

# An Experimental Study on Mechanical Properties of Sisal Fiber Reinforced Concrete

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**Abstract** - This experimental study investigates the influence of natural sisal fibers on the mechanical properties of M25 and M30 grade concrete. Sisal fibers, treated to enhance durability, were incorporated into the concrete mix at varying percentages of 0.5%, 1.0%, 1.5%, and 2.0% by weight of cement, with a fiber length of 30mm. The study focuses on evaluating compressive strength, split tensile strength, and flexural strength at 7, 14, and 28 days of curing, comparing them to conventional concrete. The results indicate that the addition of sisal fibers improves the tensile and flexural strength significantly, with an optimum fiber content of 1.0% to 1.5% found to maximize the strength parameters for both M25 and M30 mixes. The findings suggest that incorporating sisal fiber can enhance the structural performance of concrete while providing a sustainable and cost-effective construction material.

**Key Words:** Sisal fiber, Compressive strength, Split tensile strength, Flexural strength, Durability Test

## 1. INTRODUCTION

Concrete's low tensile strength and brittleness limit its use. Sisal fibres, a natural and sustainable alternative to synthetic fibres, can enhance concrete's mechanical properties. This study evaluates the compressive, split tensile, and flexural strength of M25 and M30 concrete reinforced with sisal fibres. Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. The character of fiber reinforced concrete changes with varying concretes.

### 1.1 Role of Sisal Fiber in Concrete:

1. It increases the tensile strength of the concrete.
2. It reduces the air voids and water voids the inherent porosity of gel.
3. It increases the durability of the concrete.
4. Fibers such as graphite and glass have excellent resistance to creep, while the same is not true for most resins. Therefore, the orientation and volume of fibres have a significant influence on the creep performance of rebars/tendons.
5. Reinforced concrete itself is a composite material, where the reinforcement acts as the strengthening fibre and the concrete as the matrix. It is therefore imperative that the behavior

### 1.2 Scope of The Work:

- 1) Properties of all ingredient materials cement, sand, aggregate, water, sisal fiber are studied experimentally.
- 2) To design of required concrete mix is prepared.
- 3) For different doses of the concrete parameters such as compressive strength and flexural and workability of concrete is determined.
- 4) Based on the experimental results the compressive strength for various dosages are compared with conventional concrete.

## 2. Literature review

Silva et al.'s 2024 study on treated sisal fiber reinforced concrete revealed increased tensile and compressive strength, emphasizing improved durability and bonding. Kumar and Rao examined SFRC in 2023 and discovered that at greater percentages, ideal fiber content decreases workability while increasing tensile and impact strength.

Ali et al. examined sisal fiber reinforced concrete in 2022 and highlighted improvements in overall durability, toughness, and crack resistance. Zhang et al. examined SFRC in 2022 and emphasized its potential as a sustainable substitute for traditional reinforcement materials. In their 2021 study, Ramesh and Kumar found that SFRC had better resistance to shrinkage cracking and less permeability. Santos et al. assessed the durability of SFRC in 2021 and found that greater fiber levels increased water absorption. Gupta et al. examined fiber properties in 2021 and came to the conclusion that sisal fibers enhance concrete's mechanical performance and bonding. SFRC was shown to have improved flexural strength and energy absorption capability under loading by Ahmed et al. in 2020.

In 2020, Esrat Jahan et al. investigated the tensile, flexural, and hardness characteristics of polypropylene composites including chemically treated pineapple leaf and sisal fibers. Self-compacting concrete reinforced with sisal and mixed sisal-steel fibers was researched by Spoorthi S, M Divyashree, and T M Prakash in 2020. They discovered that the addition of fiber enhances both fresh and hardened qualities, such as compressive and flexural strength. Vinaykumar B K et al. investigated the effects of sisal fiber, a biodegradable natural fiber, on concrete strength and environmental advantages in 2019 using different percentages. Patel and Desai examined the structural behavior of SFRC in 2019 and found that it had lower brittle failure and higher tensile strength and ductility. Singh et al. looked at SFRC in 2018 and found that concrete pieces had better impact resistance and narrower cracks. Rao et

al. examined the post-cracking behavior of SFRC in 2017 and discovered that fiber bridging enhanced load-carrying ability. In 2017, K.T. Radha Sumithra and Absdadapheer discovered that while sisal fiber reinforced concrete increases tensile and bond strength at low fiber contents, mechanical parameters deteriorate when the fiber percentage rises above 1%. The mechanical characteristics and environmental advantages of sisal fiber-reinforced polymer composites were reviewed by Idowu David Ibrahim et al. in 2016. Karthik and Murthy investigated SFRC in 2016 and found that the ideal fiber dose improved flexural and split tensile strength. Joseph et al. examined SFRC in 2015 and noted enhanced resistance to heat cracking and shrinkage. When Banerjee and Roy investigated SFRC in 2014, they found that concrete structures had greater ductility and toughness. Suryawan Murtiadi et al. investigated fibrous lightweight concrete containing agave sisalana fibers in 2013. They discovered that the concrete's elastic modulus and compressive strength rose with fiber content up to 1.5%, reaching a maximum strength of 17 MPa.

### 3. Fiber Reinforced Concrete

The Fiber reinforced concrete contains fibrous material that is uniformly distributed and randomly oriented and its structural integrity increases by this. Possessing certain characteristics properties fiber is a small piece of reinforcing material and they can be flat or circular. Each fiber lends varying properties to the concrete and it includes steel fibers, glass fibers, synthetic fibers, and natural fibers.

Types of Fiber Reinforced Concrete

- 1) Steel Fiber Reinforced Concrete
- 2) Glass Fiber Reinforced Concrete
- 3) Asbestos Fibers
- 4) Carbon Fibers
- 5) Organic Fibers
- 6) Synthetic fiber.

### 4. Materials

Natural sisal fiber materials can be used with concrete and used for increases the durability of the concrete. By this way, a good mean to sisal fiber, by using it as an alternative material in the application of civil and industrial engineering. The strength characteristic of concrete containing sisal fiber material are determined through various studies.

#### 4.1 Cement

A Cement is a binder, a substance that sets and hardens and can bind other materials together. The word "cement" traces to the Romans, who used the term opus cementitious to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick supplements that were added to the burnt lime, to obtain a hydraulic binder.

Table 1. Properties of cement

Properties	IS-Code	Result
Normal consistency	IS 4031-1988(Part-4)	34%
Initial setting time	IS 4031-1988(Part-5)	30 min
Final setting time	IS 4031-1988(Part-5)	600 min
Fineness test	IS 4031-1966(Part-1)	6%
Specific gravity test	IS 4031-1988(Part-11)	3.13

#### 4.2 Aggregates:

Fine Aggregates-The Aggregates which has a size less than 4.75 mm is known as fine aggregate.

Table 2. Properties of fine aggregate

Physical properties	IS-Code	Result
Fineness modulus	IS 383-2016	2.8
Specific gravity	IS 2383-1963(Part-3)	2.78
Moisture content	IS 2383-1963(Part-3)	2.44%

Coarse Aggregates-The Aggregates which has a size of more than 4.75 mm is known as Coarse.

Table 3. Properties of coarse aggregate

Physical properties	IS-Code	Result
Fineness modulus	IS 383-2016	7.56
Specific gravity	IS 2383-1963(Part-3)	2.56
Water absorption	IS 2383-1963(Part-3)	0.49%

### 4.3 Sisal Fiber

Sisal fiber is one of the most widely used natural fibres and is very easily cultivated. It has short renewal times and grows wild in the hedges of fields and railway tracks. Nearly 4.5 million tons of sisal fiber is produced every year throughout the world. Tanzania and Brazil are the two main producing countries. Sisal fiber is a hard fiber extracted from the leaves of the sisal plant (*Agave sisalana*). Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East. Sisal fibres are extracted from the leaves



Fig 1. Sisal fiber

Table 4. Properties of sisal fiber

Physical properties	Result
Fiber length	20 to 40 mm
Diameter	0.1 to 0.3 mm
Color	White and yellowish

Fibers largely are used in concrete to conventional cracking by plastic shrinkage and drying shrinkage. They furthermore decreases the permeability of concrete and in this way, reduce bleeding of water. Sisal fiber concrete makes greater impact, abrasion and shear resistance in bond. Sisal fiber concrete increases the flexural nature of the bond, and moment resisting or essential steel reinforcement. Sisal increase the durability of concrete.

### 4.5 Mix Design And Specimen Preparation

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30N/mm<sup>2</sup>. No control testing is necessary reliance being placed on the masses of the ingredients.

#### Mix Design M25

Target strength = 31.6 N/mm<sup>2</sup>, Water cement ratio = 0.46· Water content = 166 lits· Cement content = 362 kg· Fine aggregate = 861 kg· Coarse aggregate = 1051 kg

#### Mix Design M30

Target strength= 38.25 N/mm<sup>2</sup>· Water cement ratio = 0.45· Water content = 197 lits· Cement content = 438 kg· Fine aggregate = 701 kg· Coarse aggregate = 1054 kg

#### 4.6 Specimen preparation:

For the process of manufacturing of concrete there are some basic steps that are to be considered.

These steps help in maintaining proper quality of the concrete that is required to be produced.

##### Mixing of concrete

Mixing of concrete is done by different method, they are namely Continuous mixing, Batch or Drum mixing etc. For the project we are using hand mixing.

Hand mixing of concrete is suitable for a small quantity of concrete production or where mixing machine is not available. Firstly, cement and sand are mixed in the dry stage by the shovels on a clean hard impermeable or non-percolating platform. This type of mixing is continued until the mixture attains uniform color. After this, the mix is spread on the measured stock of coarse aggregate in required quantity and these are mixed again to have a uniform color. After this, the remaining quantity of water is added to acquire the uniform workability. In this type of mixing, the cement is lost due to possible water flowing out of the mix i.e., add 10% more cement to make good strength characteristic to the inferior result of hand mixing.

##### Compaction of concrete

Compaction is the process which expels entrapped air from freshly placed concrete and packs the aggregate particles together so as to increase the density of concrete and to remove air void from placed concrete.

The body of the paper consists of numbered sections that present the main findings. These sections should be organized to best present the material. It is often important to refer back (or forward) to specific sections. Such references are made by indicating the section number, for example, "In Sec. 2 we showed..." or "Section 2.1 contained a description..." If the word Section, Reference, Equation, or Figure starts a sentence, it is spelled out. When occurring in the middle of a sentence, these words are abbreviated Sec.

##### Curing of concrete:

Curing of Concrete is a method by which the concrete is protected against loss of moisture required for hydration and kept within the recommended temperature range. Curing will increase the strength and decrease the permeability of hardened concrete

### 5. EXPERIMENTAL INVESTIGATION

#### 5.1 Workability Test

Workability of concrete is defined as the ease and homogeneity with which a freshly mixed concrete or mortar can be mixed, placed, compacted and finished. Strictly, it is the amount of useful internal work necessary to produce 100% compaction.

According to the road research laboratory, UK; workability is defined as "the property of concrete which determines the amount useful internal work necessary to produce the full compaction." Thus, it is the ease with which the concrete can be placed and compacted under various situations.

##### Slump Test

Workability is a term associated with freshly prepared concrete. This can be defined as the ease with which concrete can mixed, placed, compacted and finished. Slump test is the most commonly used method of measuring 'Workability of concrete in a laboratory or at site of work. It is used conveniently as a control test and gives an indication of uniformity of concrete from batch to batch. Vertical settlement of a standard cone of freshly prepared concrete is called 'slump'.

#### 5.2 Compressive Strength Test

Testing hardened concrete plays an important role in controlling and conforming the quality of cement concrete work. One of the important properties of the hardened concrete is its strength which represents its ability to resist forces. The compressive strength of the concrete is considered to be the most important and is often taken as an index of the overall quality of concrete. The compressive strength of concrete is defined as the load which causes the failure of specimen per unit cross section on compression under given rate of loading



Fig 2. Compressive strength test

#### 5.3 Split Tensile Strength Test

The split tensile strength of concrete is the maximum tensile stress generated when a cylindrical specimen undergoes a diametral compressive load. This indirect method is used to determine concrete's tensile strength, as direct tensile testing is challenging. During the test, the specimen is placed horizontally and loaded along its diameter, inducing tensile stress perpendicular to the load. This stress

causes the specimen to crack and split. The resulting value provides insight into the cracking behavior and strength of concrete in structural applications.



Fig 3. Split tensile strength test

#### 5.4 Flexural Strength Test

Flexural testing on concrete was carried out on cubic specimens of size (500x100x100) mm and the strength was recorded at 7, 14, and 28 days of curing. The average reading of tested cubes was recorded as the strength at the respective age. The bed of the testing machine shall be provided with two steel rollers, 38 mm in diameter, on which the specimen is to be supported, and these rollers shall be so mounted that the distance from centre to centre is 60cm for 15.0 cm specimens or 40cm for 10.0 cm specimens



Fig 4. Flexural strength test

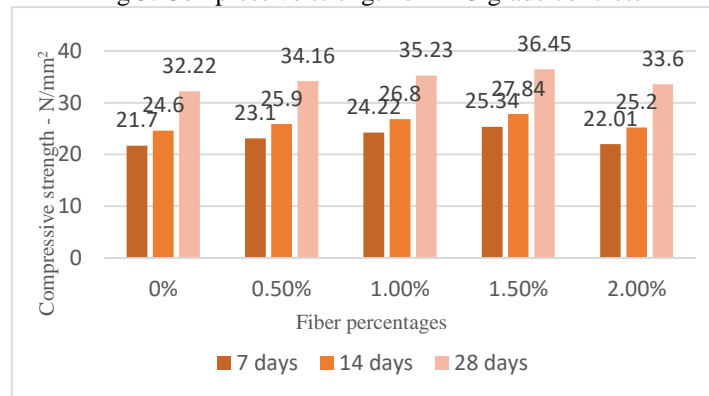
#### 5.5. Durability Test

The capacity of concrete to withstand weathering, chemicals, and water damage over time is known as durability. Low water absorption and little weight loss in acid tests are signs of durable concrete, which retains its strength and quality.

### 6. Results And Discussion

This chapter shows the result of the 9 cubes compressive strength under the different curing period of 7 days, 14 days, and 28 days prepared with partial addition (0.5%, 1.0%, 1.5% and 2.0% of sisal fiber). The compressive strength of concrete was compared with normal concrete under same physical conditions. This chapter also evaluate the effect of sisal fiber in slump value and compaction factor value with each percentage of partial addition. **Test Results: 6.1 Slump Cone Test:** Slump cone test was conducted for each concrete batches before they were casted in order to check the workability of concrete, having the least value of 25 mm slump deemed to be workable, the results of the test are below.

Fig 5. Compressive strength of M25 grade concrete



## 6.2 Compressive Strength test

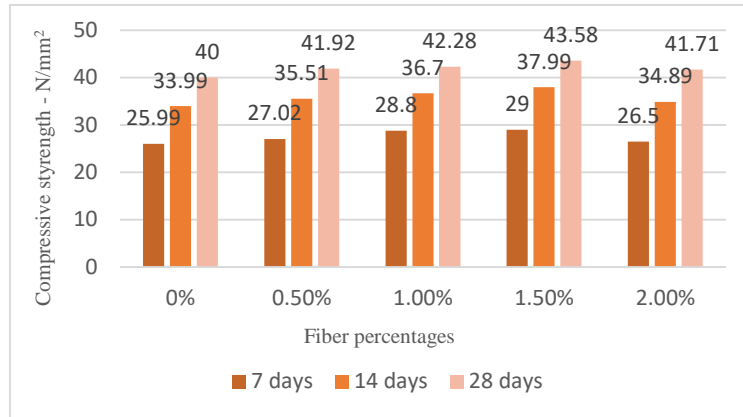


Fig 6. Compressive strength of M30 grade concrete

- Up to 1.5% of sisal fibers are added to M25 and M30 concrete to boost its compressive strength.
- Compared to regular concrete, M25 concrete has a maximum 28-day compressive strength of roughly 36.45 N/mm<sup>2</sup> at 1.5% fiber.
- The maximum strength of M30 concrete at 1.5% fiber is approximately 43.58 N/mm<sup>2</sup>.
- Because of decreased workability and incorrect fiber distribution, the compressive strength somewhat drops when the fiber content rises to 2.0%.
- For both grades of concrete, the ideal proportion of sisal fiber to achieve maximum compressive strength is 1.5%.

## 6.3 Split Tensile Strength test

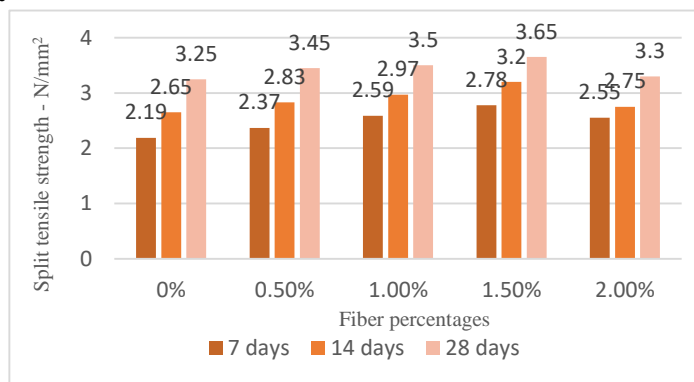


Fig 7. Split tensile strength of M25 grade concrete

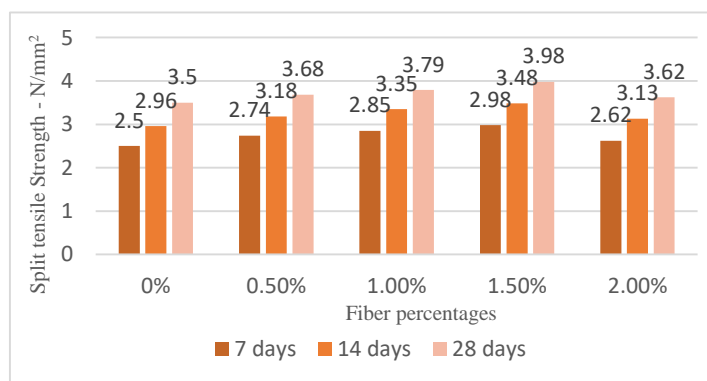


Fig 8. Split tensile strength of M30 grade concrete

- Up to 1.5% of sisal fibers are added to M25 and M30 concrete, increasing their split tensile strength.
- At 1.5% fiber, the maximum 28-day split tensile strength for M25 concrete is approximately 3.65 N/mm<sup>2</sup>.
- The maximum value for M30 concrete with 1.5% fiber is roughly 3.98 N/mm<sup>2</sup>.
- Due to poor workability and fiber clustering, the split tensile strength somewhat drops at 2% fiber concentration.
- Therefore, the ideal proportion of sisal fiber to increase the tensile strength of concrete is 1.5%.

## 6.4 Flexural strength Test

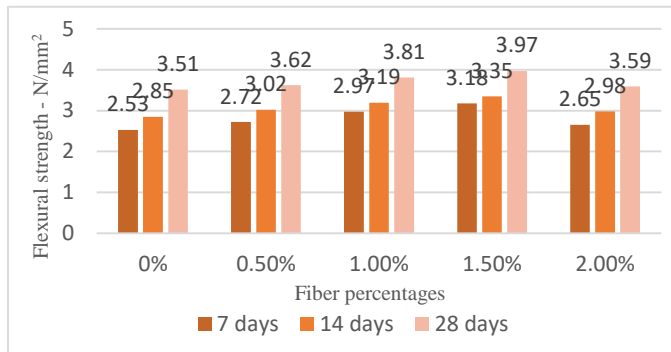


Fig 9. Flexural strength of M25 grade concrete

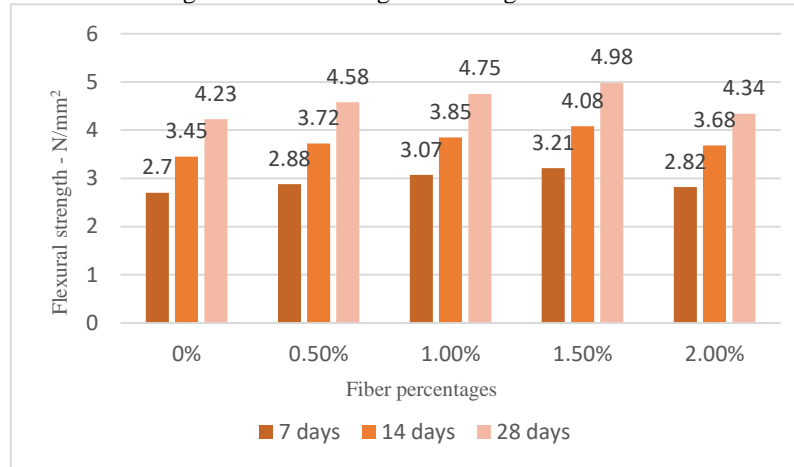


Fig 10. Flexural strength of M30 grade concrete

- Up to 1.5% of sisal fibers are added to M25 and M30 concrete to boost its flexural strength.
- The maximum 28-day flexural strength of M25 concrete at 1.5% fiber is approximately 3.97 N/mm<sup>2</sup>.
- The maximum flexural strength for M30 concrete at 1.5% fiber is approximately 4.98 N/mm<sup>2</sup>.
- Flexural strength somewhat declines at 2.0% fiber concentration because of decreased workability and fiber clustering.
- For both classes of concrete, the ideal percentage of sisal fiber to achieve maximum flexural strength is 1.5%.

## 6.5 Durability Tests

Concrete's long-term performance is assessed by durability tests like acid resistance and water absorption. Acid resistance evaluates chemical endurance, whereas water absorption shows porosity. When combined, these tests guarantee that concrete can withstand chemical and environmental problems..

### 6.5.1 Water Absorption

To assess durability characteristics, water absorption experiments were performed on standard concrete (0%) and sisal fiber reinforced concrete (SFRC) with fiber contents of 0.5%, 1.0%, 1.5%, and 2.0% at 28 and 56 days. In order to determine the saturated weight (W<sub>2</sub>), the specimens were first oven dried to a consistent weight (W<sub>1</sub>), then submerged in water for a whole day. The following formula was used to get the water absorption percentage:

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad \text{-----( 1 )}$$

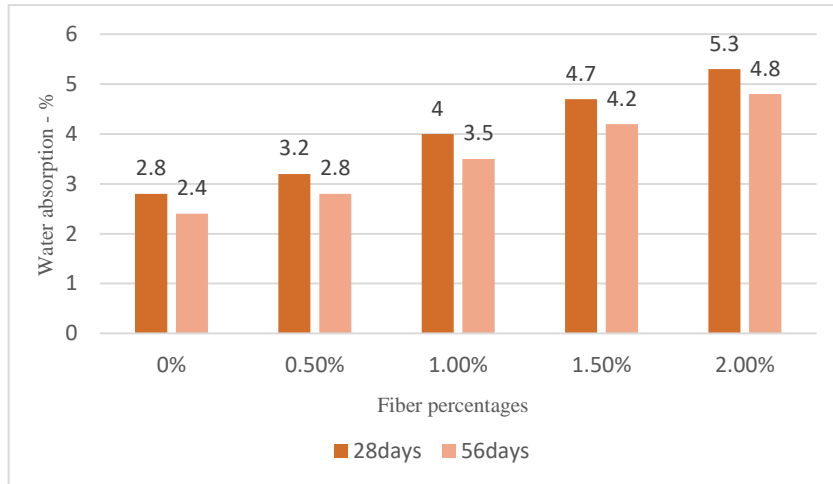


Fig 11. Water absorption of M25 grade concrete

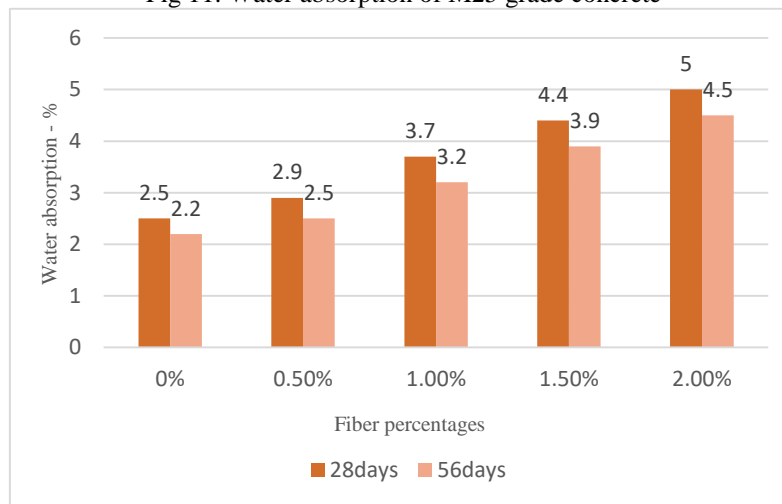


Fig 12. Water absorption of M30 grade concrete

- In both M25 and M30 concrete, water absorption rises as the amount of sisal fiber increases.
- Because of its denser matrix, M30 concrete absorbs less water than M25.
- Continued hydration causes water absorption to drop from 28 days to 56 days.
- 1.0% to 1.5% is the ideal fiber concentration because 2% causes poor workability and increased absorption.

### 6.5.2 Acid resistance of HCL

To assess chemical durability, mortar cubes measuring 70 × 70 × 70 mm from regular concrete (0%) and sisal fiber reinforced concrete (SFRC) with fiber contents of 0.5%, 1.0%, 1.5%, and 2.0% were submerged in hydrochloric acid (HCl). The specimens were weighed both prior to immersion (W1) and following a predetermined exposure duration (W2), and the following formula was used to determine the % weight loss:

$$\text{Weight Loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{-----( 2 )}$$

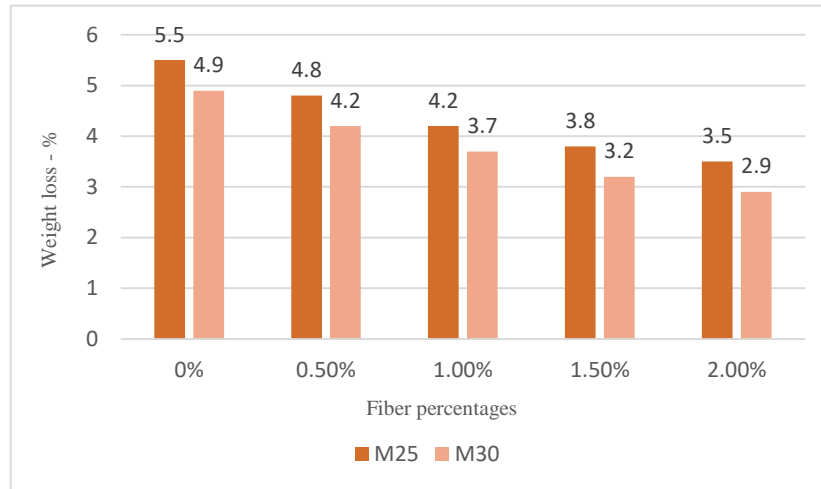


Fig 13. SFRC Weight Loss Percentage in a 5% HCl Solution

- As the concentration of HCl rises, acid resistance falls.
- Compared to M30 grade, M25 grade exhibits more resistance.
- M30 deteriorates a little more than M25.
- Reduction results from concrete's cement compounds being attacked by acid.

### 6.5.3 Acid resistance of H<sub>2</sub>SO<sub>4</sub>

To assess resilience to harsh acidic conditions, mortar cubes measuring 70 × 70 × 70 mm from standard concrete (0%) and sisal fiber reinforced concrete (SFRC) with fiber contents of 0.5%, 1.0%, 1.5%, and 2.0% were submerged in sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). The specimens were weighed both before and after immersion (W<sub>1</sub> and W<sub>2</sub>), and the following formula was used to determine the % weight loss:

$$\text{Weight Loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{-----( 3 )}$$

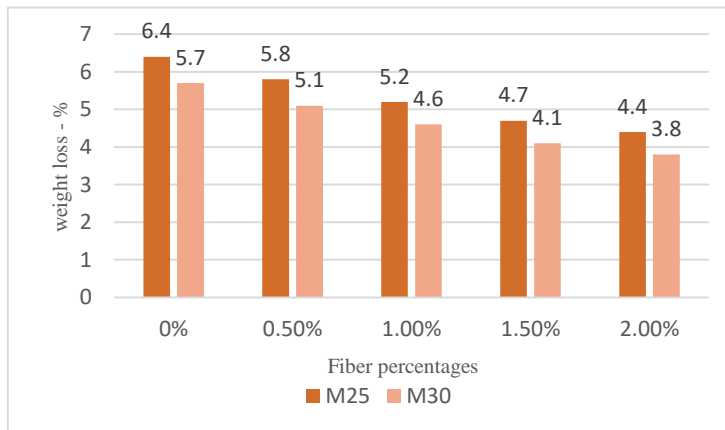


Fig 14. SFRC Weight Loss Percentage in 5% H<sub>2</sub>SO<sub>4</sub> Solution

- As the concentration of H<sub>2</sub>SO<sub>4</sub> rises, acid resistance falls.
- At all doses, M25 continuously exhibits greater resistance than M30.
- M30 deteriorates a little more than M25.
- H<sub>2</sub>SO<sub>4</sub> reacts with cement compounds to cause reduction, which weakens the concrete.

### 7. Conclusion

In terms of compressive strength, split tensile strength, and flexural strength, the experimental study found that sisal fiber reinforced concrete (SFRC) performed better than regular concrete. Both varieties showed increasing density over time in water absorption tests, with SFRC exhibiting somewhat better absorption because of the natural fibers. SFRC showed better chemical resistance in acid exposure tests using HCl and H<sub>2</sub>SO<sub>4</sub>, and it lost less weight and strength than regular concrete. All things considered, adding sisal fibers to concrete improves its durability and mechanical qualities, making it a more sustainable and crack-resistant choice for structural applications.

- The mechanical qualities of M25 and M30 concrete were enhanced by the addition of 1.5% sisal fibers.
- Due to the denser mix of M30, compressive strength improved by approximately 10–11% for M25 and around 12–14% for M30.
- In both classes, split tensile strength increased by around 20–25%, indicating improved crack resistance.
- Significant improvements in flexural strength (~25–30%) indicate improved toughness and bending.
- Concrete reinforced with sisal fibers showed moderate to good resistance to HCl and H<sub>2</sub>SO<sub>4</sub>, with M30 outperforming because of its denser structure.
- Because of its increased overall endurance, it can be used in situations that are vulnerable to chemical attack (M30).
- Because of the heavier mix, M30 was marginally less workable than M25.
- With only a slight cost increase for higher-grade concrete, the use of sisal fiber is cost-effective.
- M25 is appropriate for typical construction projects.
- M30 is perfect for structural and heavy load-bearing applications.

If the mix is properly calibrated, adding more than 1.5% fiber can improve the mechanical qualities of concrete, such as tensile and flexural strength, without appreciably decreasing workability. Furthermore, the tensile and flexural performance can be further enhanced by combining sisal fibers with other natural or synthetic fibers, such steel or polypropylene, to create a hybrid reinforcement system that capitalizes on the advantages of several fiber types.

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