testing materials properties, mix design, proportioning concrete mix, and mixing producer, concrete test.

2.2. Study Variables

The dependent variable which is to be observed and measured to determine the effect of the independent variables is sisal fiber and the independent variables which are to be manipulated to determine its relationship to the observed phenomena are compressive strength and Flexural Strength.

2.3. Materials

The physical characteristics of concrete making materials such as cement, fine aggregate, coarse aggregate, water, and sisal fiber are used. As the following table.

Table 1. *Physical characteristics of concrete making materials and their sources.*

Cement	Locally available Dangote Ordinary Portland cement (OPC) produced as per CEM-I-42.5 grade, which was found in Jimma
Fine Aggregate	Normal river sand from the market in Jimma town, originated from Chawaqa's river sand, which is extracted around the area
Coarse Aggregate	Crushed normal weight aggregate used was locally available in the market, which were produced at Agaro aggregate crushing plant site in Jimma zone.
Water	Blow water delivered by Jimma Town Water and Sewerage Authority at room temperature were used in all mixes.
Sisal Fiber	Sisal fiber used in this research study was extracted from the leaves of the plant Agave Sisalana. It is locally available in Jimma town. Mix proportion with different proportion of 0.5%, 1%, 1.5 [11]

2.4. Sampling Technique

This study followed a purposive sampling selection process. The choice of the fiber was depending on the average length of the fiber, continuity of the fiber. The other materials for concrete production such as sand and gravel were sampled using the splitting method. For the sisal fiber reinforced laboratory test, the samples were depending on the types of test requirement and standards. The output of the study was to produce sisal fiber reinforced concrete and verified through laboratory tests.

2.5. Experimental Procedure

2.5.1. Preparation Procedure Sisal Fiber

The fibers are taken out from the plant by hand with the help of knife. First, the leaves were cut in a longitudinal way into strips for comfort fiber extraction and hand-pulled in the longitudinal direction, gently removing the resinous material as shown in Figure 1 below. The inner skin, with excess amount of waste from sisal leaves, was washed with pure water to remove and separate unwanted dusts from the fiber. It was sun-dried over a period of 1 to 2 days until the surface were fully dried. The sisal fiber was cut into an accepted fiber length of 50mm using a pair of scissors. Then, the same length was used for both compressive and flexural strength samples of fiber-reinforced concrete.

Figure 1. *Sisal plant, and beaten by a knife and removing excess amount of waste and sundried sisal fiber in 50 mm.*

Cement: Normal Consistency and Cement Setting Time; *Fine Aggregate:* Silt Content, Sieve Analysis and Fineness Modules, Unit Weight of Aggregates, Specific Gravity and Absorption Capacity of fine Aggregates, Moisture Content of Fine Aggregates; *Coarse Aggregate:* Sieve Analysis and Specific Gravity was performed.

2.5.2. Mix Design and Procedures

Concrete mix design was prepared by [8] method. A control mix without sisal fiber was cast to make a comparative analysis. By keeping the mix proportion constant for each sisal fiber addition, the compressive and flexural strengths were determined.

According to [7], test the ages often used are 7, 14, and 28 days for compressive strength tests. For flexural test, the ages often used are 7 and 28 days of curing. The 7th, 14, and 28-day compressive strengths were determined compared with the results of the control mix group and checking the percent gained or lose. The same procedures were also applied for the flexural strengths.

After proportioning the amount of material by weight, the aggregates and cement were mixed dry for a minute. Then the addition of water, all materials were mixed for two minutes by using manual hand mixing. The sisal fiber was then added little by little to avoid lumps in the mixture, and then the rest of the water was added and continued mixing to produce a well-mixed concrete. The total mixing time was approximately 10-15 minutes. The mixing procedure is shown in Figure 2.

Figure 2. *Concrete mix without sisal plant fiber and concrete mix with sisal plant fiber.*

The specimens were then placed on a fixed and level surface of the prepared molds 150 mm *150 mm *150 mm for compressive cubes and 50 mm*10 mm *10 mm for flexural beam strength by compacting in three layers using 25 strokes of a 25 mm diameter steel rod and hammered in both sides of the mold by using a plastic hammer.

After compaction of the final layer, the top surface was finished using a trowel. Placing, compaction and finishing were completed before 15 minutes. After 24 hours, the specimens were demolded from the mold and were cured in a curing tank for 7, 14, and 28 days at room temperature. Finally, for all addition percentages of sisal fiber, the compressive and flexural strengths were checked at the age of 7, 14, and 28 days and 7 and 28 days of curing, respectively.

2.5.3. Test for Hardened Concrete

A. Compressive Strength of Sisal Fiber Concrete

According to Concrete Laboratory Manual [6], to determine the compressive strength of concrete, the concrete should be kept in the mould for 24 hours. The specimen will then be removed and cured by soaking in water up to the required curing date. The specimen was tested at the days specified in the procedure mentioned above.

a. Cube specimen ready for test b. Fiber reinforced concrete cube sample after test

Figure 3. *a. Cube specimen ready for test and b. Fiber reinforced concrete cube sample after test.*

B. Flexural Strength of Sisal Fiber Concrete

According to the concrete laboratory manual [6, 9], to determine the flexural strength of concrete, the concrete should be kept in the mould for 24 hours. Load concrete specimens to failure at 7 and 28 days of curing by using a testing machine and record the failure load. In this test, the concrete sample to be tested was supported at 30mm towards its both ends and loaded at the center the load a gradually fail as illustrated in Figure 4. The failure load at which the concrete cracks was then recorded in KN. To determine the flexural strength of sisal fiber reinforced concrete using the calculation formula for the modulus of rupture as follows:

$$\text{Flexural strength, } R = PL/BD^2 \quad (1)$$

where:

P = total load;

L = the distance between the lower supporting rollers;

B = breadth of the beam;

D = depth of the beam.

Generally, according to [9], the formula was applied, when the fracture initiates in the tension surface within the middle third of the span length, as shown in Figure 5.

Figure 4. *Center point loading flexural strength test.*

2.6. Data Gathering and Determination

The data was gathered based on the tests conducted on the prepared specimens in the laboratory and the test results of the samples were compared with the respective control concrete properties and the results were discussed, analyzed, and presented using relevant formulas, tables, figures, charts and graphs. Conclusions and recommendations were finally forwarded based on the findings and laboratory experimental results.

3. Results and Discussions

3.1. Experimental Result

3.1.1. Cement

According to the laboratory result test, the normal consistency of Dangote OPC cement was of 30% by manual Vicat Apparatus used and the initial and final setting time of Dangote OPC cement was 104.31min and 215 mm respectively. The standards of OPC cement initial and final setting time according to Ethiopian standard recommended that the initial and final setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10 hours.

3.1.2. Fine Aggregate

Physical Properties of Fine Aggregate

The sand was sieved as defined by [10]. to achieve a standardized grain size distribution. From the laboratory experimental results, the specific gravity of the sand was found to be 2.6 and the fineness modulus is 2.5. The importance of determining the fineness modulus and specific gravity of sand was to identify the grain size distribution of sand and to estimate the density of aggregates.

The fineness modulus ranges from 2.3 to 3.1 as stated in [10]. The particle size distribution of the fine aggregate used in the preparation of concrete is presented in Figure 5.

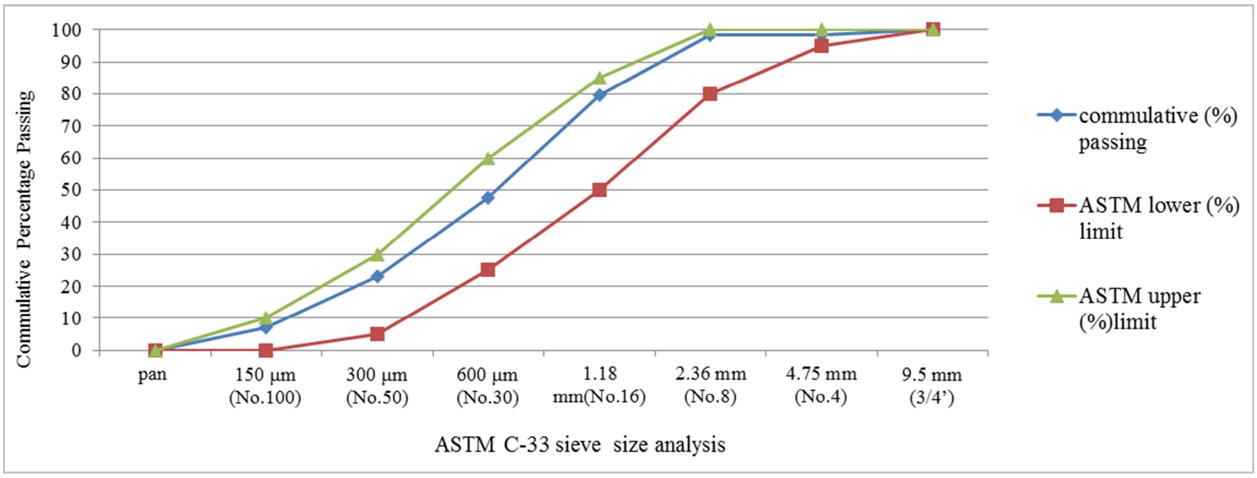

Figure 5. *Fine aggregate gradation chart.*

Table 2. *Summarized test results for fine aggregate.*

Physical properties of fine aggregate		Laboratory experimental Result	Typical Ranges of [11].
Fineness modulus		2.5	2.0 to 3.1
Absorption		1%	0 to 8 percent
Bulk specific gravity		2.6	2.30 to 2.90
Surface moisture content		0.5%	0 to 10 percent
Silt content	Before washed	8%	If it is > 6% rejects recommend to wash according ES Standard
	After washed	4%	-

The laboratory experimentation was determining the physical properties of fine aggregate was to determine the quality of aggregate, the grain size distribution, fineness modulus of aggregate, pouring of aggregate that both permeable and impermeable aggregate and important to adjust the amount of water content in the in the concrete mix.

3.1.3. Coarse Aggregate

Physical Properties of Coarse Aggregate

The coarse aggregate was sieved to determine the particle size distribution and grading of aggregate. As shown in Figure 6, the coarse aggregate used in the research is well graded. The result of the gradation is an S-curve which implies its well gradeness of the coarse aggregate.

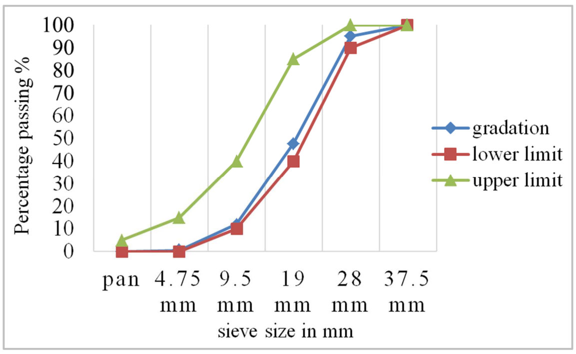

Figure 6. *Course aggregate gradation curve.*

Table 3. *Summarized test results for physical properties of coarse aggregate.*

Physical properties of coarse aggregate		Laboratory Result	Ranges of ASTM C-33
Absorption		0.5%	0 to 8 percent
Nominal maximum size		-	37.5 to 9.5 mm
	Bulk specific gravity	2.47	
Bulk specific gravity	Bulk specific gravity (SSD)	2.48	2.30 to 2.90
	Apparent specific gravity	2.51	
Dry-rodded bulk density		1721kg/m^3	1280 to 1920 kg/m^3
Surface moisture content		0.12%	0 to 2 percent

The physical properties of coarse aggregates were determined in laboratory, the importance of determining the physical properties of aggregates was to estimate the water-cement ratio due to the absorption capacity of the aggregate. It can be used also to estimate the weight of aggregate in the concrete as well as the weight of the concrete itself. The summary of the results for the physical properties of aggregates was presented with the above in Table 3.

3.2. Effect of Sisal Fiber on Compressive Strength

The compressive strength of concrete was determined by a compressive testing machine at a rate of 6.8 MPa/s. Cube and cylinder samples can be used to determine the compressive strength of the hardened concrete. In this study, cube samples were utilized in determining this property. Samples were tested at 7, 14, and 28 days of curing. For each curing date, three samples were tested and the average mean was computed. The result of the compressive strength of concrete are presented in Figure 7. The strength reductions due to using an incremental percentages of sisal fibers were compared with the control group.

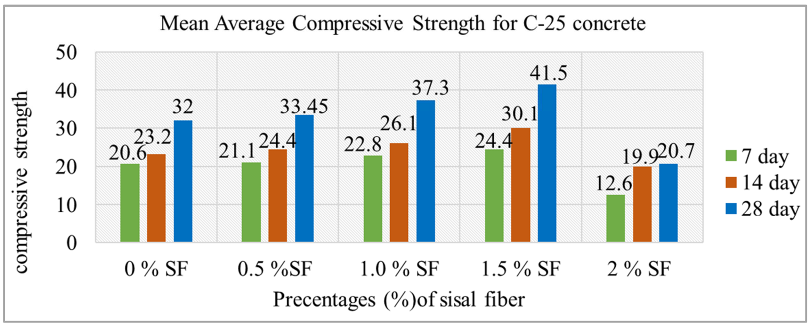

Figure 7. *Effect of sisal fiber on the compressive strength of fiber reinforced concrete for C-25.*

At seven-days, the results show that the addition of sisal fiber resulted an increase in the compressive strength compared to the control group. The concrete gained compressive strength of 2.43, 10.68, 18.45% and lost 38.83% when 0.5, 1, 1.5, and 2% of sisal fiber addition, respectively. The compressive strength increased up to 1.5% of sisal fiber added and at 2% sisal fiber, the compressive strength was decreased. For 1.5% sisal fiber added in concrete, the observed rate of compressive strength development was increased by 3.8 MPa or 18.45%, 1.2 or, 15%, 1.6Mpa or 7% and 11.8MPa or 93% from 0%, 0.5% 1%, and 2% sisal fiber was added in the concrete.

At fourteen-days, the results show that the addition of sisal fiber resulted an increase in the compressive strength compared to the control group. The concrete gained compressive strength of 5.17, 12.5, 31.03 and lost 14.22% when 0.5, 1, 1.5, and 2% of sisal fiber addition, respectively. The compressive strength increased up to 1.5% of sisal fiber added and at 2% sisal fiber, the compressive strength was decreased.

For 1.5% sisal plant fiber was added concrete, the observed rate of compressive strength development was increased by 7.2 MPa or 31.03%, 6MPa or 24.59%, 4.3Mpa or 16.48% and 10.5MPa or 52.88% from 0%, 0.5%, 1%, and 2% sisal fiber was added concrete.

At the age of twenty-eight days, the results show that the addition of sisal fiber resulted an increase in the compressive strength compared to the control group. The concrete gained compressive strength 4.53, 16.5, 29.69 and lost 35.31% when 0.5, 1.0, 1.5, and 2% of sisal fiber addition, respectively. The compressive strength increased up to 1.5% of sisal fiber added and at 2% sisal fiber, the compressive strength was decreased.

For 1.5% sisal fiber was added concrete, the observed rate of compressive strength development was increased by 9.5 MPa or 29.69%, 1.2MPa or 12.3%, Mpa 4.2Mpa or 11.26% and 120.8MPa or 100% from 0%, 0.5%, 1%, and 2% sisal fiber was added in concrete.

3.3. Effect of Sisal Fiber on Flexural Strength

The Samples were tested at 7 and 28 days of curing, respectively. For each curing date, three samples were tested and the average mean was computed. The results of the flexural strength of concrete were presented in Figure 8.

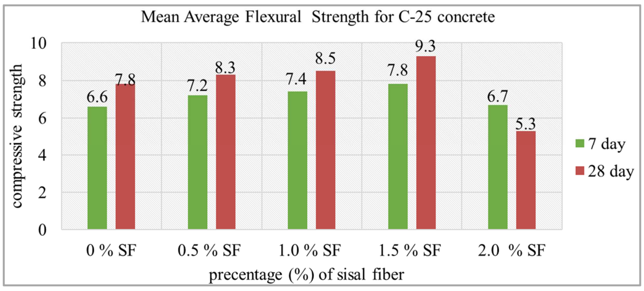

Figure 8. *Effect of sisal fiber on the flexural strength of fiber reinforced concrete for C-25.*

At the age of seven days, the results show that the addition of sisal fiber resulting an increase in the flexural strength compared to the control group. The concrete gained compressive strength of 9, 12.1, 18.2, and lost 0.15% when 0.5, 1, 1.5, and 2% of sisal fiber addition, respectively. The flexural strength increased up to 1.5% of sisal fiber added and at 2% sisal fiber, the flexural strength was decreased.

For 1.5% sisal fiber added concrete the observed rate of flexural strength development was increased by 1.2 MPa or 18.2%, 0.6MPa or 8.33%, 0.4Mpa or 6.8% and 2.6MPa or

38.8% from 0%, 0.5%, 1% and 2% sisal fiber was added concrete.

At the age of twenty-eight days, the results show that the addition of sisal fiber resulting an increase in the flexural strength compared to the control group. The concrete gained compressive strength of 6.4, 8.97, 19.23, and lost 75% when 0.5, 1, 1.5, and 2% of sisal fiber addition, respectively.

The flexural strength increased up to 1.5% of sisal fiber added and at 2% sisal fiber, the flexural strength was decreased.

For 1.5% sisal fiber was added concrete, the observed rate of flexural strength development was increased by 1.5 MPa or 19.23%, 1MPa or 12%, 0.8Mpa or 9.4% and 4MPa or 75.5% from 0%, 0.5%, 1% and 2% sisal fiber was added in concrete.

3.4. Optimum Proportion of Sisal Fiber on Concrete Properties

According to the laboratory experiment results, the strength used to determine the properties of concrete by addition of different percentage of sisal fiber compared to in the control group of concrete. From the study results, the optimum percentage of sisal fiber obtained was 1.5%. This optimum percentage addition of sisal fiber was recommended depending on both and compressive and flexural strength of concrete for better results.

4. Conclusion and Recommendation

4.1. Conclusions

From this experimental investigation, the compressive strength 4.53%, 16.56%, 29.69%, and lost 35.31 of the mix in concrete by the addition of 0.5%, 1%, 1.5% and 2% of sisal fiber at the ages of 7, 14 and 28 days of curing respectively with constant water cement ratio.

As observed during the compressive strength testing, the control group was very brittle in such a way that the materials were completely broken while those samples with sisal fibers remained intact after the failure load. It was concluded that the sisal fiber can help concrete from initial cracking.

As test results shows that, the flexural strength is increasing to 9%, 12.1%, 18.2% and lost 0.15% of the mix of concrete by the addition of 0.5%, 1%, 1.5% and 2% of sisal plant fiber at the age of 7 and 28 days of curing. The maximum flexural strength was recorded with 1.5% of sisal fiber reinforced concrete. Therefore, 1.5% addition of sisal fiber is chosen to be the optimum percent addition by weight of cement for the production of C-25 concrete.

4.2. Recommendation

As investigated in this study, the sisal fiber can be used to produce fiber reinforced concrete with economic and environmental benefits. It is recommended that sisal fiber can be of use for all construction work where concrete is applied.

1. It is recommended that further studies should be done about the effects of sisal fiber in different length to improve the rebound occurred when fibers kicked in and at the time when sisal added with the ingredient procedure of mix in concrete.
2. It is recommended also that further studies should be done to check the sisal fiber with regard to alkaline resistivity and to chemical treatment.

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