Assessing amid Water absorption and Compressive strength of Hybrid Textile Reinforced Concrete

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ABSTRACT

Textile-reinforced concrete (TRC) is a material that is acquiring new ground in the construction field. It eliminates the problem of corrosion by using non-corrosive textile fibre mesh materials, helps in manufacturing lightweight structures and reduces CO_2 emission. The paper aims to find the Compressive Strength (CS) and Water Absorption (WA) properties of Hybrid interlayer TRC with 3, 4 & 5 layers of hybrid combinations with Aramid and Alkali-Resistant (AR) glass fibre meshes reinforcement compared to identical fibre mesh reinforced TRC and reference mix cementitious matrix composition after 28 and 180 days of water curing. Based on the studies it was found that hybrid TRC improved the CS irrespective of layers by about 2 and 1.2 times when compared to reference mix and identical fibre mesh TRC. Four layers of an alternative arrangement of a combination of AR-Glass and Aramid fibre mesh reinforcement (4L4) is attributed to the maximum CS of about 99.12 MPa and increased WA of about 0.39% to that of the least water-absorbed combination (5L16). Even though reduced pores and densification of composite is achieved in three-layer combinations it has a reduced CS of 22.3% at 180 days compared to the 4L4 combination. On the other hand, combinations and identical matrix of 5 layers of fibre mesh reinforced TRC showed a loose and porous behavior due to inadequate bonding between the fibre meshes and the cementitious matrix but a high percentage of volume-fraction of fibres resulted in reduced WA in these composites with also 21.2% reduction in CS accordingly.

Keywords Textile reinforced concrete, Hybrid Textile fibre meshes, Compressive strength, water absorption.

1. Introduction

Textile Reinforced Concrete (TRC) is a modern construction material that replaces conventional steel reinforcements with fibre textile materials [1]. Its thin, economical, and lightweight characteristics make TRC ideal for creating a range of structural elements in both architectural and civil engineering projects. Hybridization in Textile Reinforced Concrete (TRC) involves the combination of different types of fibers within the same concrete matrix to create a composite material that leverages the unique strengths and compensates for the weaknesses of each individual fiber type [2]. This approach not only optimizes the performance characteristics of the resulting concrete but also introduces a synergistic effect, where the interaction between the different fibres enhances the overall properties of the material beyond what could be achieved with any single type of fiber. The bond between the matrix and the fibre mesh geometry relies significantly on the cementitious matrix, which ensures structural stability and compressive strength. The composition of the matrix is designed for excellent fluidity, enabling complete integration of technical textiles [3]. Among synthetic fibres, the durability of alkali-resistant glass fibres is enhanced by using self-crosslinking styrene–butadiene polymers [4]. Aramid fibre, a high-performance synthetic material, offers superior strength, modulus, and heat resistance compared to steel fibre. Aramid fibre provides five to

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six times the strength, two to three times the modulus, twice the toughness, and is only one fifth the weight of steel [5–7]. To bridge the existing knowledge gap, this study examines how different numbers of layers and combinations of AR Glass and Aramid fibre meshes affect the performance of a cementitious matrix in hybrid textile-reinforced concrete. The research experimentally assesses compressive strength and water absorption to determine the optimal mesh combinations for hybrid TRC.

2. Materials used

2.1 Reference mix

The materials used for the Reference mix in this research consist of Cement (OPC 53), Fly ash (FA) - Class C, Undensified Silica fume (SF) and Silica Sand [0 - 0.25 mm & 0.2 -0.6 mm] as shown in Figure 1 confirming to respective IS codes [8-12]. Flow table test was conducted as per IS: 5512, 2013 [13], for the mix proportion mentioned in Table 1. to find the quantity of portable water and Super plasticizer (SP) necessary for the mix to achieve a highly flowable consistency, ensuring a uniform structure and facilitating easy penetration between the textile layers for this research.

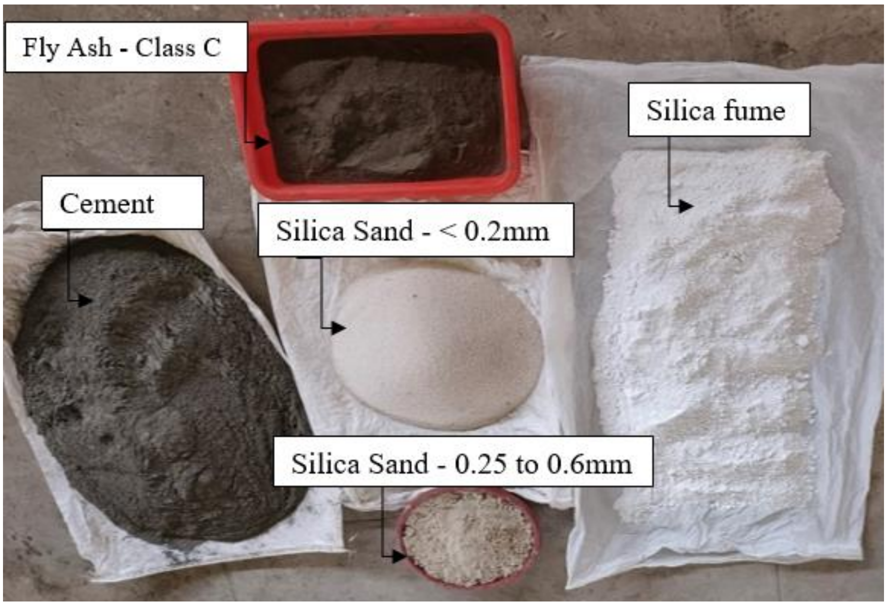


Figure 1. Cementitious matrix constituents

Table 1. Reference Cementitious mix proportion used in kg/m^3 [14]

Cementitious matrix composition	*Quantity*
Cement (c)	554
Fly Ash (FA)	233
Silica Fume (SF)	89
Super Plasticizer (SP)	1.5
Silica Sand <0.2mm	118
Silica Sand 0.25-0.6mm	168
Water (w)	230
w/c	0.42

2.2 Textile fibres

Two types of textile fibre meshes, namely Alkali-Resistant (AR) Glass and fabricated Aramid fibre meshes (Figure 2), were utilized as reinforcements in the interlayer or layer-by-layer hybrid TRC specimens. Their properties are detailed in Table 2. The Aramid fibre meshes are produced by coating the Aramid fibres with an epoxy resin mixed in a 1:2 ratio of epoxy hardener to base, woven in a bonded style with a grid spacing of 5x6 mm. The fabrication process is described as follows: [14],

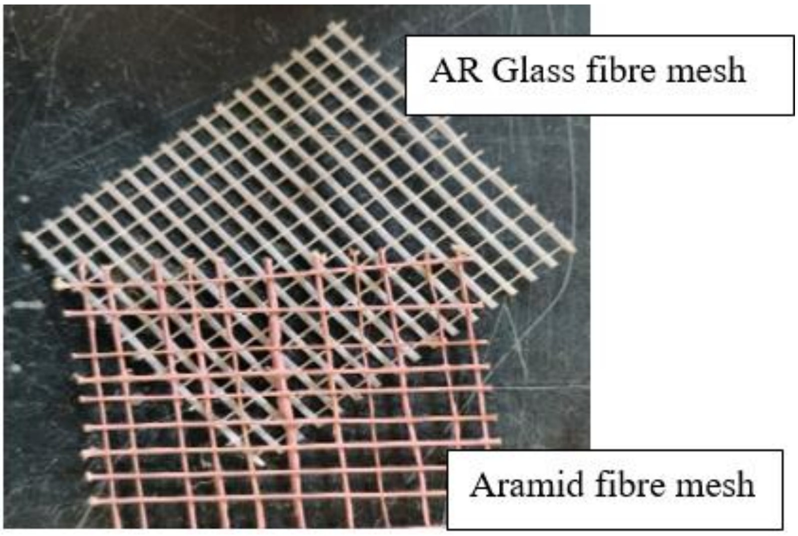
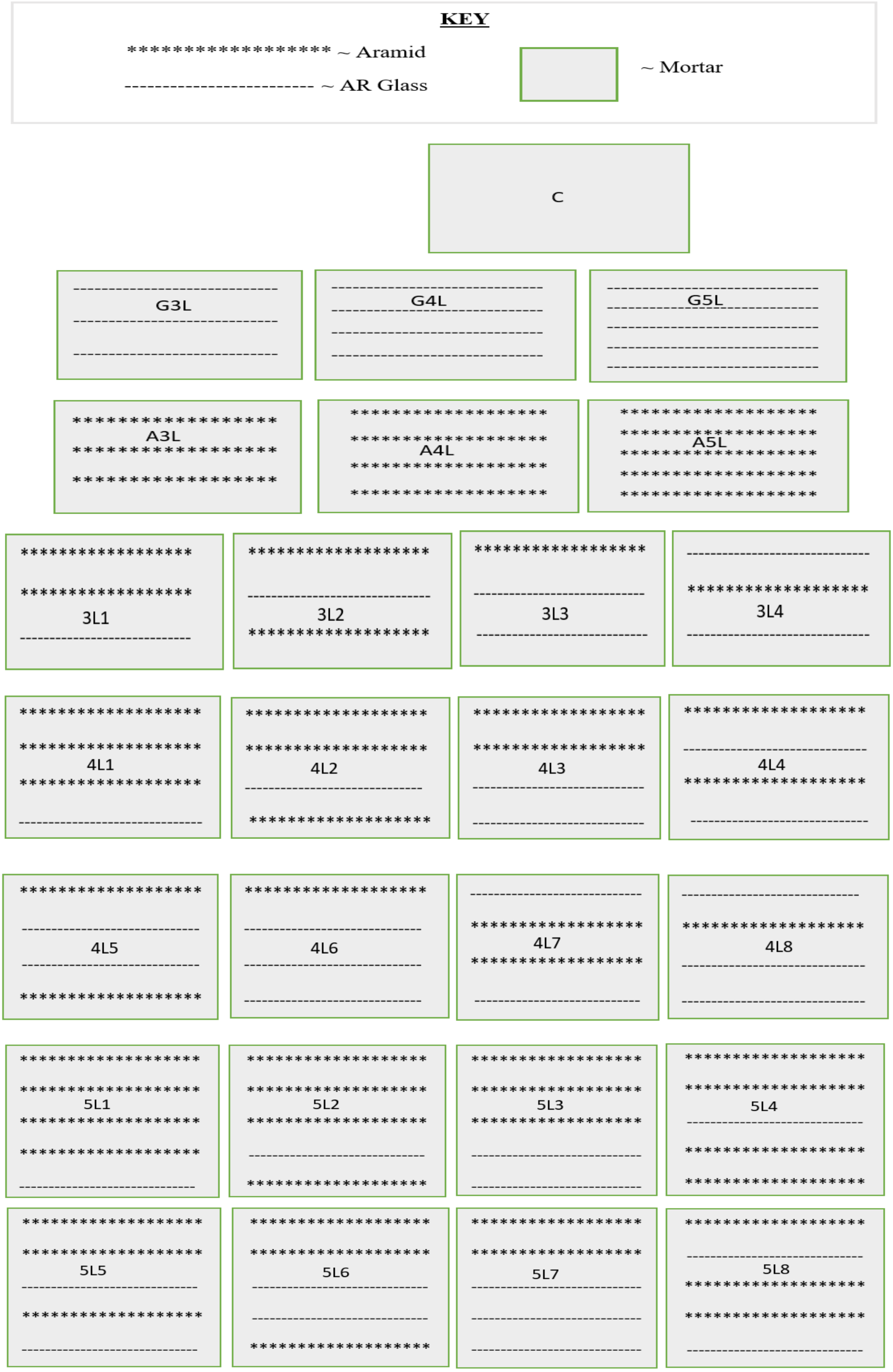


Figure 2. Textile reinforced fibre meshes

Table 2. Properties of Textile fibre meshes [14].

Fibre Characteristics	*Epoxy coated Aramid Fibre mesh*	*AR Glass fibre mesh*
Grid size, mm x mm	5 x 6	5 x 6
Diameter, μm	900	1100
Weight, gm/m^2	350	145
Tensile strength, GPa	3	1.5
Young’s Modulus, MPa	139,000	72,000
Poisson’s ratio	0.40	0.21

The fibre mesh reinforcement layers were designed to be evenly spaced at 3, 4, and 5 layers, with a volume fraction ranging from 0.5% to 1.5%, depending on the specific combination used. Incorporating 1 or 2 layers of fibre mesh resulted in little to no change in compressive strength, due to the small volume of fibre mesh included only about a 2% increase compared to the reference cementitious matrix. Conversely, using more than 5 layers of fibre mesh led to a notable decrease in compressive strength compared to the reference matrix. This reduction is due to the excessive concentration of fibres, which creates a less dense and weaker structure with poor bonding between the mortar and fibre mesh [14]. The study presents the results for hybrid and identical combinations of 3, 4, and 5 layers of fibre meshes, along with the reference mortar (Figure 3).



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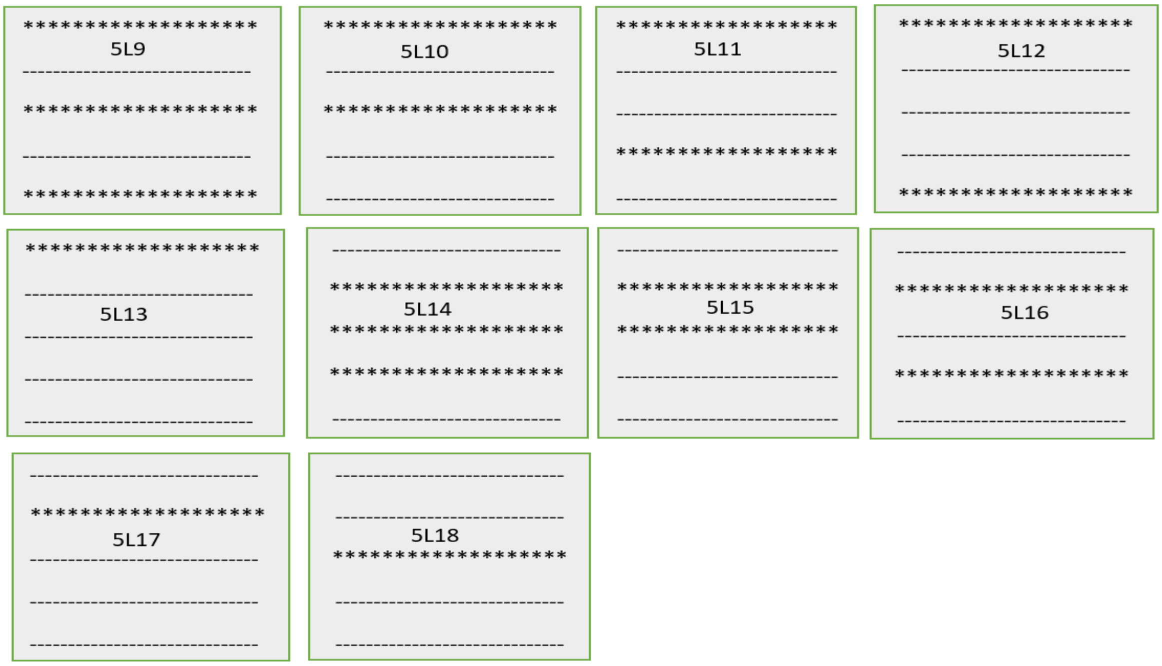

Figure. 3 Representation of combinations of specimens with its codes [14].

3. Experimental investigations

The Compressive Strength (CS) and Water Absorption (WA) properties of Hybrid interlayer TRC with 3, 4 & 5 layers of hybrid combinations with Aramid and Alkali-Resistant (AR) glass fibre meshes reinforcement is compared to identical fibre mesh reinforced TRC and reference mix cementitious matrix composition after 28 and 180 days of water curing.

3.1 Compressive Strength Test

The cubes of standard size 70.6 x 70.6 x 70.6 mm were casted as shown in figure 4 and used to acquire the compressive strength of Hybrid TRC as per IS: 516 (part 1), 2021 [15]. The specimens were positioned on the bearing surface of a 2000 kN capacity Compression Testing Machine (CTM), ensuring no eccentricity. A uniform loading rate of 140 kg/cm² per minute was applied. The maximum load was noted and the compressive strength was calculated.

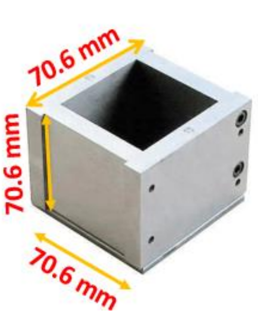

Figure. 4 Preparation and testing of cube compressive strength test

Compressive strength refers to a material's or structure's ability to endure axial pushing forces. When this strength limit is exceeded, brittle materials tend to fracture or crumble. A total of

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222 cube specimens with 37 combinations of 3 sample specimens each at the age of 28 and 180 days are tested in Compression testing machine as shown in figure 4.

3.2 Water Absorption Test

Water absorption test is used to determine the moisture content absorbed under specific conditions by the specimen as per percentage of its dry weight confirming to ASTM-C642 1981 [16]. The hybrid TRC cube specimens were casted of dimensions 70.6x70.6x70.6mm and are water cured for 28 and 180 days & oven dried as shown figure 5 for testing. A total of 148 cube specimens with 37 combinations of 2 sample specimens each at the age of 28 and 180 days are casted and tested.

Figure. 5 Specimens cured in Hot Air Oven

4. Results and discussions

As mentioned earlier, a total of 37 different fibre mesh layer arrangements within the cementitious matrix, illustrated in Figure 3, were tested to determine both compressive strength and water absorption. The tests were conducted at 28 days and 180 days of curing. The results are tabulated in Table 3 and are discussed in the subsections below.

Table 3 Compressive strength and water absorption

Sl.No.	Specimen Name	Compressive strength (N/mm^2)		Water absorption (%)	
		28 Days	180 Days	28 Days	180 Days
1.	C	57.75	60.24	3.94	3.50
2.	G3L	61.98	61.94	5.17	4.87
3.	G4L	66.62	66.55	4.97	4.62
4.	G5L	71.75	72.20	4.86	4.77
5.	A3L	74.17	60.40	5.34	5.15
6.	A4L	82.05	75.22	4.62	4.37
7.	A5L	72.98	78.12	4.27	4.09

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1.	3L1	51.84	52.75	3.73	3.64
2.	3L2	78.96	78.89	3.63	3.67
3.	3L3	68.70	71.66	3.69	3.73
4.	3L4	78.11	77.98	3.56	3.33
5.	4L1	60.53	61.62	3.99	3.67
6.	4L2	63.86	64.00	3.59	3.67
7.	4L3	68.77	69.23	4.60	4.52
8.	4L4	98.82	99.12	3.41	3.39
9.	4L5	86.71	85.97	3.97	3.87
10.	4L6	54.99	56.19	4.62	4.55
11.	4L7	80.98	81.03	3.83	3.90
12.	4L8	70.98	71.54	4.43	4.42
13.	5L1	42.62	45.28	4.84	4.79
14.	5L2	56.66	58.64	4.77	4.64
15.	5L3	54.86	55.32	4.23	4.16
16.	5L4	60.82	60.97	3.95	3.85
17.	5L5	56.91	58.63	3.54	3.36
18.	5L6	54.11	55.36	3.68	3.52
19.	5L7	54.79	55.14	4.02	3.94
20.	5L8	60.95	61.89	3.25	3.35
21.	5L9	63.77	64.95	3.19	3.02
22.	5L10	57.46	56.87	3.62	3.20
23.	5L11	54.92	55.09	3.39	3.39
24.	5L12	59.31	61.54	3.27	3.03
25.	5L13	57.07	58.30	3.57	3.44
26.	5L14	61.59	62.97	3.75	3.62
27.	5L15	58.33	58.45	3.81	3.71
28.	5L16	65.12	65.86	3.06	3.00
29.	5L17	61.75	62.59	3.25	3.16
30.	5L18	59.33	60.47	3.55	3.57

4.1 Compressive Strength Test

The compressive strength increased with the number of fibre mesh layers in combinations up to 4 layers, using both Aramid and AR Glass fibres. It was observed that TRC with identical fibre mesh reinforcements exhibited higher compressive strength compared to the reference cementitious mortar. Specifically, for 4 layers at 180 days, Aramid fibre mesh provided approximately 1.13 times greater compressive strength than AR Glass fibre mesh. Hybrid TRC demonstrated a 11% increase in compressive strength compared to TRC with identical fibre meshes, due to the synergistic effect of the hybrid combinations. However, at 3 and 5 layers of fibre mesh, the maximum compressive strength of the Hybrid TRC decreased by 23.41% and 22.34%, respectively, compared to the 4-layer configuration. This reduction was due to fibre congestion and inadequate bonding between the mortar and the fibre mesh for 5 layers [1].

Maximum compressive strength is obtained for the combination with alternative arrangement of fibre meshes reinforcement. (i.e., For 3layer combination the 3L4, 4layer combination 4L4 & 5layer combination 5L16) at both 28 &180 days. The maximum compressive strength achieved was approximately 98.82 and 99.12MPa for hybrid TRC having 4 layers of alternative combinations of AR-Glass and Aramid fibre mesh reinforcement – 4L4 at 28 and 180 days respectively and shows no much difference between them, the maximum rate of strength development at 180 days for reference and fibre mesh reinforced TRC was about 0.51% when compared to 28 days. Even-though 4L4 and 4L7 has same number of Aramid and AR Glass fiber meshes (each 2 layers) in their combinations 4L4 having alternate arrangement resulted good in bonding with binder when compared to 4L7.

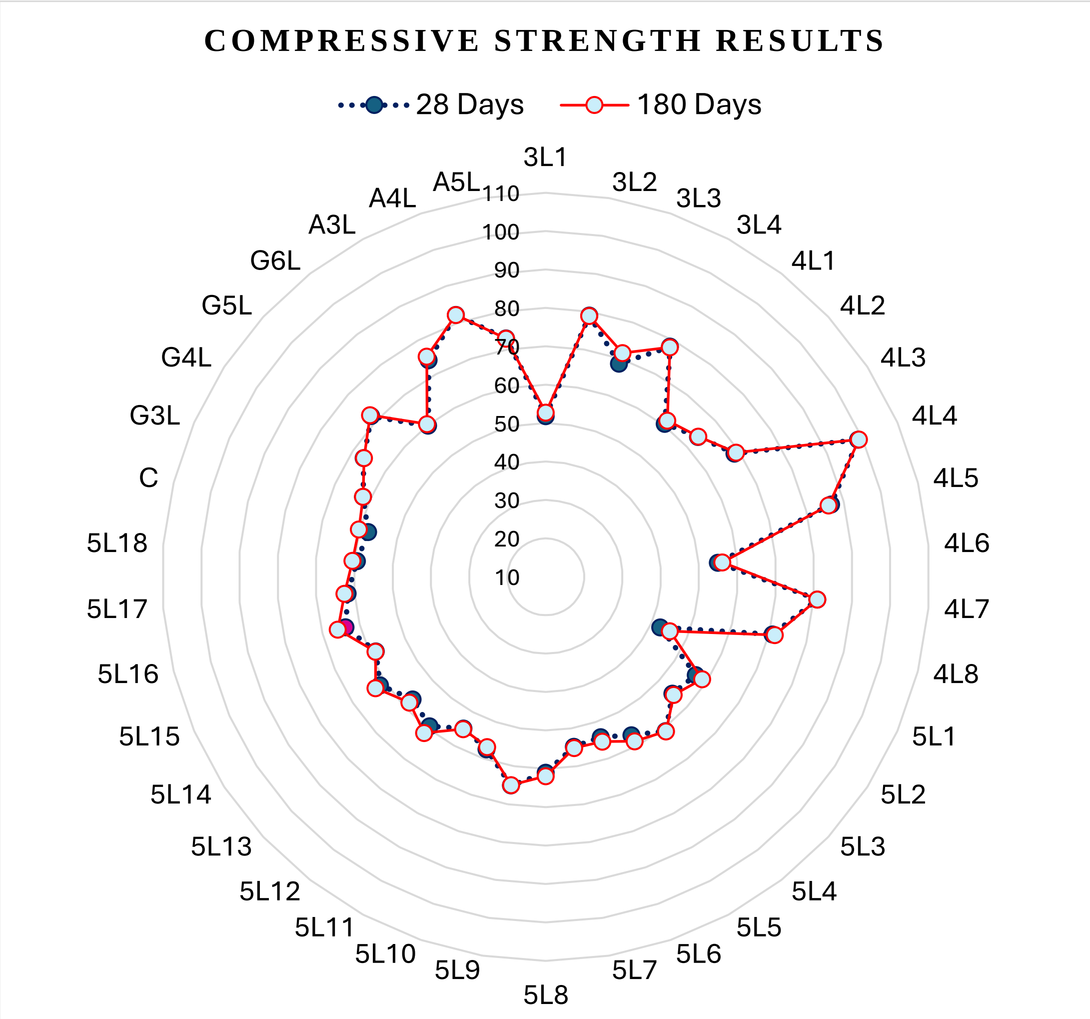

Figure. 6 Radial representation of Compressive strength results at 28 and 180 days

4.2 Water Absorption Test

Water absorption test was conducted showing absorption range from 3.06 % to 4.84% and 3.00 % to 4.79% for hybrid TRC specimens at 28 and 180 days respectively as shown in figure 7. reference mix without fibre meshes water Absorption was found to be 3.50% & 3.94% at 28 and 180 days respectively. Water absorption was reduced by about 21.82% for TRC with fibre mesh hybrid reinforcement for 5 layers with 3.00% of absorption in 5L16 when compared to

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reference mix because of the water resistant fibres used in this research. Whereas, Five-layer combination have about 8.7% less water absorption when compared to 4layer combination and shows that as the volume fraction of fibres increases lower the absorption present in the specimen. Maximum reduction in water absorption is obtained for the combination with alternative reinforcement fibre meshes. (i.e., For 3layer combination the S3L4, 4layer combination S4L4 & 5layer combination S5L16 has alternative fibre meshes in their combination arrangement). It was noticed that water absorption of all mixes was within 5% level.

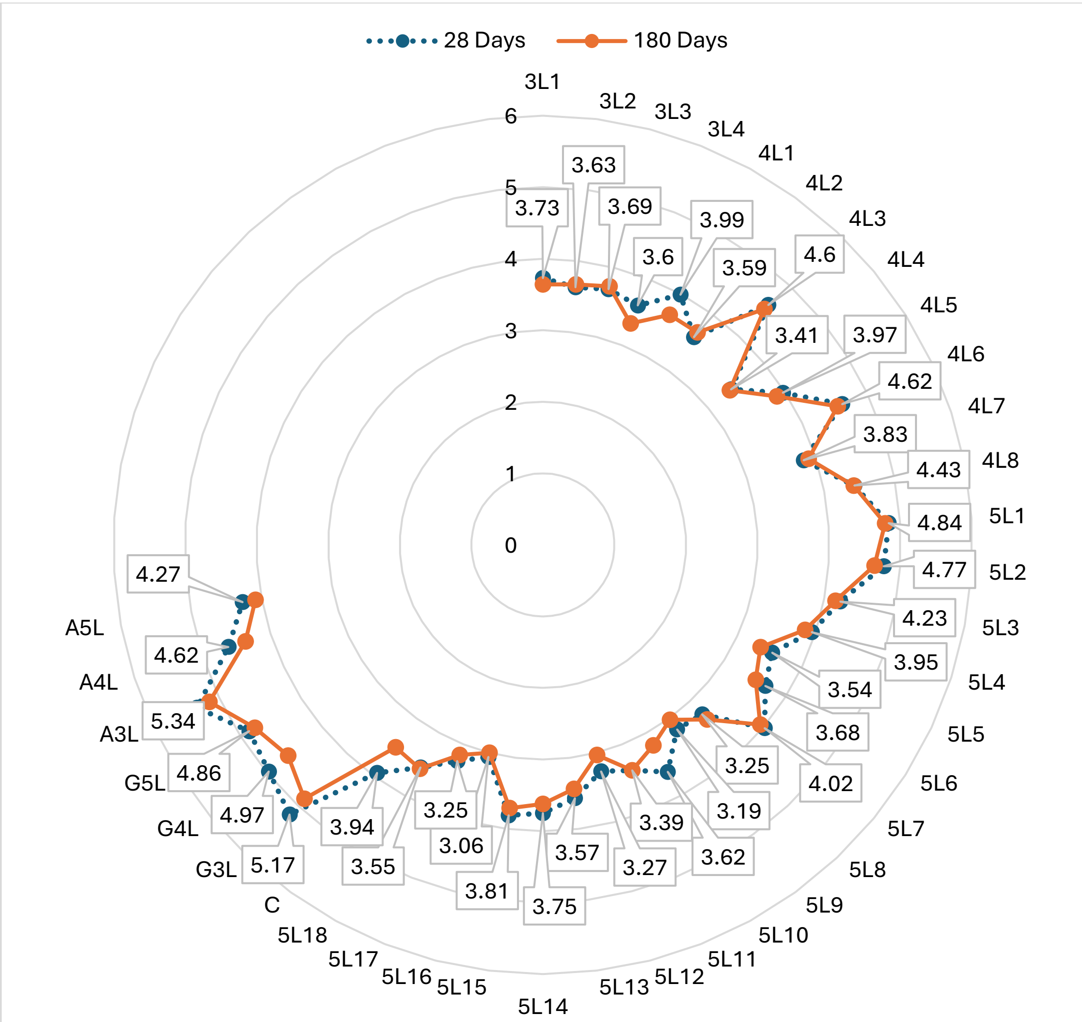

Figure.7 Radial representation of water absorption results at 28 and 180 days

5. Conclusions

Overall, hybrid fibre meshes reinforced concrete with a cementitious matrix enhanced compressive strength by approximately 1.07 times compared to the reference mix, and 1.06 times compared to TRC with identical fibre meshes, due to the synergistic effects of the hybrid combinations. Among all the combinations, 3L2 in 3 layers and 4L4 in 4 layers with compressive strength of 78.96MPa and 99.12MPa respectively achieved significantly higher compressive strength in hybrid TRC. The five-layer hybrid combinations exhibited a reduced compressive strength, approximately 32% lower, compared to other hybrid combinations. Alternate arrangement of fibre mesh type achieved least water absorption in 3 layers, 4 layers and 5 layers combinations (i.e., For 3 layer combination - 3L4, 4 layer combination - 4L4 & 5 layer combination - 5L16). Mixes having least water absorption values resulted in maximum compressive strength due to presence of minimum voids and good bonding between the fibre mesh and cementitious matrix. Hybrid TRC with Alternate arrangement of aramid and AR Glass fibre mesh reinforcement (4L4 combination) having maximum compressive strength and less water absorption can be recommended. In future, Hybrid TRC with thin-walled lightweight facades, panels and columns can be fashioned with aesthetic, cost-effectiveness, superior mechanical, durable and thermal performance in various building and infrastructure projects.

Conflict-of-interest

The author declare that they have no conflicts of interest relevant to this study.

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