ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26may438

Experimental Investigation on Cellular Concrete Using Sisal Fibre and Brick Bat as Sustainable Materials

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Publication Date: 2026/05/13

Abstract: Rapid growth in construction activities has led to the depletion of conventional construction materials, necessitating the development of sustainable alternatives. This study investigates the performance of cellular concrete incorporating natural sisal fibres and brick bat as partial replacement of coarse aggregate. Concrete specimens were prepared with varying fibre contents (0.5%, 1%, 1.5%, and 2%) along with 20% replacement of coarse aggregate by brick bat and the inclusion of foaming agent to produce lightweight cellular concrete. Mechanical properties such as compressive strength, split tensile strength, and flexural strength were evaluated at different curing periods. Results indicate that the addition of sisal fibres enhances tensile and flexural properties due to crack-bridging action, with optimum performance observed at 1%–1.5% fibre content. However, higher fibre content reduces workability and strength due to fibre clustering. The use of brick bat contributes to weight reduction, making the material suitable for lightweight applications. This study demonstrates that sisal fibre reinforced cellular concrete can serve as a sustainable and eco-friendly construction material.

Keywords: *Cellular Concrete, Sisal Fibre, Brick Bat, Lightweight Concrete, Sustainable Materials.*

How to Cite: R. Harish; Dr. K. Sharmiladevi; P. Vignesh (2026) Experimental Investigation on Cellular Concrete Using Sisal Fibre and Brick Bat as Sustainable Materials. *International Journal of Innovative Science and Research Technology,* 11(5), 141-146. https://doi.org/10.38124/ijisrt/26may438

I. INTRODUCTION

The rapid expansion of the construction industry has led to an unprecedented demand for conventional building materials such as cement, natural sand, and coarse aggregates. This increasing demand has not only resulted in the depletion of natural resources but has also raised serious environmental concerns, including high carbon emissions, excessive energy consumption, and disposal of construction waste. Therefore, the development of sustainable, lightweight, and eco-friendly construction materials has become a major area of research in civil engineering.

Concrete is the most widely used construction material due to its versatility, durability, and compressive strength. However, conventional concrete possesses inherent limitations such as low tensile strength, brittle behaviour, poor resistance to crack propagation, and relatively high self-weight. These drawbacks restrict its performance, especially in applications where tensile stresses, impact loads, and weight reduction are critical. To overcome these limitations, fibre reinforcement techniques have been widely adopted.

Fibre-reinforced concrete (FRC) has emerged as an effective solution to enhance the mechanical properties of concrete. Fibres act as crack arresters by bridging micro-cracks, thereby improving tensile strength, flexural strength, toughness, and ductility. While synthetic fibres such as steel, glass, and polypropylene have been extensively used, they are often expensive, non-biodegradable, and energy-intensive in production. In contrast, natural fibres offer a sustainable alternative due to their low cost, renewability, biodegradability, and minimal environmental impact.

Among various natural fibres, sisal fibre has gained significant attention due to its favourable mechanical properties, including high tensile strength, good bonding characteristics, and resistance to deterioration in alkaline environments. Sisal fibres are derived from the leaves of the Agave plant and are abundantly available in many regions. Their incorporation in concrete not only improves mechanical performance but also contributes to sustainable development by utilizing renewable resources.

In addition to fibre reinforcement, the concept of lightweight concrete has become increasingly important in modern construction. Cellular concrete, also known as foamed concrete, is a type of lightweight concrete in which stable air voids are introduced into the cement matrix using a foaming agent. This results in reduced density, improved thermal insulation, and better workability. Cellular concrete is particularly suitable for applications such as partition walls, insulation layers, and non-load-bearing structural elements. However, the presence of air voids reduces the overall strength of the material, necessitating the use of reinforcement techniques such as fibre addition to compensate for strength loss.

Another important aspect of sustainable construction is the utilization of waste materials. Brick bat, which is obtained from demolished masonry structures, is one such material that can be effectively used as a partial replacement for coarse aggregate. The use of brick bat not only reduces construction waste but also decreases the self-weight of concrete, making it suitable for lightweight applications. However, due to its porous nature and lower strength compared to conventional aggregates, careful evaluation of its impact on concrete properties is essential.

In this context, the present study focuses on the experimental investigation of cellular concrete incorporating sisal fibres and brick bat as sustainable materials. The combined use of natural fibre reinforcement and recycled aggregate aims to develop an eco-friendly concrete with improved mechanical performance and reduced environmental impact. The study evaluates the workability, compressive strength, split tensile strength, flexural strength, and structural behavior of reinforced concrete beams with varying percentages of sisal fibre.

The significance of this research lies in identifying an optimum combination of fibre content and material replacement that enhances the performance of cellular concrete while maintaining its lightweight characteristics. The findings of this study are expected to contribute to the development of cost-effective, sustainable, and high-performance construction materials suitable for modern engineering applications.

➢ *Objectives*

- To study the feasibility of using sisal fibre in cellular concrete
- To evaluate compressive, tensile, and flexural strength
- To analyze the effect of brick bat replacement on concrete properties
- To determine the optimum fibre content

II. MATERIALS USED

➢ *Cement*

43-grade Ordinary Portland Cement with specific gravity of 3.15 was used.

➢ *Fine Aggregate*

River sand conforming to Zone II with fineness modulus of 3.0.

➢ *Coarse Aggregate*

Crushed granite of size 20 mm.

➢ *Brick Bat*

Used as 20% replacement of coarse aggregate to reduce weight.

➢ *Sisal Fibre*

- Length: 40 mm
- Percentage: 0.5% to 2%
- Acts as crack arrestor

➢ *Foaming Agent*

Used to produce cellular (lightweight) concrete.

III. METHODOLOGY

➢ *The Methodology Adopted Includes:*

- Material collection and testing
- Mix design as per IS 10262
- Preparation of concrete mixes
- Casting of specimens
- Curing (7, 21, 28 days)
- Testing and analysis

➢ *Mix Proportion*

Concrete mix was designed for M20 grade.

- *Mix Ratio:*

1 : 1.8 : 3

Water-Cement Ratio = 0.5

Different mixes were prepared with varying fibre percentages and brick bat replacement.

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IV. EXPERIMENTAL INVESTIGATION

➤ *Compressive Strength:*

Table 1 Compressive Strength Results

Mix	7 Days (MPa)	21 Days (MPa)	28 Days (MPa)
S1	14.2	18.5	22.6
S2	12.8	17.2	21.0
S3	15.0	19.6	24.2
S4	14.5	18.9	23.5
S5	13.6	17.8	22.1
S6	12.9	17.0	21.3
S7	12.2	16.2	20.4
S8	11.5	15.6	19.8
S9	10.8	14.9	18.7
S10	10.2	14.2	17.9

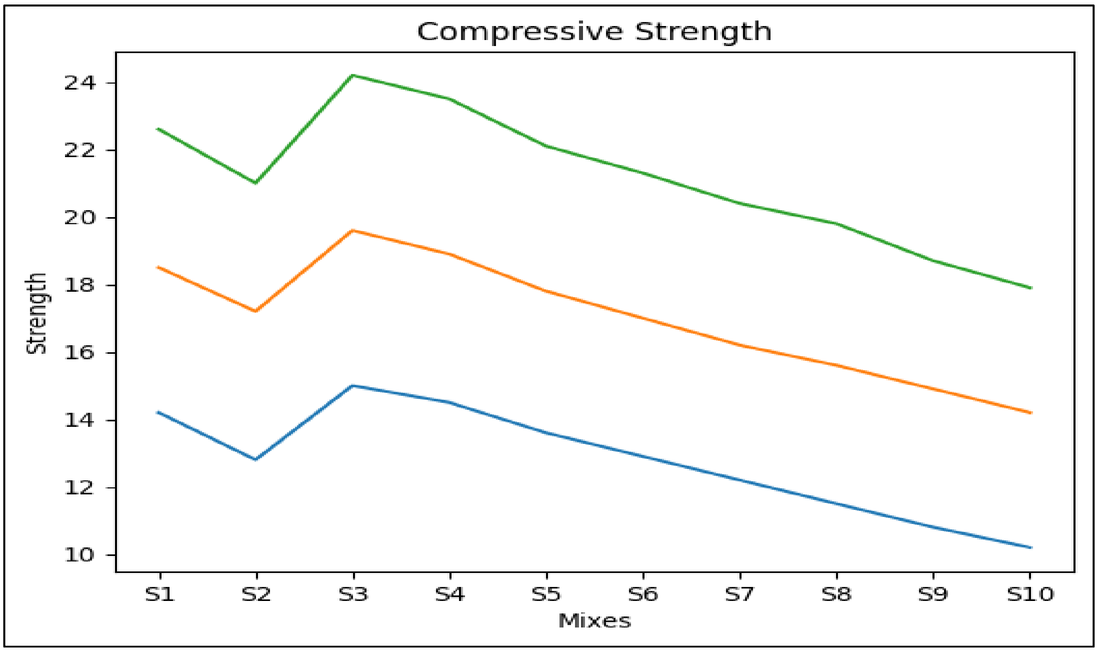

Fig 1 Compressive Strength Results

From the compressive strength graph, it is clearly observed that strength increases with curing age for all mixes. The conventional mix (S1) attained a compressive strength of 22.6 MPa at 28 days, which satisfies the requirement for M20 grade concrete.

Among all mixes, S3 (1% sisal fibre) exhibited the highest compressive strength of 24.2 MPa at 28 days, followed by S4 (1.5% fibre) with 23.5 MPa. This indicates that the addition of sisal fibres improves compressive strength up to an optimum level.

However, beyond this optimum fibre content, a gradual reduction in strength is observed. Mixes S5 to S10 show decreasing strength, with S10 recording the lowest value of 17.9 MPa at 28 days. This reduction is attributed to fibre clustering, poor workability, and increased void content in the concrete.

Overall, the graph confirms that optimum fibre content lies between 1% and 1.5%, beyond which compressive strength decreases.

➤ *Split Tensile Strength Test:*

Table 2 Split Tensile Strength Results

Mix	7 Days (MPa)	21 Days (MPa)	28 Days (MPa)
S1	1.6	2.1 Split Tensile Strength Results	2.8
S2	1.5	2.0	2.6
S3	1.8	2.4	3.1
S4	1.7	2.3	3.0
S5	1.6	2.2	2.8

S6	1.5	2.1	2.7
S7	1.4	1.9	2.5
S8	1.3	1.8	2.4
S9	1.2	1.7	2.2
S10	1.1	1.6	2.0

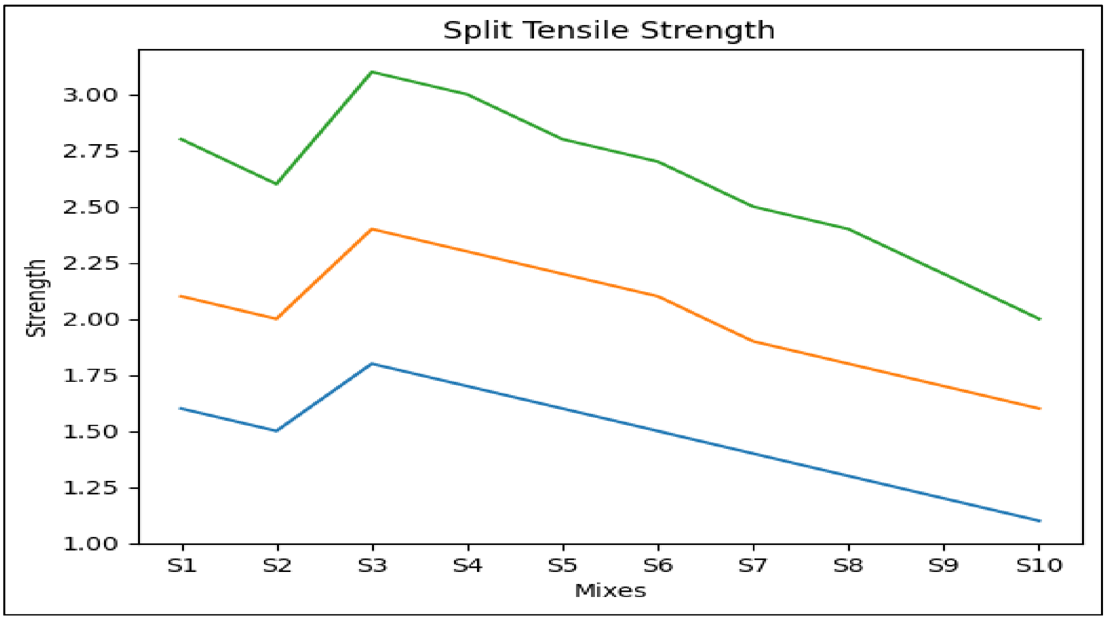

Fig 2 Split Tensile Strength Results

The split tensile strength graph shows a similar trend as compressive strength. The strength increases with curing age and improves with the addition of sisal fibres up to an optimum level.

The conventional mix (S1) recorded a tensile strength of 2.8 MPa at 28 days, whereas the maximum tensile strength was achieved by S3 (1% fibre) with 3.1 MPa, followed by S4 (1.5% fibre) with 3.0 MPa.

The improvement in tensile strength is due to the crack-bridging ability of sisal fibres, which restricts crack propagation and enhances load resistance.

Beyond 1.5% fibre content, the tensile strength decreases gradually. Mix S10 recorded the lowest value of 2.0 MPa at 28 days, due to poor fibre distribution and weak bonding.

Thus, the graph indicates that optimum fibre content for tensile strength is around 1%–1.5%.

Flexural Strength of concrete

➢ *Flexural Strength Test*

Table 3 Flexural Strength Results

Mix	**7 Days (MPa)**	**21 Days (MPa)**	**28 Days (MPa)**
S1	3.2	4.1	4.8
S2	3.0	3.9	4.5
S3	3.5	4.5	5.3
S4	3.4	4.4	5.1
S5	3.2	4.2	4.9
S6	3.1	4.1	4.8
S7	2.9	3.8	4.4
S8	2.7	3.6	4.1
S9	2.5	3.3	3.8
S10	2.4	3.2	3.7

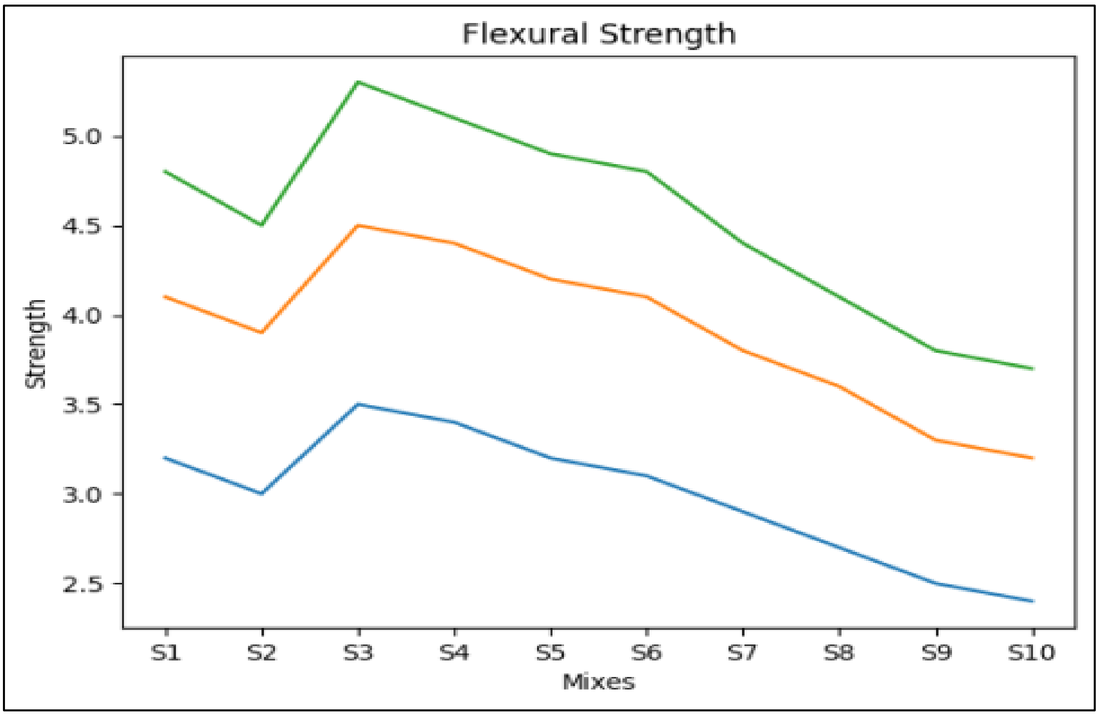

Fig 3 Flexural Strength Results

From the flexural strength graph, it is observed that flexural strength increases with curing age for all mixes. The conventional mix (S1) achieved a flexural strength of 4.8 MPa at 28 days.

The highest flexural strength was observed in S3 (1% fibre) with 5.3 MPa, followed by S4 (1.5% fibre) with 5.1 MPa. This improvement is due to the enhanced crack resistance and energy absorption capacity provided by the fibres.

However, with further increase in fibre content (S5 to S10), flexural strength decreases gradually. The lowest value was recorded for S10 at 3.7 MPa, which is due to poor workability, fibre balling, and increased porosity.

The graph clearly shows that moderate fibre addition improves bending performance, while excessive fibre content reduces strength.

V. RESULTS AND DISCUSSION

The experimental results indicate that the performance of cellular concrete is significantly influenced by sisal fibre content and material composition. Workability decreased with increasing fibre dosage due to fibre interlocking and the presence of brick bat and air voids. However, strength properties improved up to an optimum fibre content of 1%–1.5%. The maximum compressive strength (24.2 MPa), split tensile strength (3.1 MPa), and flexural strength (5.3 MPa) were achieved at 1% fibre content. Beyond this level, strength decreased due to poor dispersion, increased porosity, and inadequate compaction. The inclusion of brick bat reduced density, while fibres enhanced crack resistance and ductility. Overall, the material is suitable for lightweight and non-load-bearing applications.

VI. CONCLUSION

The present study investigated the performance of cellular concrete incorporating sisal fibres and brick bat as sustainable materials. Based on the experimental results, the following conclusions are drawn:

- The inclusion of sisal fibres significantly improves the tensile and flexural properties of cellular concrete due to effective crack-bridging action.
- The optimum fibre content was found to be 1%–1.5%, at which maximum compressive (24.2 MPa), split tensile (3.1 MPa), and flexural strength (5.3 MPa) were achieved.
- Beyond the optimum fibre dosage, strength decreases due to poor workability, fibre clustering, and increased porosity.
- The incorporation of brick bat as partial replacement of coarse aggregate reduces the density of concrete and promotes sustainable material utilization.
- The use of a foaming agent produces lightweight cellular concrete but introduces a strength–density trade-off.
- Structural performance of RC beams improved in terms of first crack load, ultimate load, and reduced deflection for optimum fibre mixes.
- Overall, sisal fibre reinforced cellular concrete is suitable for lightweight, non-load-bearing, and semi-structural applications.

FUTURE SCOPE

- Incorporation of chemical admixtures to improve workability at higher fibre content
- Study on durability properties such as water absorption, permeability, and resistance to chemical attack

- Investigation on long-term performance including creep and shrinkage behaviour
- Use of hybrid fibres (combination of natural and synthetic fibres) to enhance performance
- Application in precast elements, panels, and modular construction systems
- Optimization of density–strength relationship for structural lightweight concrete
- Exploration of alternative waste materials as partial replacements for aggregates.

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