Experimental Investigation on High-Performance Light-Weight Concrete Using Cotton Fine Trash as Partial Cement Replacement

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Abstract
The use of cotton fine trash, a byproduct of the cotton industry, as a partial substitute for cement in high-performance concrete is examined in this study. The key objective is to assess how various replacement levels (0%, 5%, 10%, 20%, and 30%) influence concrete's workability, density, tensile strength, flexural strength, and compressive strength. The 10% level of replacement (M2) provided the best property balance among the evaluated mixes. The 10% mix showed greater workability, as seen by higher slump, compaction factor, and flow table values as well as a shorter Vee-Bee time. This was explained by better particle packing and less friction because the cotton fine trash was fibrous. Along with higher flexural and tensile strengths, the 10% replacement level also showed the strongest compressive strength at 7, 14, and 28 days. These advantages are attributed to greater particle packing, possible pozzolanic reactions, and enhanced bonding characteristics of the cotton fine trash. Furthermore, the concrete's density dropped as the amount of cotton fine trash increased, which makes the 10% mix advantageous for lightweight concrete applications. Higher negative mechanical qualities, and the concrete cement content, and the negative organic material content of the negative organic material. By encouraging the recycling of industrial waste and lowering reliance on conventional cement, the study emphasizes the sustainability advantages of employing cotton fine rubbish in concrete.

Keywords: High-Performance Concrete, Cotton Fine Trash (CFT), Workability, Lightweight Concrete

1. Introduction

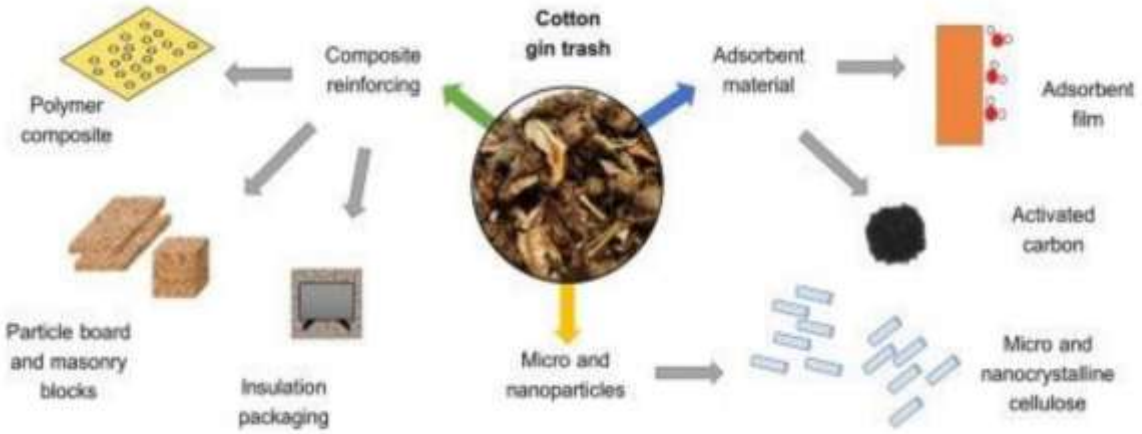
The construction sector consumes enormous quantities of natural resources every year. Continuous extraction of limestone for cement production and aggregates for concrete has created environmental concerns. Simultaneously, agricultural industries generate large quantities of biomass waste that often remains underutilized. Cotton Fine Trash is abundantly available in cotton-producing regions but has limited commercial applications. Disposal of this waste not only occupies valuable landfill space but also creates environmental pollution. Researchers have found that natural fibers can improve the toughness and crack resistance of cementitious materials. Therefore, Cotton Fine Trash offers potential as a sustainable additive in concrete. High Performance Concrete (HPC) is an advanced type of concrete designed to provide superior mechanical properties, durability, workability, and resistance to harsh environmental conditions. Compared to conventional concrete, HPC exhibits higher compressive strength, lower permeability, improved resistance to chemical attack, and enhanced long-term performance.

The Main Objectives of this project

1. To Study the feasibility of using Cotton Fine Trash as a partial replacement for cement in the production of High-Performance Light-Weight Concrete.
2. To study the effect of Cotton Fine trash on the fresh properties of Light-weight concrete, such as workability and flowability characteristics.
3. To measure and evaluate the concrete density of the concrete mixes containing Cotton Fine Trash and Compare with the nominal mix.
4. To identify the optimal proportion of Cotton Fine Trash in the concrete mix that provide the best combination of workability, density and mechanical performance.

Significance of Study

The significance of this study lies in its potential to develop an environmentally sustainable, economically viable, and high-performance construction material through the effective utilization of Cotton Fine Trash (CFT) as a partial replacement for cement in High- Performance Lightweight Concrete (HPLC). The research addresses several environmental, technical, economic, and social challenges associated with conventional concrete production while promoting sustainable development.



Cotton Fine Trash

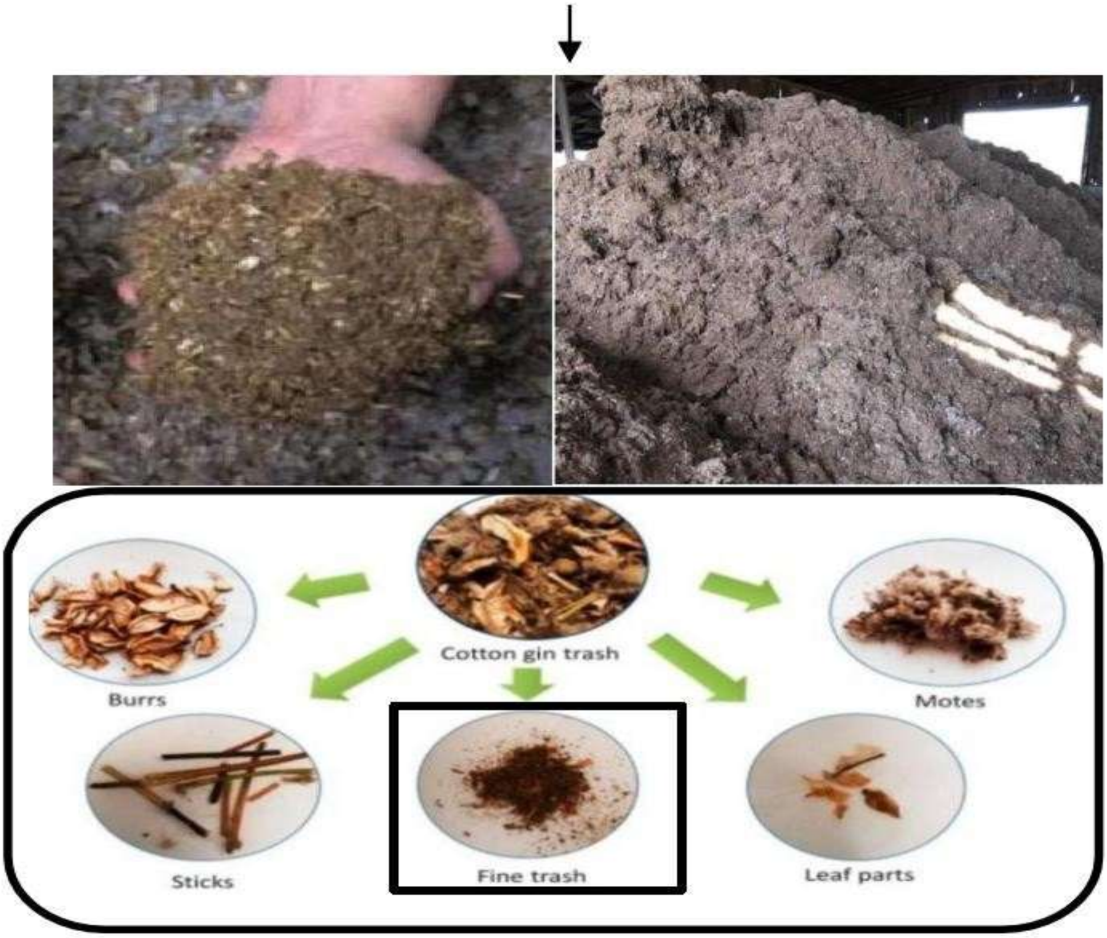


Figure: 1 Cotton Fine Trash

2. Literature Study

Literature Study on the Use of Cotton Fine Trash from Cotton Gin Waste in Concrete

1. Joel Kimarai Musyoka Naftary Gathimba, Silvester Ochieng Abuodha

Cotton Waste Fibers (CWF), a non-synthetic industrial by-product, form a type of micro- diameter concrete reinforcing fibrous material. Fiber dispersion and fiber balling reduce the application of CWF in structural concrete due to discontinuous interfacial transition zones (ITZ) in the concrete matrix. In this paper, compressive strength development and flexural toughness of concrete with 0%–1.5% 0.25 mm diameter and 50 mm length CWF fibres, designed using the densified mix design algorithm (DMDA) method, were studied.

2. Musyoka, J. K., Gathimba, N., Abuodha, S. O., et al. (2026)

The textile industry is one of the world's largest polluters, generating millions of tons of waste annually and contributing significantly to greenhouse gas emissions. Each year, the world generates a staggering 92 million tons of textile waste, and the figure is projected to soar to 134 million tonnes by 2030 without drastic changes. Moreover, the textile industry accounts for a shocking 10% of global greenhouse gas emissions. For example, the United States produces a staggering 16.2 million tons of textile waste per year, of which a mere 15% is recycled. In China, only 3.5 million tonnes of textile waste are recycled, despite 45% of the total textile waste being discarded.

3. Md Faiyaz Shahriar, Rizwanur Rahman & Takia Kamal [2025]

Cotton Fine Trash (CFT) as a partial replacement for cement in High-Performance Lightweight Concrete (HPLC) influences the fresh properties of concrete. Their study observed that increasing the percentage of Cotton Fine Trash reduced the workability of the concrete mix due to the higher water absorption capacity of the fibrous material. However, they concluded that this reduction in workability could be effectively compensated by optimizing the water-to- cement ratio or by using suitable superplasticizers.

3. Mix Design

Mix Design as per IS 10262:2019 for Different Proportions of Cotton Fine Trash Introduction

The following mix designs are prepared as per IS 10262:2019, incorporating cotton fine trash at varying proportions (5%, 10%, 20%, and 30% by weight of cement) with the incorporating or addition of a super plasticizer. These mixes are designated as M1, M2, M3, and M4 respectively.

3.1 Assumptions and Material Properties

- **Grade of Concrete:** M30
- **Type of Cement:** Ordinary Portland Cement (OPC) 53 grade
- **Fine Aggregate:** River sand
- **Coarse Aggregate:** Crushed stone with a maximum - 20 mm Size
- **Water-Cement Ratio:** 0.40
- **Super plasticizer:** Polycarboxylate ether-based, dosage 1.1% by weight of cement
- **Cotton Fine Trash:** Processed and sieved to ensure uniform particle size
- **Workability:** Slump of 75-100 mm

3.2 Step-by-Step Mix Design Calculation

1. Target Mean Strength Calculation

$$fck = fck + 1.65 \times \sigma$$

For M30 grade concrete, fck=30 MPa Assuming standard deviation (a) of 5 MPa Target mean strength 30+ 1.65 x 538.25 MPa

2. Selection of Water-Cement Ratio

Using a water-cement ratio of 0.45 for M30 grade concrete.

3. Calculation of Water Content

For a slump of 75-100 mm, water content can be taken as 186 liters (as per IS 10262:2019). 4.Calculation of Cement Content

5. Volume of Coarse and Fine Aggregate

Assume fine aggregate percentage as 35% of total aggregate volume.

6. Mix Proportion Calculation

For the control mix (MO), the mix proportions are calculated as follows:

$$\text{Volume of cement} = \frac{\text{cement content}}{\text{Specific gravity of cement} * 1000} = \frac{412}{3.15*1000}$$

Volume of concrete = 1 m3

$=0.131 m^3$

$$\text{Cement content} = \frac{\text{water content}}{\text{water-cement ratio}} = \frac{186}{0.45} = 412\ kg/m^3$$

Mass of fine aggregate = Volume of fine aggregate x Specific gravity of fine aggregates Given specific gravities:

Coarse Aggregate (20 mm): 2.74 Fine Aggregate (Zone II): 2.65 Volume of

$$\text{Volume of water} = \frac{186}{1000} = 0.186m^3$$

$$\text{Volume of all in aggregate} = 1 - (0.131 + 0.186) = 0.683\ m^3$$

Mass of coarse aggregate =
Volume of coarse aggregate x Specific gravity of coarse

coarse aggregate 0.683 x 0.65 =0.444 m^3

Volume of fine aggregate = 0.683 × 0.35= 0.239 m^3

Mass of coarse aggregate =0.444 x 2.74 x 1000 = 1216 kg Mass of fine aggregate = 0.239 x 2.65 x 1000 = 634kg

7. Incorporation of Cotton Fine Trash

Replace cement with cotton fine trash at different percentages (5%, 10%, 20%, and 30%).

3.3 Mix Proportions

1. **M1 (5% Cotton Fine Trash)**

- **Cement:**413×0.95=392.35 kg413 \times0.95=392.35\
- { kg}413×0.95=392.35 kg
- **Cotton Fine Trash:** 413×0.05=20.65 kg413\times0.05= 20.65 \{ kg}413×0.05=20.65 kg
- **Water:** 186 liters
- **Fine Aggregate:** 634 kg
- **Coarse Aggregate:** 1216 kg
- **Super plasticizer:** 413×0.01=4.13 kg413\times0.01=4.13 \ {kg}413×0.01=4.13 kg

2. **M2 (10% Cotton Fine Trash)**

- **Cement:**413×0.90=371.7kg413\times 0.90=371.7\{kg} 413×0.90=371.7 kg
- **Cotton Fine Trash:**413×0.10=41.3 kg413\times0.10=41.3 \{ kg}413×0.10=41.3 kg
- **Water:** 186 liters
- **Fine Aggregate:** 634 kg
- **Coarse Aggregate:** 1216 kg
- **Super plasticizer:** 413×0.01=4.13 kg413\times0.01=4.13 \{ kg}413×0.01=4.13 kg

3. **M3 (20% Cotton Fine Trash)**

- **Cement:** 413×0.80=330.4 kg413 \times 0.80=330.4\text{kg} 413×0.80=330.4 kg
- **Cotton Fine Trash:** 413×0.20=82.6 kg413\times0.20=82.6 \{ kg}413×0.20=82.6 kg
- **Water:** 186 liters
- **Fine Aggregate:** 634 kg
- **Coarse Aggregate:** 1216 kg
- **Superplasticizer:** 413×0.01=4.13 kg413\times0.01=4.13 \text{ kg}413×0.01=4.13 kg

4. **M4 (30% Cotton Fine Trash)**

- **Cement:** 413×0.70=289.1 kg413 \times 0.70=289.1\text{kg} 413×0.70=289.1 kg
- **CottonFineTrash:** 413×0.30=123.9 kg413 \times 0.30 = 123.9 \text{ kg}413×0.30=123.9 kg
- **Water:** 186 liters
- **Fine Aggregate:** 634 kg
- **Coarse Aggregate:** 1216 kg
- **Superplasticizer:** 413×0.01=4.13 kg413\times0.01=4.13

\text{ kg}413×0.01=4.13 kg

Table 1.Mix Proportions

Mix Designation	Cement (kg/m³)	Cotton Fine Trash (kg/m³)	Water (L/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Super plasticizer (kg/m³)
M1-5%	391.30	20.60	186	634	1216	4.13
M2-10%	371.72	41.25	186	634	1216	4.13
M3-20%	330.43	82.65	186	634	1216	4.13
M4-30%	2891.12	123.80	186	634	1216	4.13

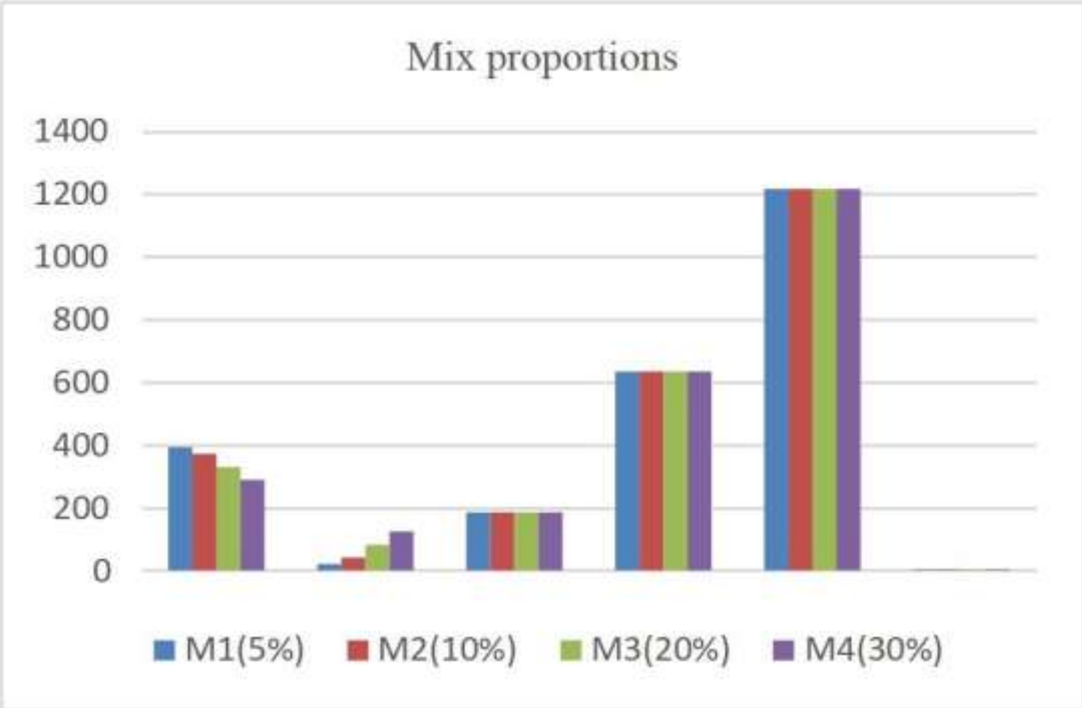


Figure: 2 Summary Of Mix-Proportions

4. Experiment And Results For Scc Mixes

4.1Explanation and Importance of Concrete Tests for Cotton Fine Trash Incorporation 1.Workability Test

Description: Workability tests evaluate the ease it is to mix, lay, compact, and finish concrete. The compaction factor test, flow table test, and slump test are common techniques. The slump test is most frequently used to evaluate the workability of mixes including cotton fine waste. It gauges the concrete mix's fluidity and uniformity.

Several standard tests are used to evaluate the workability of concrete, including the slump test, compaction factor test, flow table test, and Vee-Bee consistometer test. The choice of test depends on the consistency and intended application of the concrete mix

2. Compressive Strength Test

Explanation: The compressive strength of concrete is ability to withstand compressive loads without failure. A universal testing machine is used to test concrete cubes or cylinders under a compressive force after they have been cast and cured. The highest load the specimen can support before failing is used to calculate strength.

The compressive strength of concrete is determined by testing standard concrete cubes (150 mm × 150 mm × 150 mm) or cylinders (150 mm diameter × 300 mm height) after specified curing periods, typically 7, 14, and 28 days. Before testing, the specimens are properly cured under controlled conditions to ensure complete hydration of cement.

3. Flexural Strength Test

Explanation: The ability of concrete to withstand bending forces is measured by its flexural strength. This test is usually carried out on beam specimens is conducted on beam specimens. To determine the flexural strength, a central load is applied to the beam until it fractures and fails, and the maximum load is noted.

Flexural strength is an important mechanical property of concrete that measures its ability to resist bending or tensile stresses caused by applied loads. The flexural strength test is generally performed on beam specimens of standard dimensions, such as 100 mm × 100 mm × 500 mm or 150 mm × 150 mm × 700 mm, after the required curing period, usually 28 days. The specimens are cured under standard conditions to ensure proper strength development.

Importance:
- To determine how effectively concrete can withstand bending loads and avoid cracking, flexural strength is crucial. This is very significant structural structure structural features.
- Performance in Structural Applications: High flexural strength guarantees longevity and resistance to deformation under applied loads for beams, slabs, and other structural components.
- Impact of Cotton Fine Trash: Flexural strength testing aids in comprehending how the addition of cotton fine trash impacts overall performance and the concrete's capacity to withstand bending forces. Strength and Resistance to Cracking: .

4. Tensile Strength Test
Explanation: Tensile strength measures how well concrete can withstand direct tension. Usually, split cylindrical specimens or notched beams are used for this test. The maximum tensile stress is noted after the specimen is subjected to a tensile load until it splits or fails.

Importance:
Crack Control: The tensile strength of concrete is essential for evaluating its ability to withstand tensile forces, which contribute to cracking. This knowledge aids in the design of concrete components to reduce the likelihood of cracks.
Workability Test Outcomes: The workability of various concrete mixes was evaluated using tests such as slump, compaction factor, flow table, and Vee-Bee time. The summarized results are presented below:

Table 2. Workability Test Result

Mix Designation	% Cotton Fine Trash	Slum p (mm)	Compacti on Factor	Flow Table (mm)	Vee-Vee Time (seconds)
M0 (Control)	0%	89	0.92	448	10
M1 (5%)	5%	89	0.91	445	11
M2 (10%)	10%	94	0.93	455	9
M3 (20%)	20%	91	0.90	452	12
M4 (30%)	30%	87	0.89	440	12

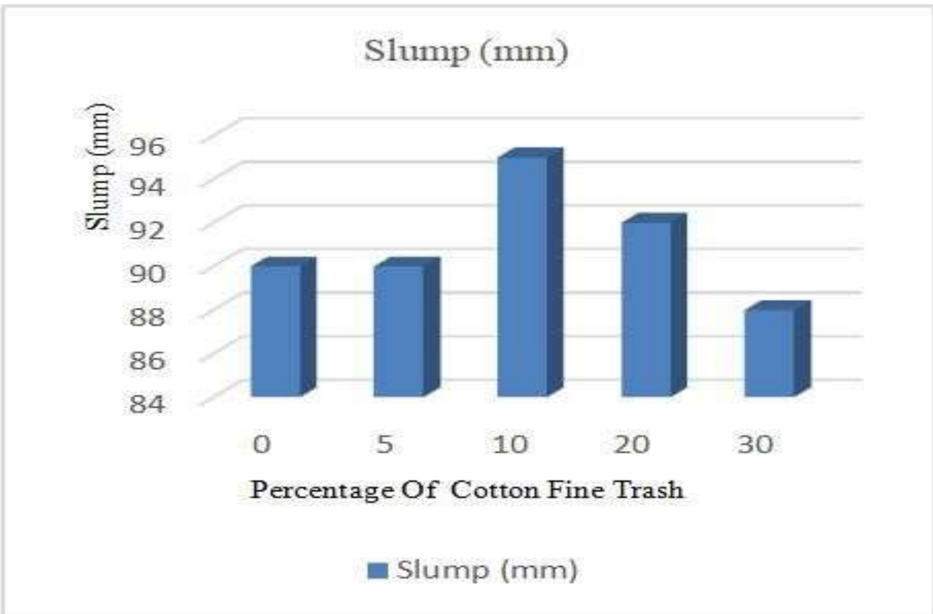


Figure: 3 Slump Test Result

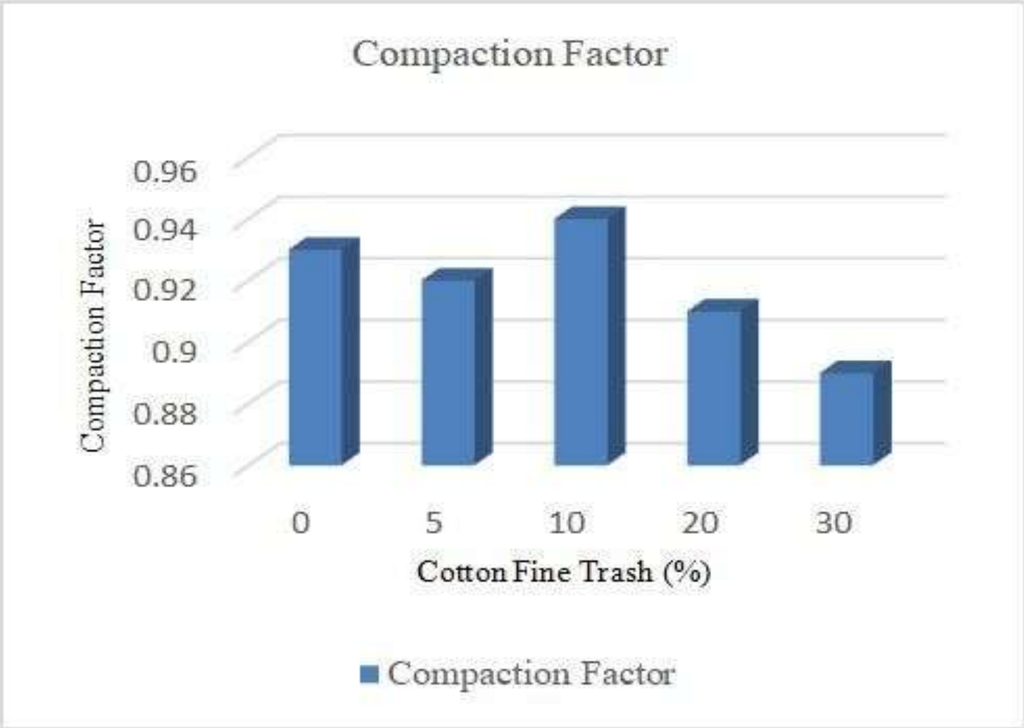


Figure: 4 Compaction Factor Test-Result

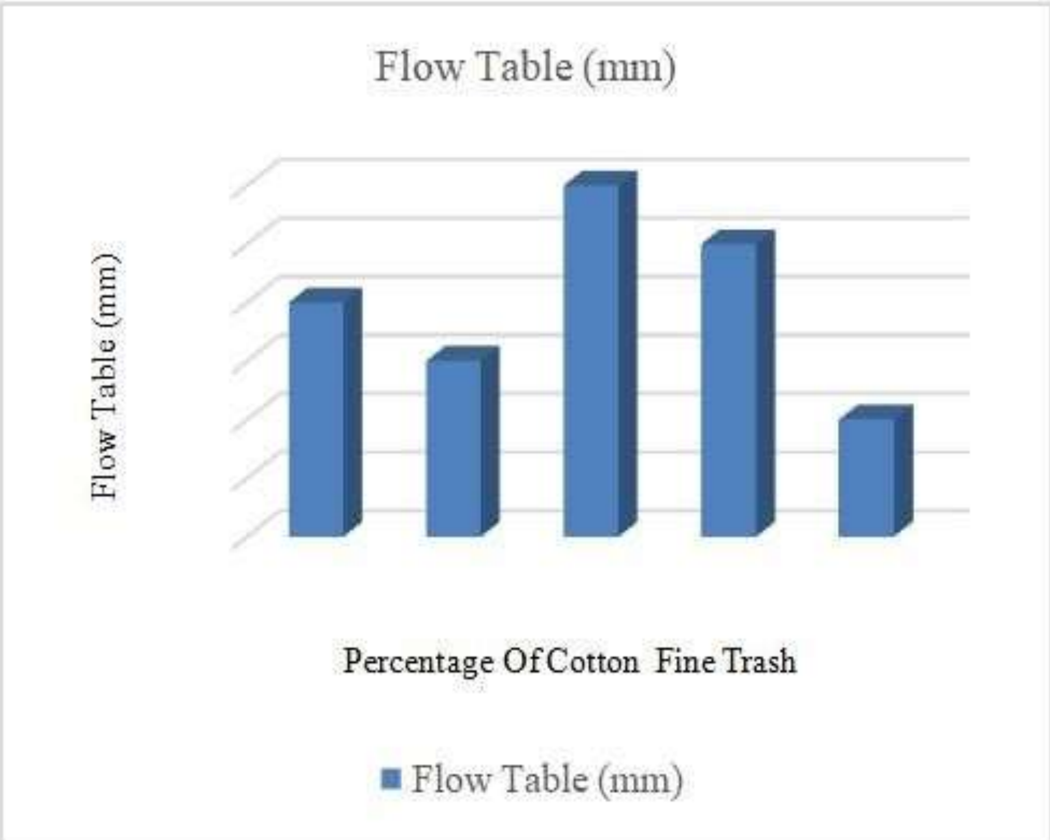


Figure: 5 Flow-Table Test Result

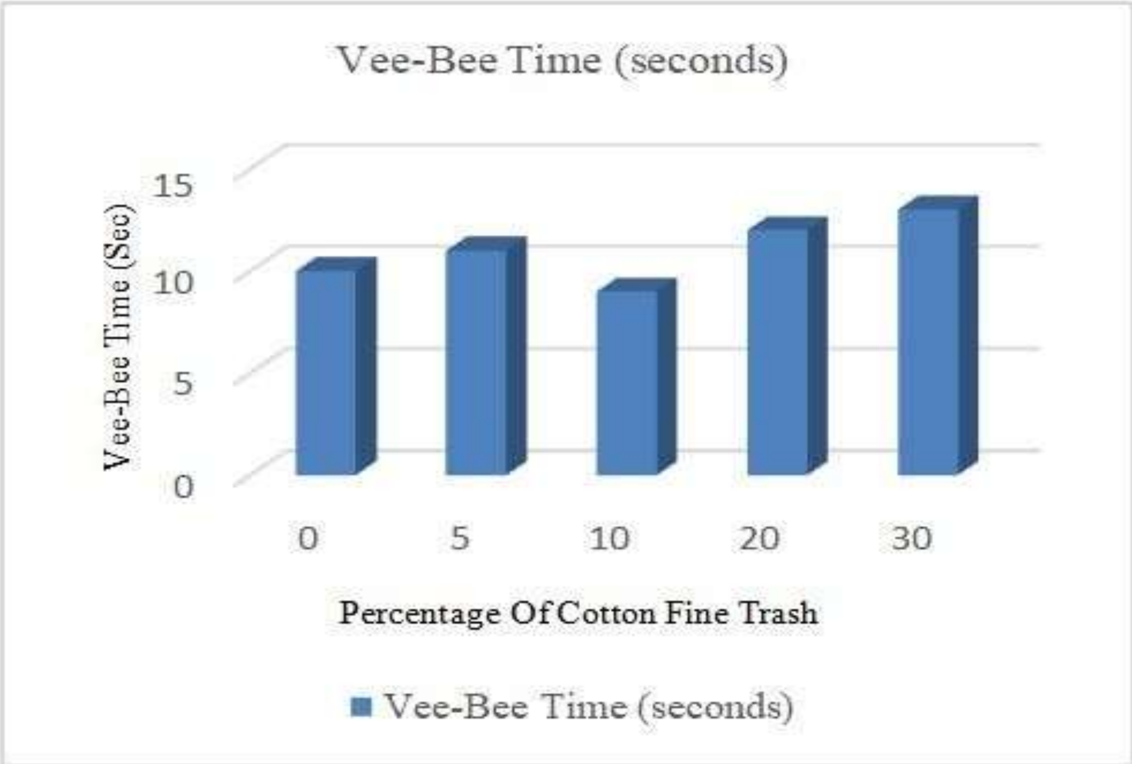


Figure: 6 Vee-Bee Time

The combination with 10% cotton fine trash (M2) showed the best workability, according to the data. This is obvious from the largest slump value of 94 mm, the highest compaction factor of 0.93, the highest flow table value of 455 mm, and the lowest Vee-Bee time of 9 seconds.

1. Compressive Strength

Table 3.Compressive Strength Result

Mix Designation	% Cotton Fine Trash	7Days (MPa)	14 Days (MPa)	28Days (MPa)
M0 (Control)	0%	21.40	30.15	37.0
M1 (5%)	5%	22.10	30.50	38.0
M2 (10%)	10%	24.59	31.158	39.0
M3 (20%)	20%	22.0	29.50	35.0
M4 (30%)	30%	20.5	25.20	33.0

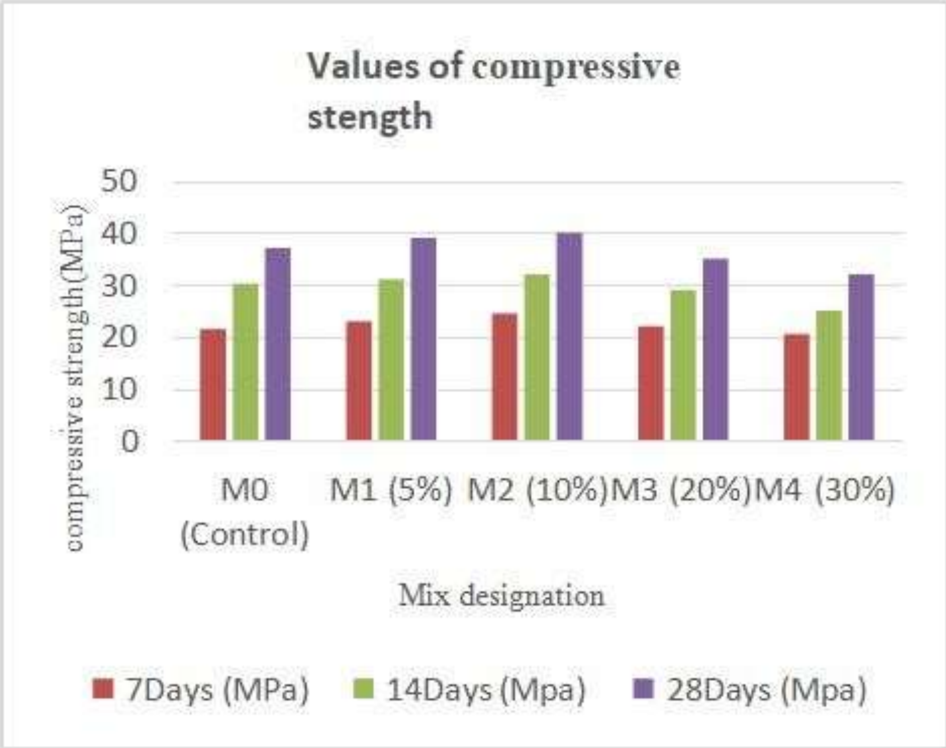


Figure: 7 Compressive Strength For Various Proportions At 7,14,28 Days

The M2 mix with 10% cotton fine trash achieved the highest compressive strength at all ages, with 24.59 MPa at 7 days, 31.158 MPa at 14 days, and 39 MPa at 28 days. The increase in compressive strength at 10% replacement can be attributed to several factors:

- Improved Ingredient Packing: The fine and fibrous quality of the cotton waste aids in filling the spaces between cement particles, leading to a denser and more compact mix.
- Pozzolanic Reaction: Cotton waste contains some organic elements that might react pozzolanically with calcium hydroxide generated during cement hydration, contributing to further strength gain.
- Improved Bonding: The fibrous composition of the cotton waste might promote the bonding between the cement matrix and the aggregate, resulting to better stress distribution and higher compressive strength.
- At greater replacement levels (20% and 30%), a drop in compressive strength is seen, possibly due to the reduction in the effective cement content and the potential deleterious effects of excessive organic content on the hydration process.

2. Flexural Strength

Table 4.Flexural Strength Result

Mix Designation	% Cotton Fine Trash	7Days (MPa)	14 Days (MPa)	28Days (MPa)
M0 (Control)	0%	3.6	4.75	6.1
M1 (5%)	5%	3.6	4.70	6.3
M2 (10%)	10%	3.65	4.85	6.5
M3 (20%)	20%	3.20	4.60	6.0
M4 (30%)	30%	3.10	4.20	5.0

The flexural strength test is generally performed on beam specimens of standard dimensions, such as 100 mm × 100 mm × 500 mm or 150 mm × 150 mm × 700 mm, after the required curing period, usually 28 days. The specimens are cured under standard conditions to ensure proper strength development.

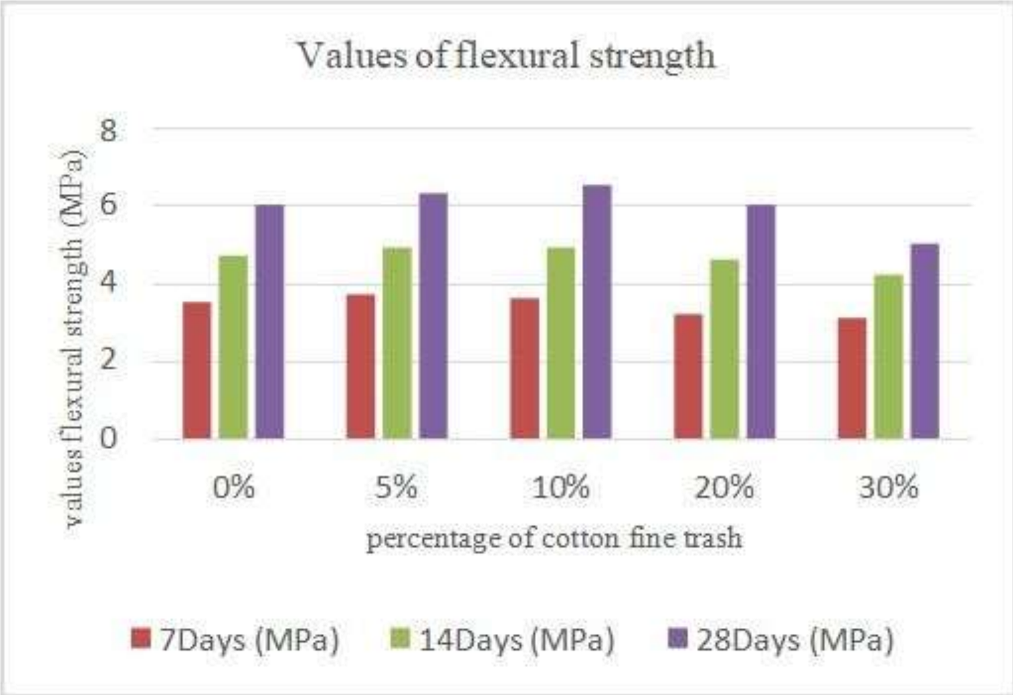


Figure: 8 Flexural-Strength For Various Proportions At 7, 14, 28 Days

The M2 mix with 10% of the cotton fine trash gave the highest flexural strength 3.65 MPa (7 days), 4.85 MPa (14 days) and 6.5 MPa (28 days). The improved bonding and stress distribution due to the fibrous cotton trash is advantageous in counteracting the bending stresses more efficiently contributing to the increased flexural strength.

3. Tensile Strength

The maximum tensile strength was observed in M2 mix with 10% cotton fine trash i.e. 2.3 MPa at 7 days, 2.85 MPa at 14 days and 3.8 MPa at 28 days. It is observed that the fibrous cotton trash has the ability to enhance the bonding and crack bridging properties that resist the tensile stresses more effectively.

Table 5.Tensile Strength Result

Mix Designation	% Cotton Fine Trash	7Days (MPa)	14 Days (MPa)	28Days (MPa)
M0 (Control)	0%	2.0	2.7	3.5
M1 (5%)	5%	2.2	2.8	3.7
M2 (10%)	10%	2.3	2.85	3.8
M3 (20%)	20%	2.1	2.7	3.4
M4 (30%)	30%	2.0	2.5	3.0

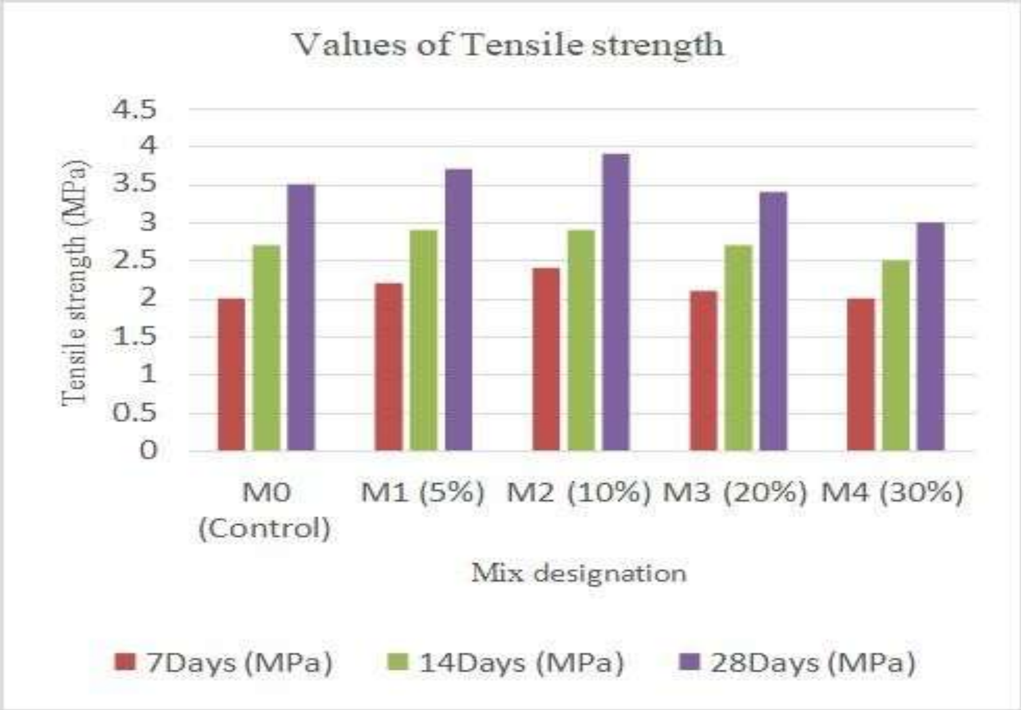


Figure: 9 Tensile-Strength For Various
Proportions At 7,14,28 Days

5. Conclusion

1. Optimal Replacement Level: 10% Cotton Fine Trash (M2) showed the best compromise between workability and mechanical properties and it was the optimal replacement level among the tested percentages.

2. Better Workability: The best workability was obtained at replacement level of 10%, with more slump, compaction factor and flow table values, and less Vee-Bee time. This is because of better particle packing and less friction due to fibrous nature of cotton fine trash.

3. Enhanced Mechanical Properties
Compressive Strength: M2 showed the highest compressive strength at 7, 14 and 28 days due to better packing of particles, possible pozzolanic reactions and better bonding.
Flexural Strength: The 10% mix also showed better flexural strength, which indicated better resistance to bending stresses..
Tensile Strength: The maximum tensile strength was obtained for 10% replacement mix due to improved crack bridging and bonding properties.

1. Density reduction:
The density of concrete decreases with increasing content of cotton fine trash. The 10% mix obtained a lower density which is beneficial for lightweight concrete applications.

2. Replacement Levels in excess of:
Mechanical properties were decreased for replacement levels higher than 10% (20% and 30%) probably caused by the lower cement content and the adverse effects of the excess of the organic material on the concrete matrix.

3. Advantages of sustainability:
10% cotton fine trash utilisation for sustainable construction practices by recycling waste material and reduced dependence on conventional cement with acceptable mechanical properties.

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