

A Study on Strength Characteristics of Confined Concrete Columns using Textile Reinforced Concrete

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Abstract - Textile Reinforced Concrete (TRC) is an innovative composite material consisting of a concrete matrix and textile reinforcement. TRC offers corrosion resistance, allowing for a reduction in the concrete cover typically required in reinforced concrete constructions. By confining concrete columns with TRC, lateral expansion can be restricted, leading to a multiaxial compressive stress state that enhances compressive strength. This study explores how TRC serves as an efficient alternative to traditional reinforcement methods, offering improved crack control, durability, and load-bearing capacity in construction applications. The experimental study involved testing 12 reinforced concrete square columns of two different sizes, 200×200×500 mm and 150×150×500 mm, to failure. Six columns were unstrengthened as references, while the other six were reinforced with two layers of Alkali Resistance (AR) Glass Fiber Textile Reinforced Concrete. The specimens underwent testing at 7, 14, and 28 days. Results showed TRC-reinforced columns achieved compressive load improvements of 52.21% to 71.96% over conventional RCC columns, demonstrating that TRC is a viable high-performance confinement system.

Key Words: Textile Reinforced Concrete; Alkali Resistance Glass Fiber (AR Glass Fiber); Confinement; Column; Compressive Strength; Reinforced Concrete.

1. INTRODUCTION

Textile Reinforced Concrete (TRC) is an innovative type of reinforced concrete in which conventional steel reinforcement is replaced with fibre textile materials. The thin, cost-effective and lightweight nature of TRC enables it to be used for creating different types of structural components for architectural and civil engineering applications. TRC is a composite material that combines textiles such as carbon, glass, or aramid fibres with concrete to enhance its structural properties, offering advantages such as higher tensile strength, improved durability, reduced weight, reduced shrinkage cracks, higher fracture toughness and increased flexibility in design.

In India, there is no industrial-scale application of TRC reported to date, even though its applications are significant in many other countries such as Germany, Israel, Brazil, Italy, France and the USA. Hence, as an alternate construction material, India requires more use and popularisation of TRC with available materials.

1.1 Replacement of Steel with Textile Materials

TRC replaces traditional steel reinforcing bars with textile materials, offering advantages such as enhanced tensile strength, flexibility, and corrosion resistance. This allows for reduction in the concrete cover and enables slimmer structural members.

1.2 Advantages of TRC

- High Compressive and Tensile Strength: TRC exhibits high compressive strength and can withstand significant tensile stress.
- Durability and Weather Resistance: TRC is known for its durability, weather resistance, and low maintenance costs.
- Versatility in Design: TRC allows for a wide range of shapes and applications due to its moldability.
- Economic Benefits: TRC is cost-effective for structures like footings, dams, piers, and precast components.

1.3 Applications of TRC

TRC presents a range of promising applications including thin and lightweight structures, bridge construction, facade elements, repair and rehabilitation of existing structures, load-bearing components, and innovative composite systems for sanitary sewer and manhole infrastructure.

1.4 AR-Glass Fibre

AR-Glass fibre is essential for Glass Fibre Reinforced Concrete (GFRC) because of its resistance to the high alkalinity levels in cement. The fibres add strength and flexibility to the concrete, resulting in a strong yet lightweight end product. The alkali resistance of AR glass fibre results from adding zirconia (ZrO₂)

to the glass; the best fibres have zirconia contents of 19% or higher.

1.5 Problem Statement

Current practices for column confinement using TRC lack standardised guidelines and efficient design methodologies, leading to uncertainties in structural performance and durability. This study aims to investigate the effectiveness of TRC as a confinement material for columns, evaluating axial behaviour and ductility of square concrete columns with TRC confinement systems and proposing optimised design solutions.

1.6 Objectives

- To evaluate the performance of TRC as a confinement system for columns subjected to axial compression, comparing its effectiveness with traditional confinement techniques.
- To determine optimal confinement configurations and material combinations to maximise the load-carrying capacity and ductility of confined columns.
- To measure safety factors associated with confined columns to ensure compliance with design codes and standards.
- To explore the enhanced design flexibility achievable through the utilisation of TRC in structural elements.

2. LITERATURE REVIEW

Polienko et al. (2023) analysed uniaxial compression tests on TRC-confined RC columns, showing increased strength and ductility compared to reference columns. Failure in specimens occurred due to tensile failure of carbon fibre textile, with continuous load loss attributed to internal steel reinforcement.

Zhang et al. (2022) investigated the confinement behaviour of concrete columns strengthened with Carbon TRC (CTRC) under uniaxial load using 20 square-section column specimens. The CTRC-confined columns achieved a maximum improvement of 67.3% in bearing capacity and 65.2% in displacement ductility compared to unstrengthened reference columns.

Ngo et al. (2020) demonstrated that TRC is a popular strengthening technique that increases strength, ductility and stiffness of columns, with failure accompanied by textile reinforcement tear. Finite element models were developed to analyse wrapped columns and investigate the reduction of tensile strength in textile reinforcement.

Faleschini et al. (2020) discussed the use of Carbon-FRCM jackets for confining axially-loaded RC columns, highlighting their high strength, corrosion resistance, and ease of application.

Eid et al. (2019) compared the efficiency of TRC-TSR dual internal confinement with conventional TSR and FRP-TSR systems. The TRC-TSR system showed good strength efficiency, and the research demonstrated feasibility through

experimental studies on large-scale HSC circular column specimens.

Liu et al. (2018) found that the flexural strength of TRC samples increases with increasing initial strain rate at room temperature. The number of textile layers in the composite samples significantly affects the reinforcing effect.

Ortlepp et al. (2009) showed that the effectiveness of the confinement effect in TRC strengthening is influenced by the geometry of the concrete column. Round columns show better results compared to rectangular ones, though the confinement effect can be activated in square columns by rounding the edges.

Peled (2007) explored the use of textiles impregnated with cement for strengthening and retrofitting structural concrete, comparing it with the conventional epoxy method. More rigid fabrics were found to contribute better to the confinement action of the repair system.

3. MATERIALS AND LABORATORY TESTS

3.1 Materials Used

The following materials were used in this investigation:

- Ordinary Portland Cement (OPC) of 53 Grade conforming to IS:12269-1989.
- Fine aggregate conforming to IS:383-1970.
- Coarse aggregate conforming to IS:383-1970.
- Potable water with pH value between 6 to 9.
- AR-Glass Fibre mesh (1 mm matrix size).
- Naphthalene-based superplasticiser (UltraTech brand).

3.2 Properties of Materials

OPC 53 Grade (JSW Company) was tested in accordance with IS:169-1989. Test results are presented in Table 1.

Table -1: Cement Test Results

S.No	Properties	Test Results	Code
1	Normal Consistency	35%	-
2	Fineness of Cement	4.8%	IS 4031 (Part 2)
3	Initial Setting Time	33 minutes	IS 4031 (Part 5)
4	Final Setting Time	10 hours	IS 4031 (Part 5)
5	Specific Gravity	3.19	IS 2720 (Part 3)
6	Le-Chatelier Soundness	2 mm	IS 4031 (Part 3)

Fine aggregate (river sand, Zone III) and coarse aggregate (crushed stone, 20 mm max size) were used. Test results are summarised in Table 2 and Table 3 respectively.

Table -2: Fine Aggregate Test Results

S.No	Description	Test Results	IS Code
1	Sand Zone	Zone-III	IS 383:2016
2	Specific Gravity	2.56	IS 2386 (P-III):1963
3	Water Absorption	0.80%	IS 2386 (P-III):1963

4	Bulking of Sand	23.3%	IS 2386 (P-III):1963
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Table -3: Coarse Aggregate Test Results

S.No	Description	Test Results	IS Code
1	Sieve Analysis (FM)	7.31	IS 383:2016
2	Specific Gravity	2.74	IS 2386 (P-III):1963
3	Water Absorption	0.66%	IS 2386 (P-III):1963

AR Glass Fibre mesh with 1 mm matrix size was used as textile reinforcement. The key chemical composition is given in Table 4.

Table -4: Properties of AR Glass Fiber

Chemical Component	AR Glass Weight %
Zirconium Oxide (ZrO ₂)	16.57
Titanium Dioxide (TiO ₂)	5.45
Cyanogen Chloride (CK)	5.87
Salt Inducible Kinase (SiK)	8.65
Calcium Potassium (CaK)	15.33
Anaplastic Lymphoma Kinase (Alk)	3.22

3.3 Mix Design (M25 Grade)

Concrete mix was designed as per IS 10262:2019 for M25 grade. The water-cement ratio was adopted as 0.45 after incorporating the naphthalene superplasticiser (20% water reduction). Final mix proportions are given in Table 5.

Table -5: Concrete Mix Proportions per Column

Column Size	Cement (kg)	Fine Agg. (kg)	Coarse Agg. (kg)	Water (kg)
150×150×500 (RCC)	5.11	7.37	13.18	2.29
200×200×500 (RCC)	9.10	13.11	23.44	4.10
150×150×500 (TRC)	3.96	7.78	13.90	1.78
200×200×500 (TRC)	7.05	13.83	24.71	3.17

3.4 Manufacturing Process

The manufacturing involved four stages: (i) Batching by weight method as per IS 10262:2019; (ii) Mixing to produce homogeneous concrete with uniform colour and consistency; (iii) Casting in cleaned and oiled moulds of 200×200×500 mm and 150×150×500 mm; and (iv) Curing in water tanks for 7, 14, and 28 days after demoulding at 24 hours. For TRC columns, two layers of AR glass fibre mesh were wrapped around the reinforcement cage before concrete was cast.

4. EXPERIMENTAL INVESTIGATION

4.1 Universal Testing Machine (UTM)

A Universal Testing Machine (UTM) with a capacity of 1000 kN was used to conduct compression tests on all column specimens. The UTM was equipped with appropriate compression platens and a spherical seat to accommodate the 150×150×500 mm and 200×200×500 mm column specimens. The machine operated under closed-loop PID control, allowing for precise application of compressive load while simultaneously displaying load and compressive stress values.

4.2 Test Procedure

The experimental investigation followed these key steps:

- Specimen Preparation: TRC column specimens were fabricated with AR glass fibre mesh as the textile reinforcement.
- Column Casting: Columns were cast according to predetermined dimensions with proper placement of AR glass fibres within the concrete matrix.
- Compression Testing: The column specimens were placed between the compression platens of the UTM and compressed at a constant rate until failure.
- Crack Monitoring: Initiation and propagation of cracks were observed visually during testing.
- Durability Testing: Resistance of TRC columns to environmental factors was assessed over curing periods.
- Comparative Analysis: Behaviour of TRC columns reinforced with AR glass fibres was compared against conventional RCC columns.

The testing programme covered 12 columns total: 6 conventional RCC columns (3 of each size) as reference specimens, and 6 TRC-wrapped columns (3 of each size) with two layers of AR glass fibre mesh.

5. RESULTS AND DISCUSSIONS

The experimental results for all column specimens are presented in Table 6.

Table -6: Compressive Load Test Results

S.No	Column Dimension (mm)	Curing Period	Compression Load (kN)
1	150×150×500 (RCC-C1)	7 days	240.9
		14 days	454.15
		28 days	577.0
2	200×200×500 (RCC-C2)	7 days	398.3
		14 days	694.0
		28 days	945.3
3	150×150×500 (TRC-C1)	7 days	411.65
		14 days	824.23
		28 days	1047.5
4	200×200×500 (TRC-C2)	7 days	578.95
		14 days	964.30
		28 days	1430.23

5.1 Effect of TRC on 150×150×500 mm Columns

Experimental testing of RCC columns of size 150×150×500 mm with and without TRC revealed significant percentage increases in compressive load, with values rising by 58.52%, 66.14%, and 52.21% at 7, 14, and 28 days of curing, respectively. The TRC-reinforced column (TRC-C1) achieved a peak compressive load of 1047.5 kN at 28 days compared to 577 kN for the reference RCC-C1 column — an improvement of approximately 81.5%.

5.2 Effect of TRC on 200×200×500 mm Columns

For the 200×200×500 mm columns, TRC addition resulted in compressive load increases of 68.79%, 71.96%, and 66.09% at 7, 14, and 28 days respectively. At 28 days, the TRC-C2 column achieved 1430.23 kN versus 945.3 kN for RCC-C2, representing a gain of approximately 51.3% in absolute terms.

5.3 Cross-Size Comparison

A comparison between the 200×200×500 mm RCC column and the 150×150×500 mm TRC column demonstrated that the smaller TRC column (TRC-C1) surpassed the larger plain RCC column (RCC-C2) in load-bearing capacity at all curing ages. This highlights the potential of TRC confinement to achieve equivalent or superior structural performance with reduced cross-sectional dimensions.

The compressive strength of TRC-reinforced columns continued to increase over the curing period, with the highest percentage gains observed at 14 days for both column sizes, indicating that TRC effectively enhances the strength development rate of concrete over time. The consistent behaviour across both column sizes demonstrates the versatility and reliability of the TRC reinforcement approach.

6. CONCLUSIONS

Based on the experimental investigation, the following conclusions are drawn:

- The addition of TRC to RCC columns led to substantial increases in compressive strength ranging from 52.21% to 71.96% across curing ages of 7, 14, and 28 days, for both 150×150×500 mm and 200×200×500 mm column sizes.
- The significant strength improvements achieved suggest that TRC confinement could enable the use of smaller column dimensions while maintaining required load-bearing capacity, leading to more efficient structural designs and potentially reduced material usage.
- Consistent strength enhancements across two different column sizes demonstrate the versatility of the TRC reinforcement approach, indicating that its benefits can be leveraged across a wide range of structural applications.
- The smaller TRC-C1 column (150×150×500 mm) outperformed the larger RCC-C2 column (200×200×500 mm) in compressive load capacity, confirming the potential benefits of TRC in terms of load-bearing capacity and overall strength.
- TRC utilisation offers enhanced design flexibility; the observed dimensional efficiency with TRC suggests that this material can achieve desired structural properties while potentially reducing the overall weight of the structure.
- The substantial increases in compressive load achieved with TRC reinforcement indicate that this technique can contribute to enhanced structural performance, including improved load-bearing capacity, ductility, and overall durability of RC columns.

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