International Journal of Scientific Research and Engineering Development-– Volume 8 Issue 4, July-Aug 2025
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Flexural Behaviour of Carbon Textile Reinforced Concrete Beams: An Experimental Study

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***Abstract*—**

Textile reinforced concrete (TRC) replaces conventional steel bars with high-strength fabrics, allowing thinner, lighter and corrosion-free members. This paper reports an experimental study on the flexural behaviour of M25 concrete beams reinforced with carbon fibre textile. Six series of beams, three specimens per series and per age, were cast and tested at 14 and 28 days under two-point loading: two plain concrete controls and four TRC series with the textile at the bottom, at the top and bottom, and at mid-depth, including a TRC beam whose depth was reduced by one-third. At 28 days the TRC beams with textile at the bottom, at top and bottom, and at mid-depth recorded 11.54, 10.86 and 10.32 N/mm², which are 31.9%, 24.1% and 17.9% above the plain control of the same size (8.75 N/mm²). The TRC beam with one-third less depth reached 11.12 N/mm², 71.9% above the deeper plain beam (6.47 N/mm²). The results show that carbon textile placed on the tension side markedly improves flexural strength and permits lighter sections.

***Index Terms*—textile reinforced concrete, carbon fibre, flexural strength, lightweight concrete, corrosion resistance and sustainability.**

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I. Introduction

Textile reinforced concrete, also called textile concrete, is a composite of fine-grained concrete reinforced with high-performance textiles such as carbon, glass or aramid fibres [1], [2]. Because the reinforcement is non-metallic, TRC avoids the corrosion that limits the durability of steel-reinforced members and does not need the thick concrete cover required to protect steel bars. It has therefore attracted considerable interest as an alternative to conventional concrete for lighter, thinner and more durable structures.

Early experiments on embedding steel wire mesh in concrete to improve tensile strength date back to the late nineteenth century, while modern TRC developed from the late twentieth century as researchers sought alternatives to conventional reinforcement. Plain concrete, in use for millennia, relies on the compressive strength of cement, aggregates and water, and is susceptible to cracking because of its low tensile strength. By incorporating high-strength fabrics, TRC improves tensile strength, flexibility and crack resistance. Research has since addressed fibre types, textile configurations and mix design [3]–[5].

A. Fibres for textile reinforcement

Fibres with high tensile strength are preferred for the fabrics, and they must have a higher elongation capacity than the concrete matrix. Unlike fibre-reinforced concrete, where short fibres are dispersed randomly, TRC uses fibres arranged in defined orientations, which allows load to be transferred efficiently. Fibres available for this purpose include aramid, carbon, glass, basalt, polyvinyl alcohol, polypropylene, jute/Kevlar, polyphenylene benzobisoxazole and hybrid combinations. Carbon fibres are 5–10 µm in diameter and offer high stiffness, high tensile strength, a high strength-to-weight ratio, chemical resistance, high-temperature tolerance and low thermal expansion, although they cost more than glass, basalt or plastic fibres [3], [4]. Several thousand filaments are bundled into a tow, which can be woven into a fabric. Carbon textile was used in the present study.

II. Objectives of the Project

The objectives of the project are: (i) to prepare a lightweight concrete element; (ii) to enhance durability; (iii) to increase flexibility; (iv) to make the concrete corrosion resistant; and (v) to make the concrete more sustainable. To work toward these objectives, the study compares the flexural strength of plain concrete beams with that of carbon-textile-reinforced beams, for different positions of the textile and for a reduced beam depth.

III. Literature Review

Ami *et al.* [5] examined the feasibility of TRC as a flexural strengthening solution in place of carbon-epoxy composites, which are constrained by cost and sustainability criteria. Five beams tested under four-point bending were used to compare TRC with CFRP and near-surface-mounted solutions in terms of deformation, cracking density, ultimate load and degradation, and CFRP predictive models were adapted to the TRC case.

Venigalla *et al.* [6] carried out a bibliometric and qualitative review of TRC as a structural member. They grouped the literature into four areas—material properties, composite behaviour, bond-slip relations and structural applications—and noted that earlier work was largely confined to retrofitting and non-structural uses.

Nivetha *et al.* [1] reviewed the properties of TRC and reported that textile reinforcement can mitigate corrosion, is

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lighter than steel bars, and combines small thickness with good strength and ductility. Beam tests showed higher load capacity with polymer-coated textiles, and bond quality strongly influenced flexural behaviour. In four-point bending of carbon-textile specimens the ultimate capacity was slightly over-predicted, and it was reported that textile reinforcement could reduce the concrete in a structural element by 60% compared with steel reinforcement. Bond between yarn and matrix remained a reported issue.

Tran *et al.* [7] built a two-dimensional meso-scale finite element model of basalt TRC under tension in ANSYS. The model reproduced the strain-hardening response, which developed in three phases depending on the number of textile layers, and a parametric study showed that the reinforcement ratio strongly affects ultimate strength.

Other recent studies have addressed the biaxial compressive capacity of TRC [8], the flexural behaviour of warp-knitted textiles impregnated with cementitious binder [9], the strengthening of reinforced concrete beams with basalt and carbon textile mortars at elevated temperature [10], hybrid steel-fibre/carbon/glass composite bars [11] and sustainable fibre-reinforced concrete design [12]. Sciegaj *et al.* [2] studied TRC members in tension, bending and in-plane loading, and Islam *et al.* [4] compared carbon and galvanised-iron textiles. The present work adds experimental data on how the position of a carbon textile layer, and a reduced section depth, affect the flexural strength of beams.

IV. Casting of Specimens

A. Materials

Ordinary Portland cement of 43 grade conforming to IS 8112 [13] was used. Manufactured sand (M-sand) served as fine aggregate, and crushed stone of 20 mm nominal size as coarse aggregate. Carbon fibre fabric supplied as a roll was used as the textile reinforcement. Material properties determined in the laboratory [14], [15] are listed in Table I.

TABLE I
Properties of Materials

Material	Property	Value
Cement (OPC 43)	Specific gravity	3.15
	Initial setting time	35 min
	Final setting time	9 h 30 min
	Fineness (sieve residue)	1.57%
M-sand	Specific gravity	2.55
	Water absorption	2.0%
Coarse aggregate	Specific gravity	2.76
	Water absorption	3.0%
Fresh concrete	Slump	75 mm

B. Mix design

An M25 mix was designed according to IS 10262 [16] for a maximum aggregate size of 20 mm, a slump of 75 mm, moderate exposure, manual placing and good supervision. With a standard deviation of 5 N/mm², the target mean strength was 31.6 N/mm². A water–cement ratio of 0.48 (below the 0.50 limit of IS 456 [17]) and a water content of 192 kg/m³ gave a cement content of 400 kg/m³, within the 450 kg/m³ limit. The resulting proportions are given in Table II, i.e. 1 : 1.71 : 2.89 by weight.

TABLE II
Mix Proportions per m³ of Concrete

Ingredient	Quantity
Cement	400 kg/m³
Water	192 kg/m³
Fine aggregate (M-sand)	684.5 kg/m³
Coarse aggregate	1159.5 kg/m³
Water–cement ratio	0.48
Cement : sand : aggregate	1 : 1.71 : 2.89

C. Specimen preparation

The ingredients were weighed on a digital balance and dry-mixed in a pan mixer until a uniform colour was obtained, after which the measured quantity of water was added. Beams were cast in oiled cast-iron moulds. Six series were prepared (Table III, Fig. 1): two plain concrete controls (S1 and S6) and four TRC series with the carbon textile at mid-depth in a beam of two-thirds depth (S2), at the bottom (S3), at top and bottom (S4), and at mid-depth (S5). Three specimens per series were cast for each test age, 36 beams in all. After demoulding, the beams were cured in a curing tank for 14 or 28 days.

TABLE III
Specimen Series

ID	Size L×b×d (mm)	Textile position
S1	700×150×150	None (plain control)
S2	700×150×100	Mid-depth (depth 2/3 of S1)
S3	500×100×100	Bottom
S4	500×100×100	Top and bottom
S5	500×100×100	Middle
S6	500×100×100	None (plain control)

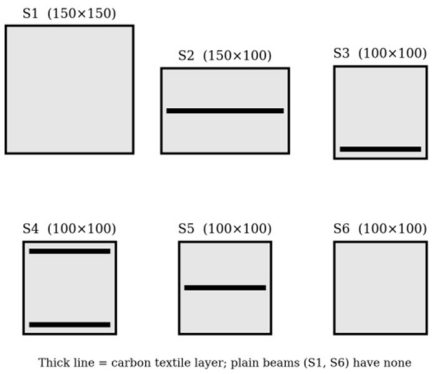


Fig 1. Cross-sections of the six specimen series (dimensions in mm).

V. Testing of Specimens

Each beam was weighed and then tested in flexure in a universal testing machine (UTM) under two-point loading at 14 and 28 days, using three specimens per series and age. The load at failure was recorded and the flexural strength was calculated as

$$f_b = P\,l\,/\,(b\,d^2) \qquad (1)$$

where P is the failure load (N), l the supporting span (mm), and b and d the width and depth of the beam (mm) [18]. Spans of 600 mm (S1, S2) and 400 mm (S3–S6) correspond to the reported loads and strengths. In the TRC beams the textile

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stayed in place across the failure crack after the concrete cracked (Fig. 2).



Fig. 2. Failed TRC beam showing carbon fibres bridging the crack.

VI. Results and Discussion

Table IV gives the average flexural strength of the three specimens in each series, together with the gain over the relevant plain control: S1 for S2, and S6 for S3–S5. The results are plotted in Fig. 3.

TABLE IV
Average Flexural Strength (N/mm²) and Gain over Control

Series	14 days	28 days	Gain, 14 d	Gain, 28 d
S1 (plain)	4.94	6.47	—	—
S2	8.53	11.12	72.7%	71.9%
S3	9.82	11.54	24.9%	31.9%
S4	9.98	10.86	27.0%	24.1%
S5	9.19	10.32	16.9%	17.9%
S6 (plain)	7.86	8.75	—	—

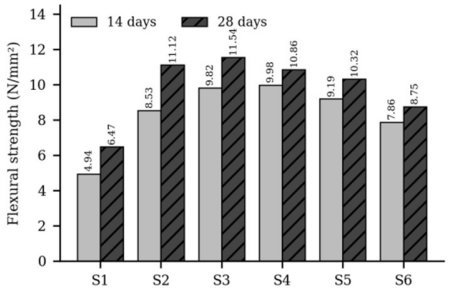


Fig 3. Average flexural strength of the beams at 14 and 28 days

A. Reduced-depth TRC beam

Although its depth was cut by 50 mm (one-third), S2 reached 8.53 N/mm² at 14 days and 11.12 N/mm² at 28 days, 72.7% and 71.9% more than the 150 mm deep plain beam S1. The reduced section also uses one-third less concrete. The two plain controls differ in size, and the 100 mm beam S6 is 35.2% stronger than S1 at 28 days (8.75 against 6.47 N/mm²), which indicates that part of the S2 gain reflects the usual dependence of flexural strength on beam size.

B. Position of the textile

At 14 days, S3 (bottom), S4 (top and bottom) and S5 (middle) achieved 9.82, 9.98 and 9.19 N/mm², i.e. 24.9%, 27.0% and 16.9% more than S6. At 28 days they achieved 11.54, 10.86 and 10.32 N/mm², i.e. 31.9%, 24.1% and 17.9% more. Textile at the bottom face gave the highest 28-day strength, as expected because it lies in the tension zone. Adding a second layer at the top did not increase strength further and the 14-day difference between S3 and S4 (1.6%) is within the scatter of the individual results (9.39–10.10 N/mm² for S3). Textile at mid-depth, close to the neutral axis, was the least effective of the three positions but still improved on the plain beam.

C. Strength gain with age

From 14 to 28 days, the plain beams gained 31.0% (S1) and 11.3% (S6), and the TRC series gained 30.4% (S2), 17.5% (S3), 8.8% (S4) and 12.3% (S5). All series therefore continued to gain strength with curing, and the textile positions that gave high early strength showed smaller later gains.

D. Limitations

Strength values were calculated with the plain-concrete formula in (1) and are apparent flexural strengths. Load–deflection response, crack patterns, textile bond and long-term durability were not measured, so the corrosion resistance and durability benefits of TRC discussed in the literature [1], [3] are not verified by these tests.

VII. Conclusion

Carbon textile improved the flexural strength of concrete beams in every configuration tested. At 28 days, the strength gains over the plain beam of the same size were 31.9% for textile at the bottom, 24.1% for top and bottom, and 17.9% for mid-depth, with the bottom position being the most effective. A TRC beam with one-third less depth was 71.9% stronger than the deeper plain beam, though part of this gain is attributable to the size effect, so lighter members with less concrete are feasible. The non-metallic textile is not susceptible to steel corrosion, and the literature indicates it can reduce material consumption; these durability and sustainability benefits were not tested here. Future work should include load–deflection and crack-pattern studies, textile layer count and surface treatment, bond behaviour, durability tests and cost assessment.

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