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Flexural Strengthening of RC Beams with Textile Reinforced Mortar (TRM)

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Abstract

In an effort to strengthen the flexural behaviour of reinforced concrete beams, this study tested how well various textile layers and fibre types including basalt and AR-glass fibers performed when used as mortar reinforcement (TRM). In total, four RC beams were cast and put to the test with two-point bending simply supported. Using externally bonded textile reinforced cement with two different types of textile fibres and unique textile layers, the remaining four beams were strengthened. As control beams, two beams without TRM layers were used. A 500kN capacity hydraulic jack is used to progressively introduce the load, and an I-section steel spreader is then used to distribute it to the beam specimen. It was found that in terms of first fracture stress, ultimate strength, flexibility, and reduced crack breadth, the beams reinforced with AR Glass textile layers significantly outperformed the control beams. For all strengthened beams, the overall improvement in flexural capacity brought about by TRM strengthening ranged from 22.72% to 27.27%. The Glass TRM with six layers of textile reinforcement showed better bending strength than Control beam, which was more flexible.

Keywords: AR-glass, Textile Reinforced Mortar, Flexural behaviour.

1. Introduction

Ageing, environmental deterioration, lack of maintenance, the necessity to adhere to current design criteria for the duration of their service life, or any combination of these issues necessitate structural retrofitting for existing reinforced concrete (RC) structures. Over the past two decades, engineers have increasingly embraced fiber-reinforced polymers (FRPs), an externally bonded composite material, as a retrofitting strategy. FRPs have a number of disadvantages, though, many of which are related to the usage of epoxy resin. These disadvantages include their high cost, inability to be utilised on wet surfaces or in cold environments, low water vapour permeability, and poor performance at high temperatures. Later, the structural engineering community gradually becomes interested in TRM. TRM is a low-cost fire-retardant substance that adheres well to masonry and concrete substrates and can be used on chilly or wet surfaces. The use of TRM rather than the more popular fiber-reinforced polymers for strengthening pre-existing concrete and masonry projects (FRPs) is more appealing for the reasons listed above. How to test the uniaxial tensile characterization of FRCM [1] Fabric Reinforced Cementitious Matrix (FRCM) composites are contemporary cement-based products made of dry-fiber fabric embedded in an inorganic matrix that are intended to be retrofitted into masonry or concrete constructions. Two test rigs were used to investigate the tensile behaviour features of this composite under various boundary circumstances. To get design parameters, a clevis grasp (pin action) was employed to simulate the field boundary conditions of a typical installation. A clamping grip was used to completely define the composite by inducing tensile failure in each of the component materials. A variety of FRCM systems, including those constructed of carbon, glass, polyparaphenylene benzobisoxazole (PBO), and carbon, were used in the experiment. Fibres or textiles are used in textile-reinforced concrete

(TRC), a type of reinforced concrete, in place of conventional reinforcement. Concrete constructions made with strong textile threads are flexible and long-lasting. TRC is only used for nonstructural and retrofitting reasons in the literature. This article aims to: [2] Test textile reinforced mortar system testing methodologies. Explain the changing direction of the research on the use of TRC as a structural member. [3] provided a description of the tensile and bond behaviour of TRM. Cementitious composite material Textile Reinforced Concrete (TRC) is reinforced with a carbon or glass fabric. Because there are no corrosion issues, TRC enables the construction of structures that are light and thin with lower concrete covers and improved longevity. In this article, an experimental and theoretical inquiry is used to examine the behaviour of TRC elements that have been under tension. The composite's failure load may be lower than the failure load of bare textile [4]. In this work, uniaxial tensile tests are used to explore the effects of the reinforcing ratio, steel fibre volume percentage, and prestressing on the uniaxial tensile behaviour of carbon textile reinforced mortar (CTRM). Additionally, the composite specimens' peak strength and breaking strength could be enhanced to 66.1 and 97.9% respectively, by using the proven anchorage techniques [6]. Overview of current technology [7]. Flexural Behaviours of an EPS, Foam, Concrete, and Glass Fibre Sandwich Panel [8]. This study evaluated the flexural behaviour of TRM-enhanced beams while accounting for the possibility of intermediate crack debonding [9]. Flexibility of TRC upon addition of carbon and glass fibres [10]. Test protocols for textile reinforced concrete design are advised by RILEM TC 232-TDT [11]. Tensile properties of basalt textile reinforced mortar (BTRM) [12]. Self-stressing concrete and textile are combined to create textile-reinforced self-stressing concrete, which increases concrete's crack resistance. Self-stresses can be formed in the concrete matrix as a result of the confinement action of textile, greatly enhancing crack resistance [13]. RC beams with TRC composite repairs are modelled numerically [14]. Investigations are made into the mechanical bending behaviour of textile-reinforced mineral matrix composite beams. Unidirectional rovings and chopped strand mat are the two types of E-glass fiber-based textile reinforcement that are taken into consideration (CSM). The inorganic phosphate cement (IPC)-based mineral matrix has the benefit of not being alkaline [15]. TRC is especially well suited for constructions that need reinforcement and are vulnerable to quasi-static loading. SHCC is the most effective method for supporting structures during impact. High endurance of RC constructions can be ensured by mending or reinforcing layers made of TRC or SHCC. There are innumerable microscopic fissures throughout TRC and SHCC, and it is crucial that they have the ability to close up and allow liquids and gases to pass through. The TRC and SHCC have enormous potential for restoring concrete structures, as demonstrated by practical applications [16]. Using a nonlinear analytical model, basalt cloth reinforced mortar-based composites are put under uniaxial tension [17], [18]. Application of multiscale mechanical textile reinforced concrete models to sandwich TRC panels [19]. TRC efficiency ratios for rigidity are larger than those for strength under strain. To assess TRCs, an innovative in-plane shear test was created. When compared to glass, TRC with aramid fibres exhibited much improved in-plane shear behaviour [20]. Tensile characteristics of the BTRM [21] and the effects of the short-dispersed carbon and glass fibres in the TRC [22]. TRM and concrete are joined together [23].

2. Materials and properties

2.1 Materials used in concrete

The experimental investigation employed OPC 53grade that complied with IS 12269-2013. Natural river sand that is readily available locally and passes through a 4.75mm screen is chosen as the fine aggregate. It complies with zone II and has a specific gravity of 2.61 and fineness modulus of 2.88. Size-based separation of crushed, angular coarse material was done. In accordance with IS 383-1970, it was sieved and separated into five groups: passing through 10mm retained on 4.75mm, similarly 12.5-10mm, 16-12.5mm, 20-

16mm, and 20-4.75mm. Since it actively participates in the chemical reactions involving cement to create the hydration product, calcium-silicate-hydrate (C-S-H) gel, water is a crucial component of concrete. For mixing the concrete and curing the specimens, potable water that was on hand in the lab and that met IS: 456-2000 criteria had a pH value between 6 and 8. Additionally, the superplasticizer creates uniform, cohesive concrete that is typically free of segregation and bleeding issues. 'CONPLAST SP 430', a chemical admixture based on sulphonated naphthalene formaldehyde was employed in this study. It was created conventional concrete with a 28-day compressive strength of 30 MPa.

2.1.1 Mechanical properties of conventional concrete

The most frequent test is the compressive strength test, which was performed using a 3000 kN AIMIL digital compression testing equipment on cube specimens with dimensions of 150 mm x 150 mm x 150 mm. Three samples for each mix combination were evaluated at room temperature.

Using a compression testing machine with a 3000 kN capacity, the splitting tensile strength tests were performed on concrete cube specimens with dimensions of 150 mm x 150 mm x 150 mm at a 28-day age.

When the prisms were 28 days old, flexural strength tests were performed using a 1000 kN capacity flexural testing machine by subjecting the specimen to two point loading to measure the flexural strength in accordance with the specifications IS: 516-2004.

Utilising cylindrical specimens with a dimension of 150 mm x 300 mm, the E for concrete values is calculated in accordance with (IS 456, 2000). Three cylinders of the usual mix are cast in total and allowed to cure for 28 days as part of this test.

Figure 1. Concrete specimens

Table 1. Mechanical properties of control specimen

Code mix	Compressive strength in MPa	Split tensile strength in MPa	Flexural strength in MPa	E for Concrete MPa
CC	40.79	4.08 N/mm^2	5.33	32041

2.1.2 Reinforcement

Rebars of 12 mm in diameter at the bottom (tension zone), 10 mm in diameter at the top (compression zone), and stirrups of 8 mm in diameter spaced 150 mm c/c in the beam were employed as reinforcements; their mechanical parameters are listed in Table 2. Figure 2 illustrates reinforcement testing.

Figure 2 Testing of reinforcement bar

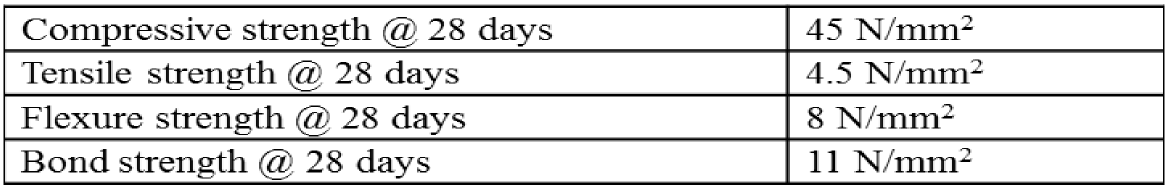
Table 2. Mechanical properties of Reinforcement bar.

Size of bar	Yield stress N/mm^2	Ultimate stress N/mm^2	Nominal breaking stress N/mm^2	Actual breaking stress N/mm^2
12mm	435.47	585.28	489.86	749.45
10mm	439.67	539.62	459.63	774.23
8mm	426.89	563.49	489.41	747.73

2.2. Mortar

To meet the plastic consistency of TRM, a ready-mix polymer mortar [9] with a w/p ratio of 0.24 was employed as the mortar. Using cube and cylinder sizes of 70.6x70.6x70.6mm and 100x200mm, respectively, the compressive and tensile strengths of the mortar were determined. At 28 days, the mortar's average compressive strength was 45 N/mm2, and its average tensile strength was 4.5 N/mm2.

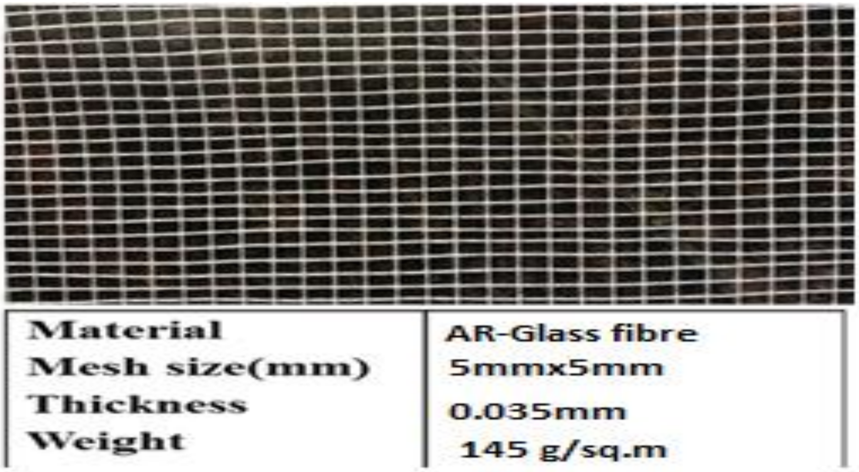
Table 3 Mechanical properties of mortar.



Compressive strength @ 28 days	45 N/mm^2
Tensile strength @ 28 days	4.5 N/mm^2
Flexure strength @ 28 days	8 N/mm^2
Bond strength @ 28 days	11 N/mm^2

2.3. AR-glass textile fibers

A fabric made of glass and basalt that has roving fibres woven in the warp and weft directions, with a mesh size of 5x5mm. Interior reinforcement is provided by the textile fibre mesh inside the plate specimen. Figure 4 shows a product data sheet that summarises the mechanical characteristics of textile fibre used in the manufacturing process.



Material	AR-Glass fibre
Mesh size(mm)	5mmx5mm
Thickness	0.035mm
Weight	145 g/sq.m

Figure 3 Textile used in this study; AR-Glass fibre.

3. Preparation of specimen and Test method

3.1 Preparation of specimen

Six beams totaling 150 mm in width, 250 mm in depth, and 3000 mm in length overall were cast and tested. Over an actual span of 2800 mm, four points of loading were tested on each beam. Two of the four beams ,beams 1 and 2-were used as ideal beams (reference beams), and the remaining two beams, beams were strengthened with TRM utilising textile reinforcing materials-AR-Glass with varying numbers of textile layers (4 and 6). The TRM strengthening had a total thickness of 10mm. Based on the strength achieved in the uniaxial tensile and flexure behaviour of TRM plate, the number of layers was chosen.

Moulds are put together before casting the beam, and the interior of the mould is coated with oil. The reinforcement structure is next placed within the mould, and cover blocks measuring 25 mm are added to the reinforcement's bottom and side sides. The top of the mould is then secured with an angled piece of steel to prevent bulging while the concrete is being poured. Fresh concrete is then poured into the beam mould after the procedures are finished. After 24 hours, the side shutters are taken off, and the beams are left to cure for 28 days while being covered with a gunny bag.

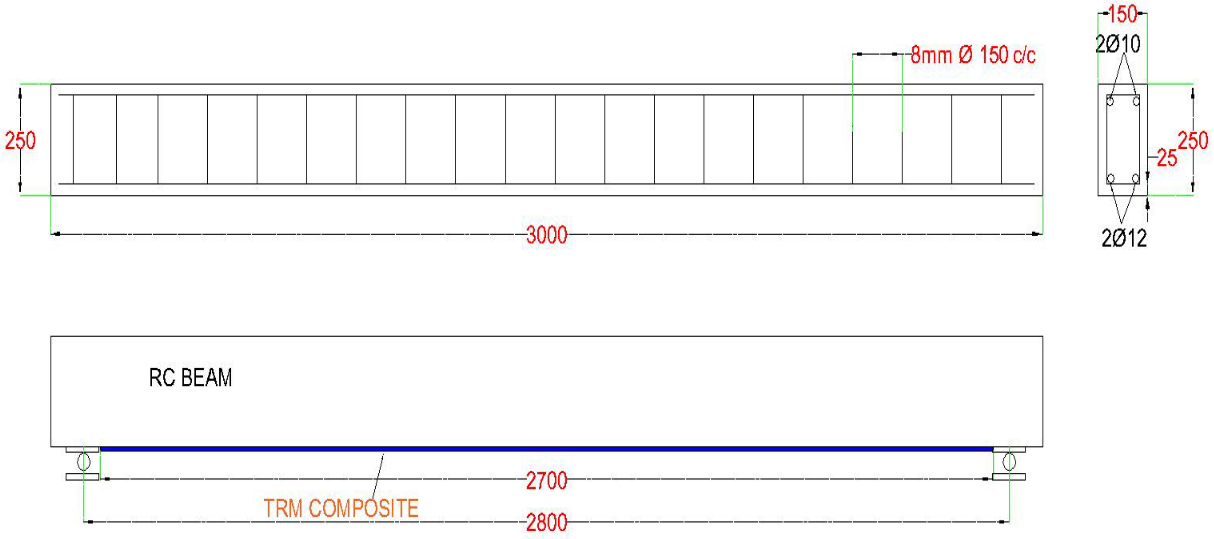


Figure 4 Reinforcement details of RC beams

Table 4. Summary of beam details

s.no	Beam code	Distress level % P_u	Type of textile reinforcement	No.of layers	Thickness of textile fibre	Reinforcement ratio		Performance evaluations
						P_t (%)	P_f (%)	
1	CB1 CB2	Perfect beams	-	-	-	0.68	-	Strength and deflection under static load
2	BG4	Without pre-crack	AR-Glass Textile	4	0.035	0.68	0.056	Undamaged, strengthened by TRM
	BG6		AR-Glass Textile	6	0.035	0.68	0.084	

3.2 Strengthening procedure

Over a length of 2700mm, the TRM's strengthening component was externally bonded to the RC beams' bottom. In order to improve the bonding between the old and new reinforcing material, the surface was roughened using a grinding machine and formed into a grid of grooves with a depth of around 3 mm. Water should be applied to the concrete surface before the mortar layer is applied. The top, bottom, and centre mortar layers of TRM plate are all 2 mm thick, and there are four textile layers that support it. In TRM with six textile layers, the mortar thickness is 1 mm between layers and 2.5 mm on top and bottom. The application of a mortar layer of the appropriate thickness was the first step in making TRM. Next, the textile layers were placed on top of the mortar layer and gently pressed by hand to guarantee mortar impregnation. After that, apply a second mortar coat. The same procedure was repeated using additional layers of material. The last layer of fabric was evened out and given the right amount of cement before being placed in the mould for 24 hours. The beams were all taken for testing after a total of 28 days of curing.

Figure 5 surface preparations of beams

Figure 6 strengthening procedure

3.3 Test Set-Up

The length of the beams is measured and divided into three pieces (L/3) before to placement of the beam specimen into the loading frame. The fracture dimensions are then measured by drawing grid patterns in the beam's flexural zone. The loading frames hinged and roller supports are positioned appropriately based on the length of the beam specimen. The beam is then positioned in the loading frame after that. To measure the strength of the simply supported beams, a two-point loading condition was used. Figure 8 depicts the beam's loading setup in the lab. The load is gradually introduced with the aid of a hydraulic jack with a 500kN capacity, and is then transferred to the beam specimen with the aid of an I-section steel spreader. To manually measure the surface concrete strain, Demec gauge pellets are mounted to the concrete surface. Using dial gauges with a 0.01 least count, the deflection at mid span was detected. After the beam has reached its maximum load, the ultimate deflection is measured using a mechanical dial gauge, as seen in Figure 8. A proving ring is used to deliberate the load after it has been applied by the hydraulic jack at 2.5kN intervals.

Figure 7 Test set-up

4. Test results and discussion

At each load increment, observations such deflections, concrete surface strain, and beam face cracks are recorded. The load bearing capacity, failure type, initial fracture load, and final crack load are all carefully monitored and recorded. Table lists the results of the experimental observations made for each group at the final stage, including the load, deflection, moment, fracture width, and failure type.

Table 3 Experimental results of RC Beams.

Beam Code	Load (kN)			Deflection (mm)			Capacity Increase (%)	Failure mode
	Crack (P_{cr})	Yield (P_y)	Ultimate (P_u)	Crack (δ_{cr})	Yield (δ_y)	Ultimate (δ_u)		
CB(1,2)	15	52.5	55	2.37	13.24	30	-	CC
BG4	20	55.0	67.5	2.46	12.80	21.33	22.72	FR
BG6	20	62.5	70.0	2.2	13.82	20.2	27.27	FR

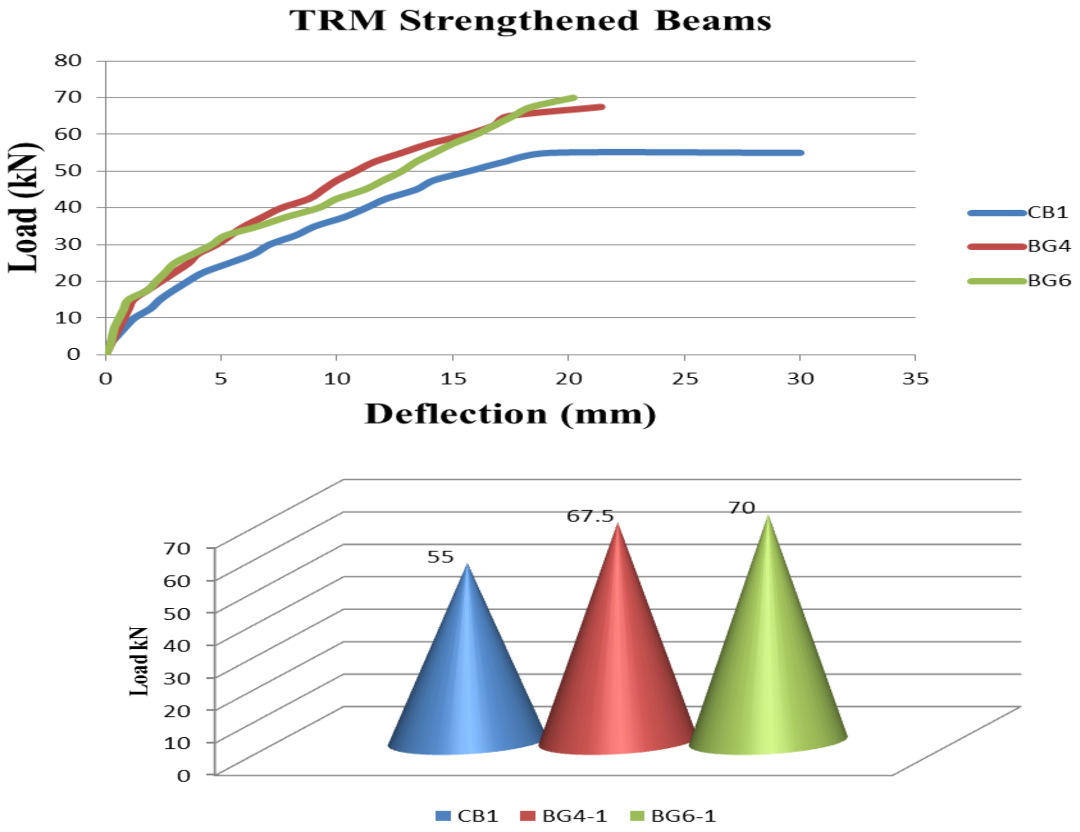


Figure 8 Comparisons of test results

In Fig. 8 the reaction of the specimens is shown in terms of load against midspan deflection curves, and the response of the reinforced specimens is contrasted with that of the control specimen (CON). As seen in Fig. 8, there are three distinct stages to the flexural response of all specimens up to the peak load, which correspond to three almost linear branches of the load-deflection curves. Stage I: uncracked beam. Stage II: development of cracking up to yielding of the steel reinforcement. Stage III: post-yielding response up to failure.

- A first branch from the unloaded state to the point of initial flexural cracking of concrete; this branch corresponds to Stage I: uncracked section (elastic);
- A second branch from the point of initial flexural cracking of concrete to the point of yielding of the tensile steel reinforcement; this branch corresponds to Stage II: cracked section (still elastic but with reduced stiffness);
- And a third branch that originates at the point of tensile steel reinforcement yielding the control specimen, or in the case of the retrofitted beams, full activation of the externally bonded TRM composite.

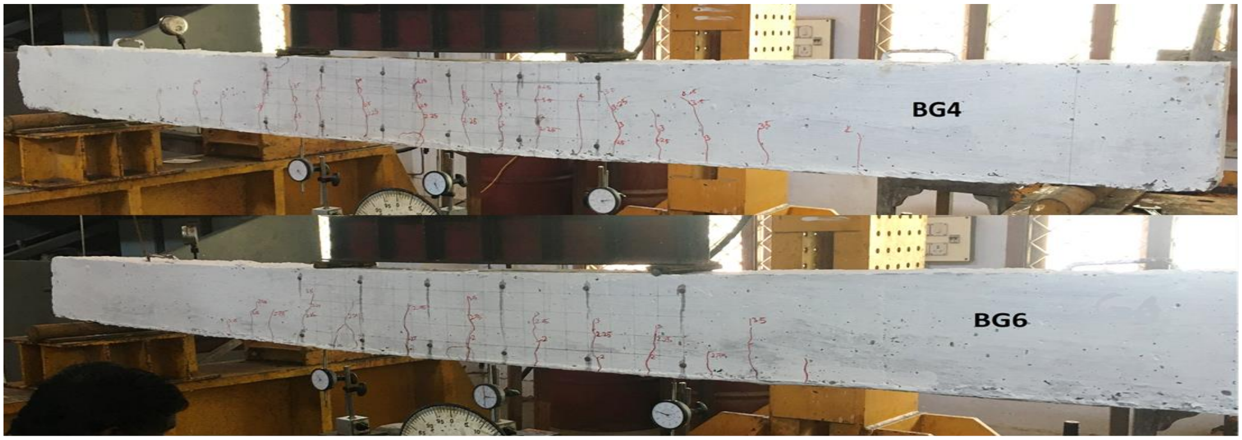


Figure 9 Failure of TRM strengthened Beams

When compared to the performance of CON beam, the inclusion of TRM-strengthening improved the flexural response of the strengthened beams, as shown in fig 9. The strengthening layers' impact in Stage I was rather minimal. However, the TRM reinforcement's influence was more noticeable in Stages II and III. Under particular, during Stage II, the flexural fractures' progressive development activated the TRM composite under tension, increasing its flexural stiffness and yield load.

5. Conclusion

Experimental research was conducted while varying the type of textile fibre and the number of layers to examine the impact of TRM composites on RC elements when applied externally to boost their flexural capacity. In total, four RC beams were created, and their ability to withstand straightforward 4-point bending was examined. Two beams were strengthened by TRM, while two beams were examined in their unenhanced, as-built state and served as the control specimen. The variables taken into account were a textile comprised of AR-Glass fibre with a small mesh size of 5mm, four vs. six reinforcing layers, and these.

The important conclusions of this inquiry are listed in the list below:

The primary variables of TRM strength are the volume % of the fibres, the number of textile layers, and the type of fibre. The majority of the tensile load during testing is supported by the vertical strands known as the warp in the weft filament yarn of the textile fibre. The horizontal strands' weft carries the majority of the flexure stress. The volume percentage of the warp and weft as well as the quantity of textile layers have an impact on strength.

The experimental findings of undamaged reinforced beams showed a large reduction in crack breadth and a significant delay in the occurrence of the initial cracking when compared to control beams. At specific load levels and during the yield stage, it was discovered that the deflection and crack breadth in the unharmed laminated beams were significantly reduced.

For all strengthened beams, the overall improvement in flexural capacity brought about by TRM strengthening ranged from 22.72% to 27.27%.

Overall, the kind of mortar had a substantial impact on the flexural performance of TRM enhanced RC beams.

The improved compatibility achieved between the old and new TRM strengthening methods;

AR glass textile performed better in terms of flexure strength. When compared to control, glass has a larger moment-carrying capacity. When the maximum stress is attained, the Glass textile reinforcement fails after great deformations with fibre rupture at the flexural zone. This exemplifies how TRM can be used as a motivating strategy for building and strengthening structures.

The outcome is based on a few tests using AR-Glass textile with 5mm mesh size. Additional research is required, including on alternative textile fibre types and different mesh openings that would have the same volume proportion of fibres, in order to increase confidence in the findings.

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