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Experimental Evaluation of Sisal-Fibre-Reinforced Concrete Utility Blocks Containing Crushed Ceramic Tile as Fine Aggregate

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Abstract: This experimental study evaluates concrete utility blocks incorporating crushed ceramic tile as a partial replacement for fine aggregate and alkali-treated sisal fibre as reinforcement. Crushed tile replaced fine aggregate at 10%, 20%, 30%, and 40% by mass. After identifying the best-performing tile replacement, sisal fibre was added at 1.0%, 1.5%, and 2.0% by mass of cement. Workability was assessed by the slump test, and compressive strength was measured after 7, 14, and 21 days of water curing. Slump decreased from 130 mm for the control mixture to 45 mm at 40% tile replacement and decreased further with increasing fibre content, confirming reduced workability. Among the tile-modified mixtures, the 30% replacement mixture produced the highest compressive strengths of 27.476, 30.298, and 31.156 MPa at 7, 14, and 21 days, respectively. When sisal fibre was incorporated into the 30% tile mixture, the 1.5% fibre dosage provided the highest reported strengths of 35.560, 41.223, and 44.184 MPa. A further increase to 2.0% fibre reduced strength, indicating an optimum within the investigated range. The findings support the technical feasibility of combining crushed ceramic fines and treated sisal fibre in non-structural concrete utility blocks. However, the study is limited to workability and compressive strength; durability, water absorption, dimensional stability, tensile performance, and full-scale paving-block compliance require additional testing before practical deployment.

Keywords: Crushed Ceramic Tile, Fine-Aggregate Replacement, Sisal Fibre, Utility Block, Workability, Compressive Strength, Waste Valorisation.

1. Introduction

Concrete production consumes substantial quantities of natural aggregates, while construction and demolition activities generate large volumes of ceramic waste. Recycling ceramic tile residues as aggregate can reduce landfill disposal and the extraction of natural sand, although the resulting performance depends on particle grading, absorption, replacement level, and mixture design [1–4]. Recent studies and reviews have shown that ceramic waste can be used as a fine or coarse aggregate in cementitious composites, but excessive replacement may reduce workability and create additional pores because crushed ceramic particles are angular and absorptive [2–5]. Natural fibres provide a complementary route for improving crack control and post-cracking behaviour in cement-based materials. Sisal fibre is renewable, low-density, and widely available, and its tensile capacity can contribute to stress transfer across developing cracks [6–9]. Nevertheless, untreated plant fibres are hydrophilic and susceptible to degradation in alkaline cement matrices. Fibre treatment, controlled fibre length, adequate dispersion, and a limited dosage are therefore necessary to reduce water uptake, fibre agglomeration, and loss of workability [7–10]. Comparative research has also shown that increasing sisal-fibre content does not continuously improve concrete strength; an optimum dosage is commonly observed because higher contents promote entrapped air and inadequate compaction [8, 9]. Utility and paving blocks require adequate early-age strength, dimensional consistency, abrasion resistance, and low water absorption. Indian practice consequently requires mix proportioning and constituent selection to be aligned with the relevant standards for concrete and precast paving units [11–15]. In the present work, crushed ceramic tile was evaluated as a partial replacement for fine aggregate at 10–40%, followed by the addition of alkali-treated sisal fibre at 1.0–2.0% by mass of cement to the best-performing tile mixture. The objective was to quantify changes in slump and compressive strength at 7, 14, and 21 days and to identify the optimum combination within the tested ranges. The study does not report split-tensile, flexural, abrasion, absorption, or durability results; conclusions are therefore restricted to the measured workability and compressive-strength data.

2. Materials and Methods

2.1 Experimental Design

The source manuscript contains conflicting references to M25 and M30 concrete and to fine- and coarse-aggregate replacement. The quantitative tables and stated mix proportion identify an M25 nominal mixture with a cement:fine aggregate:coarse aggregate proportion of 1:1.5:2 and a water–cement ratio of 0.50. Accordingly, the present revision treats crushed ceramic tile passing the 4.75-mm sieve as a partial replacement for fine aggregate. Five tile-series mixtures were evaluated: control, CT10, CT20, CT30, and CT40. The best-performing tile mixture, CT30, was subsequently modified with 1.0%, 1.5%, and 2.0% chopped sisal fibre by mass of cement. Specimens were tested after 7, 14, and 21 days of curing.

Table 1. Experimental mixture programme

Series	Mixture	Crushed tile replacement	Sisal fibre dosage	Reported curing ages
Tile series	Control	0% of fine aggregate	0%	7, 14, and 21 days
Tile series	CT10	10% of fine aggregate	0%	7, 14, and 21 days
Tile series	CT20	20% of fine aggregate	0%	7, 14, and 21 days
Tile series	CT30	30% of fine aggregate	0%	7, 14, and 21 days
Tile series	CT40	40% of fine aggregate	0%	7, 14, and 21 days
Fibre series	CT30-SF1.0	30% of fine aggregate	1.0% of cement mass	7, 14, and 21 days
Fibre series	CT30-SF1.5	30% of fine aggregate	1.5% of cement mass	7, 14, and 21 days
Fibre series	CT30-SF2.0	30% of fine aggregate	2.0% of cement mass	7, 14, and 21 days

The mixture designations and test ages used throughout the revised manuscript are summarised in Table 1.

2.2 Constituent Materials

Portland pozzolana cement, natural fine aggregate, 6.3-mm nominal coarse aggregate, potable water, crushed ceramic tile fines, and sisal fibre were used. The original manuscript reports constituent properties without identifying the laboratory method or replicate count for several measurements. These values are retained as reported and should be verified against original laboratory records before final submission.

Figure 1. Representative conventional concrete utility block used as the reference specimen.

Table 2. Reported chemical composition of the cement

Constituent	Content (%)	Reported specification limit
SiO_2	21.93	–
CaO	63.34	–
MgO	1.50	≤ 6
Fe_2O_3	4.61	–
Al_2O_3	3.72	–
SO_3	1.71	≤ 3
Loss on ignition	0.89	≤ 3
Insoluble residue	0.74	≤ 0.75
Lime saturation factor	0.97	0.66–1.02

The reported cement composition is presented in Table 2. The cement designation should be checked against the supplier certificate because the original text incorrectly described PPC using OPC grade terminology. A representative control utility block is shown in Figure 1. The manuscript reports a block size of 200 × 100 × 50 mm; mould tolerance and compaction procedure were not documented.

Table 3. Reported physical properties of the aggregates and sisal fibre

Material	Property	Reported value
Fine aggregate	Specific gravity	2.60
Fine aggregate	Fineness modulus	3.10
Fine aggregate	Water absorption	2.0%
Fine aggregate	Bulk density	1750 kg/m^3
Crushed tile	Density	2250 kg/m^3
Crushed tile	Impact value	28%
Crushed tile	Crushing value	30%
Crushed tile	Water absorption	1.5%
Coarse aggregate	Nominal size	6.3 mm
Coarse aggregate	Specific gravity	2.90
Coarse aggregate	Impact value	10.5%
Coarse aggregate	Water absorption	0.15%
Sisal fibre	Diameter	0.68 mm
Sisal fibre	Aspect ratio	104.2
Sisal fibre	Specific gravity	0.87
Sisal fibre	Reported water absorption	104.2%

Table 3 consolidates the physical properties reported separately in the source manuscript. The value reported as sisal-fibre density (2057 kg/m³) is inconsistent with the stated specific gravity of 0.87 and has therefore not been used in the analysis.

Figure 2. Crushed ceramic tile processed for use as fine-aggregate replacement.

As illustrated in Figure 2, discarded ceramic tiles were manually crushed and sieved. Only material passing the 4.75-mm sieve was used as fine-aggregate replacement. The absence of a full grading curve is an important reproducibility limitation.

Table 4. Reported oxide composition of the crushed ceramic tile

Oxide	Content (%)
SiO_2	68.85
Al_2O_3	18.53
Fe_2O_3	4.81
CaO	1.57
Na_2O	2.01
K_2O	1.63
MgO	0.72
TiO_2	0.737
MnO	0.078
P_2O_5	0.034
SO_3	0.06
Loss on ignition	0.48

The reported ceramic-tile oxide composition is given in Table 4. No analytical technique, sample preparation method, or measurement uncertainty was stated.

2.3 Sisal-Fibre Treatment and Specimen Preparation

Sisal fibres were cut to lengths of approximately 6–10 mm and treated in 1 M sodium hydroxide solution at 80 °C for 2 h under mechanical stirring. The fibres should subsequently be rinsed to neutral pH and dried before mixing; although these steps are necessary, they were not explicitly documented in the source manuscript. Dry constituents were mixed before water addition, and fibre was introduced gradually to reduce balling. Utility blocks were cast in 200 × 100 × 50 mm moulds, compacted, demoulded, and water-cured. The number of specimens per mixture, mixing duration, curing temperature, and loading rate were not reported and must be supplied from laboratory records for full reproducibility.

2.4 Test Methods and Data Analysis

Workability was evaluated using the slump-cone test. Compressive strength was reported at 7, 14, and 21 days. The source manuscript does not identify the specimen loading area, testing-machine capacity, loading rate, replicate number, or dispersion statistics. Therefore, the reported values are treated as single mean values of unspecified replication. Percentage improvement was calculated relative to the corresponding control value. No statistical significance testing was possible.

3. Results and Discussion

3.1 Workability

Table 5. Reported slump values for crushed-tile and sisal-fibre series

Series	Dosage	Slump (mm)
Crushed tile	0%	130
Crushed tile	10%	80
Crushed tile	20%	75
Crushed tile	30%	60
Crushed tile	40%	45
Sisal fibre in CT30	0%	60
Sisal fibre in CT30	1.0%	45
Sisal fibre in CT30	1.5%	42
Sisal fibre in CT30	2.0%	35

As shown in Table 5, slump decreased progressively with both tile replacement and fibre addition. Relative to the 130-mm control, CT30 produced a slump of 60 mm. Adding 1.5% fibre to CT30 reduced slump further to 42 mm. This trend is consistent with the angular texture and absorption of ceramic fines and the large surface area and hydrophilicity of sisal fibre [2, 7–10]. The conclusion in the original manuscript that these materials improved workability was therefore incorrect and has been removed.

3.2 Effect of Crushed Ceramic Tile on Compressive Strength

Table 6. Compressive strength of mixtures containing crushed ceramic tile

Mixture	7 days (MPa)	14 days (MPa)	21 days (MPa)
Control	8.240	11.450	14.330
CT10	9.196	11.067	15.020
CT20	16.308	19.360	22.450
CT30	27.476	30.298	31.156
CT40	23.454	25.470	27.370

Table 6 shows that compressive strength increased up to 30% tile replacement and then decreased at 40%. CT30 yielded the highest values at every reported curing age. Relative to the control, CT30 increased the 21-day strength from 14.330 to 31.156 MPa. Because no replicate values or uncertainty estimates are available, this increase should be interpreted as an observed experimental trend rather than a statistically validated effect.

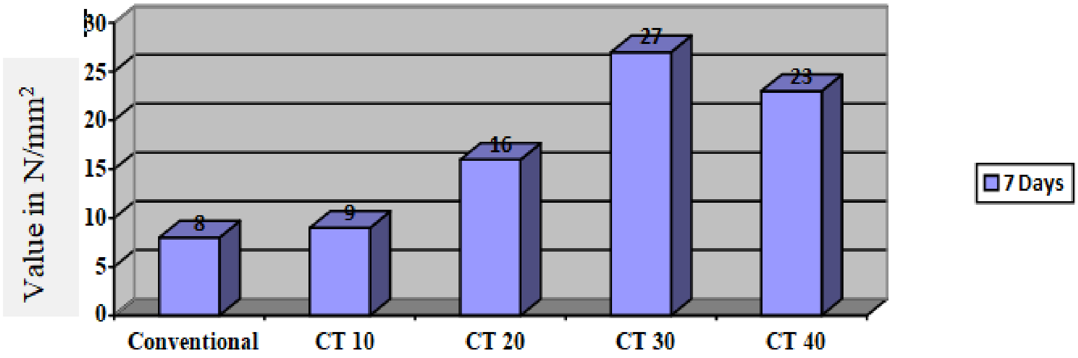

Figure 3. Reported 7-day compressive strength of the crushed-tile series.

The 7-day results in Figure 3 show a strong increase from CT10 to CT30, followed by a reduction for CT40. The graph displays rounded values, whereas Table 6 retains the reported numerical precision.

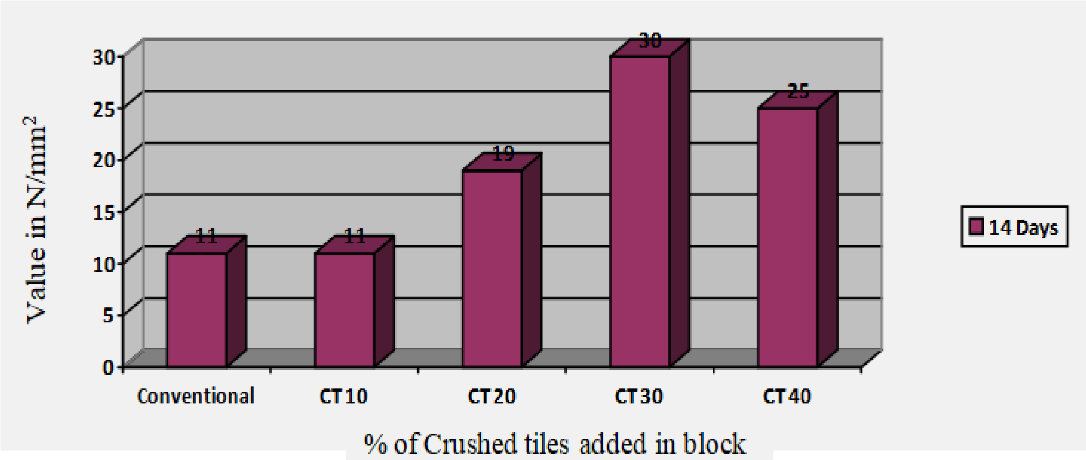

Figure 4. Reported 14-day compressive strength of the crushed-tile series.

Figure 4 confirms that CT30 remained the highest-strength mixture at 14 days. The decrease at CT40 may reflect reduced paste continuity, higher effective water demand, or increased void content, but these mechanisms were not independently measured.

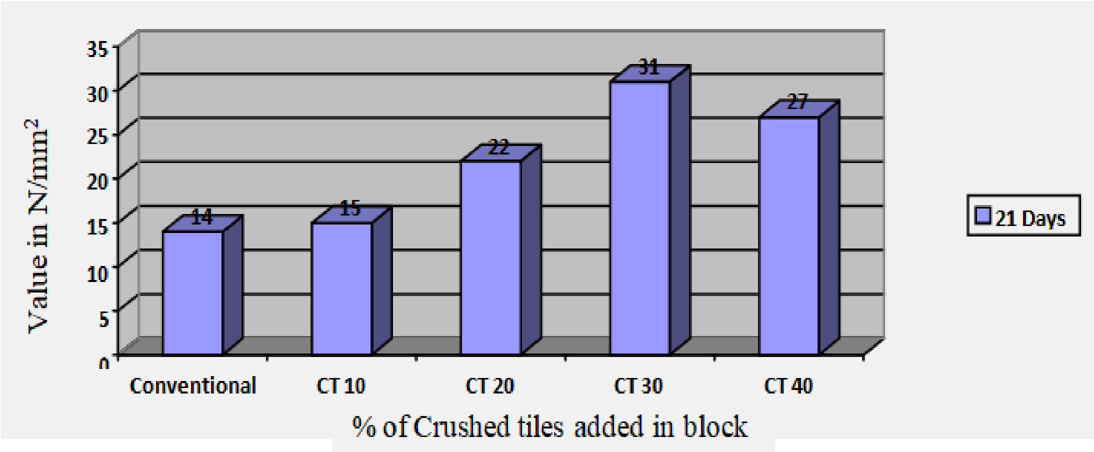

Figure 5. Reported 21-day compressive strength of the crushed-tile series.

At 21 days, the CT30 mixture reached 31.156 MPa, as shown in Figure 5. The results support 30% as the optimum replacement level within the tested range, not as a universal optimum for all ceramic sources or concrete mixtures.

3.3 Effect of Sisal-Fibre Dosage in the CT30 Mixture

Table 7. Compressive strength of CT30 mixtures containing sisal fibre

Mixture	7 days (MPa)	14 days (MPa)	21 days (MPa)
CT30 without fibre	27.476	30.298	31.156
CT30-SF1.0	31.143	33.530	34.750
CT30-SF1.5	35.560	41.223	44.184
CT30-SF2.0	34.224	39.410	41.900

The fibre-series results are consolidated in Table 7. The 1.5% dosage produced the highest strengths at all three ages, including 44.184 MPa at 21 days. Increasing the fibre dosage to 2.0% reduced the 21-day value to 41.900 MPa, although it remained above the fibre-free CT30 mixture. This optimum is physically plausible because moderate fibre addition can restrain microcrack propagation, whereas excessive fibre content can impair dispersion and compaction [6–10].

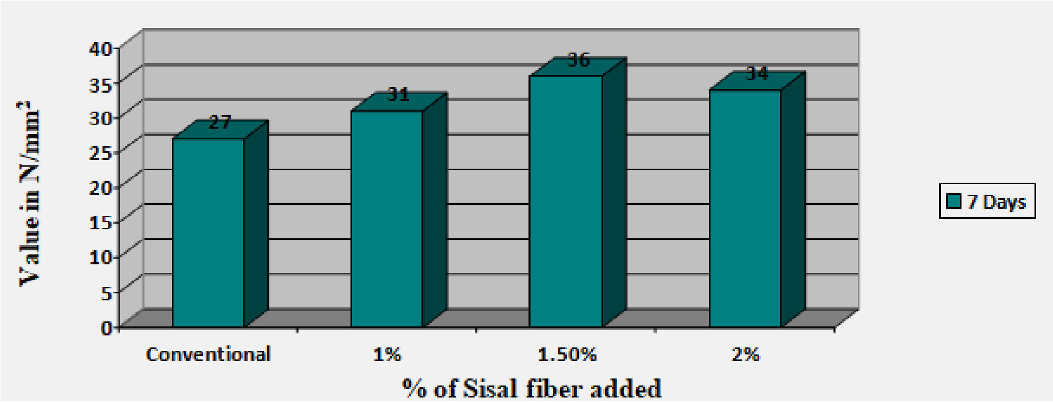

Figure 6. Reported 7-day compressive strength of CT30 mixtures containing sisal fibre.

Figure 6 shows the 7-day response of the fibre-modified CT30 mixtures. The highest value occurred at 1.5% fibre, not at 1.0% as stated in one part of the original text.

The 14-day comparison in Figure 7 again identifies 1.5% fibre as the best-performing dosage. The source graph and table are consistent at this age.

As shown in Figure 8, CT30-SF1.5 achieved the maximum reported 21-day compressive strength. The improvement relative to fibre-free CT30 was approximately 41.8%, calculated from 44.184 and 31.156 MPa. The original claim of 45.19% was not supported by the tabulated values.

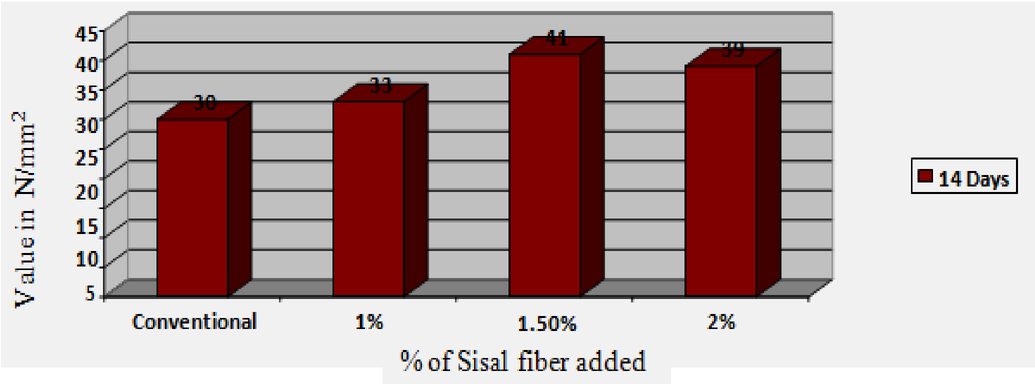

Figure 7. Reported 14-day compressive strength of CT30 mixtures containing sisal fibre.

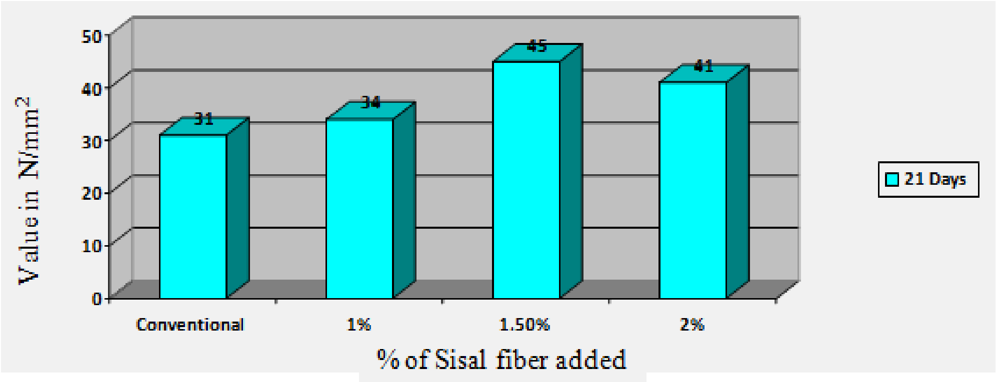

Figure 8. Reported 21-day compressive strength of CT30 mixtures containing sisal fibre.

3.4 Study Limitations and Publication Requirements

The reported dataset is insufficient to establish structural or paving-block compliance. The manuscript does not provide specimen replication, standard deviation, density, water absorption, abrasion resistance, flexural strength, splitting tensile strength, dimensional tolerance, failure modes, or long-term durability. In addition, the use of 21-day rather than the conventional 28-day reference age limits comparison with published studies and design-grade requirements. Before the material is proposed for field use, the authors should verify all raw data, report the number of specimens, repeat critical tests, and assess compliance with IS 15658 and relevant concrete-testing standards [13–15].

4. Conclusion

Within the limits of the reported experimental programme, crushed ceramic tile and treated sisal fibre influenced both workability and compressive strength of concrete utility blocks.

Replacing fine aggregate with ceramic tile reduced slump, but compressive strength increased up to a replacement level of 30%. The CT30 mixture achieved reported strengths of 27.476, 30.298, and 31.156 MPa after 7, 14, and 21 days, respectively. Incorporating sisal fibre into CT30 further increased compressive strength up to a dosage of 1.5% by mass of cement. The CT30-SF1.5 mixture produced the highest reported values of 35.560, 41.223, and 44.184 MPa at the corresponding ages. A fibre dosage of 2.0% caused a moderate reduction, indicating that excessive fibre content may adversely affect dispersion and compaction. The combined use of 30% crushed ceramic tile and 1.5% treated sisal fibre is therefore identified as the best-performing formulation within the investigated ranges. This conclusion is restricted to slump and compressive strength. Claims concerning tensile capacity, flexural performance, durability, water retention, or paving-block suitability cannot be confirmed from the supplied data. Further work should include 28-day and long-term testing, replicate-based statistical analysis, water absorption, abrasion, flexural strength, splitting tensile strength, microstructural examination, and full conformity assessment before practical application.

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