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An Investigation on Mechanical and Thermal Performance Textile Reinforced Concrete with Armid Fiber Reinforcement

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Abstract: Textile Reinforced Concrete (TRC) is an innovative high-performance composite material increasingly used in modern construction and retrofitting applications. In TRC, conventional steel reinforcement is replaced with non-corrosive textile fibre mesh, enabling reduced cover thickness and lower consumption of cementitious materials while offering superior mechanical performance. Owing to the wide variety of textile types, production methods, and binder systems available, it is essential to characterise TRC thoroughly before selecting it for specific applications. This research investigates the influence of key parameters—such as mesh size, number of textile layers, and panel depth—on the mechanical, thermal, and durability properties of TRC incorporating aramid fibre mesh. Three cementitious Des and two textile types, namely aramid and alkali-resistant (AR) glass fibre meshes with varying mesh openings, were studied through experimental, numerical, and mathematical analyses at different curing ages. A total of 432 TRC specimens were cast and tested for compressive strength, and optimisation was carried out using Response Surface Methodology (RSM). The highest compressive strengths of 99.05 MPa and 93.29 MPa were achieved at 56 days for D-3 and the economical D-1, respectively, using five layers of aramid fibre mesh. Statistical analysis confirmed the significance and accuracy of the developed models. Durability studies demonstrated superior resistance of aramid TRC to aggressive environments and significantly higher impact energy absorption than AR-glass TRC. Thermal studies revealed that aramid-based TRC sandwich panels reduced heat transfer by approximately 69%, confirming their suitability for structural and thermal applications in tropical climates.

Keywords: Textile Reinforced Concrete (TRC), Non-corrosive textile fibre mesh, Alkali-resistant (AR) glass fibre meshes, structural and thermal applications.

I. INTRODUCTIONS

Textile-Reinforced Concrete (TRC) is a novel high performance composite structural made of cementitious matrix and fabric mesh reinforcements with high bearing strength such as glass, basalt, aramid and carbon, basalt textiles for several practices. Textile Reinforced Concrete is not deliberately to replace conventional reinforced concrete in its vital fields of application but to use as an alternative if thin- structures are demanded. The major things differentiating TRC from Reinforced Concrete (RC) and Fibre Reinforced Concrete (FRC) are arrangements of fibres and steel reinforcements respectively. In FRC the short fibres are positioned in a dispersed manner which can be placed as per the tensile stresses developed in the structures equivalent to conventional RC . for the strengthening of existing concrete and masonry structures [Smitha et al., 2020]. Fig. 1.2 shows the composition of TRC. These composites are made of continuous fibres in the form of mesh embedded in an inorganic matrix with a maximum grain size of less than 2mm and can show a pseudo-ductile response when designed appropriately. In general, TRC having lower thickness results in savings of source and the less amounts of clinker make use of for the process, which significantly lowers the

CO_2 footprint. TRC is a composite material comprises of continuous textile reinforcement which is non-corrosive fibres which are positioned in a fine-grained matrix in the form of an open mesh or grid structure. Using these it is achievable to decrease the cover depth in TRC without compromising the mechanical properties. It also, enhances the ductile nature of the cementitious matrix which reduces the width of the crack, and provides high tensile strength which overcomes the brittle behavior of cementitious matrix. The inorganic matrix composition should be in highly fluid condition to get full penetration of the fibre meshes to assure a good mechanical anchoring as well as load-bearing capacity. Textile reinforcements can be made up as filaments or twisted yarns such as natural, polyethylene, polypropylene, AR-glass, a wide extent of carbon and aramid fibres. Filament yarns (a bundle of filaments) are the best choice for reinforcing purposes because they offer more strength, handling efficiency and forming. The reinforcements are in the form of short or long (continuous) fibres, sphere or ellipsoids, disks or plates. The cementitious matrix used for TRC needs to fulfill the requirements, mechanical properties, and durability, those are essential to get perfect composite material performance and allow for a reliable dimensioning of TRC structures. Usually, the maximum grain size used is less than 2 mm and hence these matrix systems can be considered as mortar. The matrix composition is highly fluid to get full penetration of fibre mesh to promising bonding and loading behavior. The use of sandwich panels in the construction of structures provides many advantages such as cost-effectiveness, lightweight configurations, faster construction practices, and enhanced durability. In many offices and industrial buildings, these panels have been used as building components. The precast panels may readily be attached to any type of structural frame and easy to transport and allow movement to occur in wall systems during a seismic event. Nowadays, their use has been extended to zero energy building construction due to their capacity to enhance the thermal and structural performance and also they are used for load and non-load bearing structures. A sandwich panel is any structure results from the assembly of a low-density core (rigid or flexible) and two skin-layers bonded on each side. Sandwich panels are like I beam, where the faces like flanges of I beam which carries normal stress and the core is like a web which carries shear stress. In the construction field, steel reinforced concrete has been commonly used as a face in sandwich panels. Optimization of Cementitious matrix composition of Textile Reinforced Concrete.

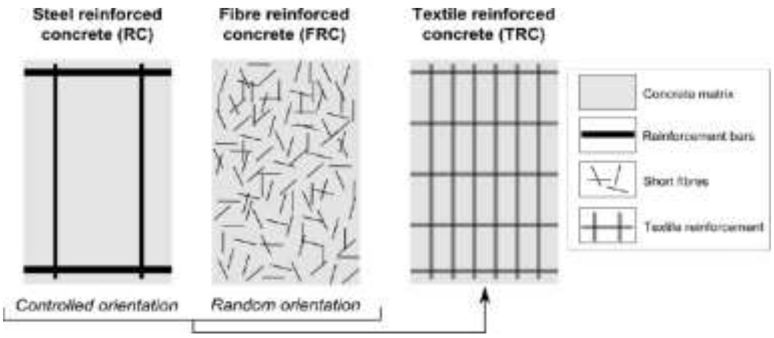

Fig 1: Formation of TRC from RC and FRC

- Design of textile reinforced concrete panels as per ACI 318.
- To optimize the dimensions of textile reinforced concrete panels based on flexural strength by experimental and analytical approach.
- To study the mechanical, durability and thermal properties of textile reinforcement concrete panels with aramid fibre mesh reinforcement.
- To study the mechanical and thermal performance of the aramid fibre mesh TRC sandwich panels with calcium silicate board as core material.

II. MATERIALS AND METHODS

A. *Materials Used*

The cement used for this research work was Ordinary Portland Cement-53 grade (OPC-53 grade) verifying to

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IS:12269:1987. The properties determined from the cement test were shown in Table 3.1. Class-C Fly ash, procured from Neyveli Thermal Power Station, India, and commercially available silica fume were used as mineral adDtures and their properties were shown in Table 3.2. White Silica fume refers to 99% undensified silica fume and silica fume containing zirconia. It consists primarily of amorphous and silicon dioxide (high-purity quartz). Polycarboxylate ether (PCE) based super-plasticizer used as water reducing agents in the production of high-performance concrete and its color is light brown-golden yellow. It has a more powerful dispersing effect and excellent fluidity retention performance without causing retardation. Silica Sand (0-0.25mm), Silica Sand (0.2-0.6mm), and Quartz Sand (0.6-1.2mm) were used as fine aggregates.

Table 1: Physical properties of OPC-53 grade cement.

Properties	Results
Physical Properties	
Specific gravity	3.12
Initial setting time (min)	110
Final setting time (min)	200
Consistency (%)	29

Table 2: Physical properties and chemical composition of fly ash and silica fume.

Properties	Fly ash (Class C)	Silica Fume*
Physical Properties		
Specific gravity	2.60	2.64
Fineness: material passing on 75 µm sieve, %	85.9	100
Colour	Grey	White

Table 3: Properties of Polycarboxylate ether.

Properties	Value
Physical State	Liquid
Color	Light brown-golden yellow
pH	5-7

Table 4: Physical Properties of Fine Aggregates.

Properties	Silica Sand (0-0.25mm)	Silica Sand (0.2-0.6mm)	Quartz Sand (0.6-1.2mm)
Specific gravity	2.63	2.62	2.52
Fineness modulus	2.0	2.23	3.82
Bulk density kg/m^3	1379.79	1593.19	1551.52
Water absorption (%)	0.5	0.3	0.6

Table 5: Properties of typical fibres mesh used.

Fibre Type	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Fabric Structures	Mesh Sizes (mm)
AR glass MT 1	2500	72000	Leno weave	6 x 5
AR glass MT 2	1500	68900	Leno weave	3 x 3
Aramid MT 1	2900	135000	Bonded	8 x 10
Aramid MT 2	3100	60000	Plain weave	NA

Provides detailed description about the physical, chemical and thermal properties of the materials used in this research

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work. The preliminary tests were conducted to find the properties of Fly ash, silica fume and silica sand were presented. The physical properties, fabric structures and size of the meshes used as a textile reinforcement were elaborated. The physical, chemical and thermal properties of Calcium Silicate Board were also explained in details along with the results.

B. Mix proportions

Table 6: Mix proportions

Des	Cement (kg/m^3)	Fly Ash (kg/m^3)	Silica Fume (kg/m^3)	Super plasticizer (kg/m^3)	Silica Sand 0-0.25mm (kg/m^3)	Silica Sand 0.2-0.6mm (kg/m^3)	Quartz Sand 0.6-1.2mm (kg/m^3)	Water (kg/m^3)	w/c	w/b	Average Compressive Strength (N/mm^2)
D1	554	233	89	2	118	168	-	231	0.42	0.26	81.502
D2	980	210	175	2	960	-	-	353	0.36	0.26	87.500
D3	980	233	210	2	118	-	325	351	0.36	0.25	91.917

C. RESULTS AND DISCUSSIONS

A. Compressive strength

The compressive strength of the cubical specimens of all of the Des was assessed in line with the criteria after 7, 28, 56, and 90 days of curing. This was done after the Dtures had been allowed to cure. [22] This was done in order to ensure that it was in accordance with the requirements of IS 516 (1991).

Table 7: Experimental results of compressive strength of TRC with various fibre meshes at various ages.

Mix	Mesh Type	No. of Layers	Experimental Compressive Strength (MPa)		
			7 days	28 days	56 days
D-1	AR glass MT 1	3	41.56	71.98	73.64
		4	44.66	78.63	80.91
		5	46.14	85.74	86.37
		6	43.69	69.92	68.92
	AR glass MT 2	3	38.54	56.25	56.79
		4	40.81	61.97	65.78
		5	43.85	71.58	73.57
		6	40.12	64.09	64.72
	Aramid MT 1	3	42.09	74.17	78.49
		4	45.65	79.98	84.36
		5	50.14	91.07	93.29
		6	46.57	71.78	71.98

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	Aramid MT 2	3	38.24	67.07	68.99
		4	43.98	74.67	75.10
		5	41.39	64.29	70.56
		6	31.06	60.49	61.60
D-2	AR glass MT 1	3	45.55	76.33	79.35
		4	48.72	80.04	83.16
		5	52.67	87.30	89.72
		6	38.01	73.21	71.61
	AR glass MT 2	3	40.48	54.82	58.92
		4	42.43	64.09	66.81
		5	47.65	74.69	72.21
		6	43.69	65.35	68.51
	Aramid MT 1	3	48.05	77.49	80.43
		4	50.59	84.50	88.09
		5	55.07	94.02	95.96
		6	45.84	75.74	78.15
	Aramid MT 2	3	40.87	71.71	73.08
		4	48.31	76.90	76.33
		5	44.23	70.51	73.83
		6	34.15	62.64	66.97
D-3	AR glass MT 1	3	48.98	78.16	82.31
		4	52.31	84.56	88.04
		5	56.26	92.53	94.99
		6	45.25	74.82	78.08
	AR glass MT 2	3	43.21	58.15	61.41
		4	47.32	69.38	71.07
		5	51.90	74.97	74.02
		6	42.73	57.22	58.64
	Aramid MT 1	3	49.21	82.02	85.77
		4	54.34	87.71	89.31
		5	61.98	98.05	99.05
		6	47.87	77.75	80.65
	Aramid MT 2	3	43.01	74.40	77.10
		4	49.38	78.14	80.37
		5	46.01	72.45	73.09
		6	39.17	51.16	55.10

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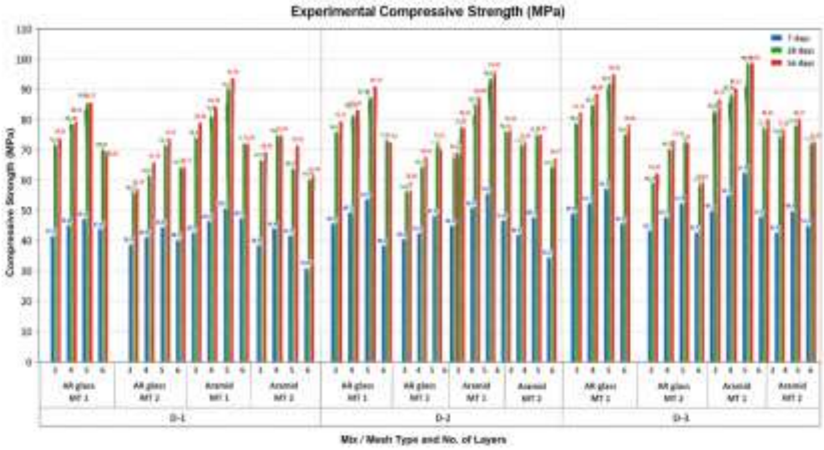

Fig 2: Experimental results of compressive strength of TRC with various fibre meshes at various ages.

It was noticed that D- 3 developed maximum compressive strength when compared to other two Des irrespective of type of mesh, mesh opening, number of layers and age. Cementitious mortar specimens without fibre mesh developed compressive strength of about 81.5 MPa, 87.5MPa and 91.9MPa for D-1, D-2 and D-3 respectively. Introduction of fibre mesh increases compressive strength by about 1.14, 1.09 and 1.08 times when compared reference cementitious mortar Des. Maximum compressive strength of 99.05 MPa was achieved for type-1 Aramid fibre mesh of five layers TRC specimens of D-3 and can be considered as optimal D. However, in D-1 about 91.96% of compressive strength of D-3 was arrived for type-1 Aramid fibre mesh of five layers TRC specimens. By considering the quantity of cementitious materials used, D-3 was proportioned with 1.62 times higher cementitious materials when compared to D-1. Hence, D-1 of type-1 Aramid fibre mesh of five layers TRC can be considered as economical D that develops comparable compressive strength to that of D-3.

B. Split tensile strength

A splitting tensile strength (STS) test was performed on the specimens for all of the Des after they had been cured for a period of ninety days. This was done in line with the International Standard 5816 (1999).

Table 8: Tensile strength and strain of TRC panels.

Fibre Mesh	**No. of Layers**	**Load (kN)**		**Tensile Stress (MPa)**		**Strain at Ultimate**
		At first crack	**At Ultimate**	**At first crack**	**At Ultimate**	
AR glass	3	1.4	1.51	2.33	2.52	0.0102
	4	1.45	2.6	2.42	4.33	0.0266
	5	1.45	3.2	2.42	5.33	0.0284
Aramid	3	1.45	2.1	2.42	3.5	0.02668
	4	1.6	3.6	2.67	6	0.0382
	5	1.45	4.7	2.42	7.83	0.0524

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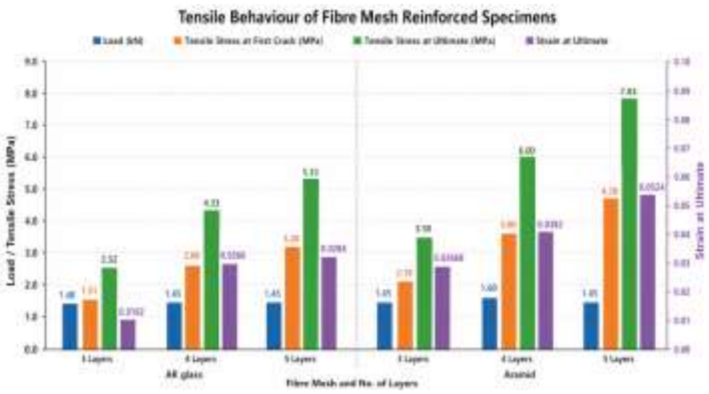

Fig 3: Tensile strength and strain of TRC panels

Typical failure pattern of TRC panels with two types of fibre mesh of various layers were shown in Fig. 6.10 and 6.11. Increasing the layers of fibre mesh in TRC results in increase in number of cracks formed, along with improvement in strain hardening behavior and reduced average crack spacing. Formation of longitudinal crack, which is an indication of debonding of fibre mesh form cement matrix during tensile loading was not noticed. It was found that cracks were formed perpendicular to the loading direction in all specimens. It was also observed that at the ultimate load, textile fibre mesh does not de-bond from the cementitious matrix, thus ensures good bonding with cement matrix. Further, it was noticed that textile fibre mesh does not split at the ultimate load, reflecting textile pullout from the cement matrix. Typical failure pattern shows that multiple cracks were formed throughout specimen with increase in the number of cracks for incremental in load.

C. Acid Attack

The acid attack test was carried out for cubes of D-1 and it was mentioned as Reference D; TRC AR glass fibre mesh of five layers, and TRC with Aramid fibre mesh of five layers. In total 6 number of specimens were casted with a standard cube size specimen of 70.6mm for the determination of percentage of weight and strength loss at 28 and 56 days. According to ASTM C 1898 -20, the acid solutions were prepared in which sulfuric acid (H_2SO_4) with pH of about 2 to 3 at 5% weight of water. The casted TRC cubes with 5 layers of fibre meshes were immersed in a water for 28 days of curing. After that the specimens were taken out from the curing tank and dried for one day. The weights of the TRC cube specimens were taken. The acid attack test on specimens was conducted by immersing the cubes in the acid solution in which the specimens are elevated from the bottom of the tank to avoid uneven exposure.

Table 9: Percentage of weight and strength loss of specimens after exposure to acid attack.

Type of Specimens	5% H_2SO_4 Solution			
	Weight Loss %		Strength Loss %	
	28 days	56 days	28 days	56 days
Reference D	2.31	12.63	13.78	21.65
AR-glass	1.87	5.44	8.41	14.16
Aramid	2.01	7.64	11.58	17.22

D. Sulphate Attack

The sulphate attack test was carried out on cubes of D-1 and it was mentioned as Reference D; AR glass fibre mesh of five layers, and Aramid fibre mesh of five layers. In total 6 number of specimens were casted with a standard cube size specimen of 70.6mm for the determination of percentage of weight and strength loss at 28 and 56 days. According to ASTM C 1012 -04 the sulphate solutions were prepared in which Sodium sulphate (Na_2SO_4) with pH in the range of 6 to 8 at 5% weight of water. The casted TRC cubes with 5 layers of fibre meshes were immersed in a water for 28 days of curing. After

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that the specimens were taken out from the curing tank and allowed to dry for one day. The weights of the TRC cube specimens were noted.

Table 10: Percentage of weight and strength loss of specimens after exposure to sulphate attack.

Type of Specimens	5% Na2SO4 Solution			
	Weight Loss %		Strength Loss %	
	28 days	56 days	28 days	56 days
Reference D	1.06	3.48	3.03	6.22
AR-glass	0.24	1.56	1.68	2.87
Aramid	0.56	2.97	2.19	3.41

E. Rapid Chloride Permeability

The Rapid Chloride Permeability Test method (RCPT) was carried out in accordance to ASTM C1202. RCPT is used to evaluate the resistance of chloride ions penetrations into the specimens through electrical conductivity measurements. The pore size and its distributions plays a major role in the chloride resistance. The three different sets of cylinders were used for this test: (1) Reference D (D-1); (2) AR glass fibre mesh; and (3) Aramid fibre mesh with 5 layers. The dimensions of the cylinders was 100 mm diameter x 50 mm depth. Fig. 8.5 shows the top view of RCPT set up. The test was conducted on the specimens at the age of 28 days. The sealed specimens were placed in the setup and the one end is filled with sodium chloride (NaCl) solution and the other end is filled with sodium hydroxide (NaOH).

Table 11: Chloride permeability of TRC specimens.

Time (mins)	Current reading (amperes) Reference D	Current reading (amperes) with AR- glass fibre mesh	Current reading (amperes) with Aramid fibre mesh
0	0.0288	0.1802	0.1412
30	0.0294	0.1921	0.1732
60	0.0300	0.2162	0.1162
90	0.0279	0.2201	0.1201
120	0.0300	0.2259	0.1259
150	0.0308	0.2395	0.1395
180	0.0279	0.2473	0.1473
210	0.0311	0.2513	0.1513
240	0.0325	0.2605	0.1605
270	0.0334	0.2714	0.1714
300	0.0338	0.2745	0.1745
330	0.03117	0.2836	0.1836
360	0.0314	0.2903	0.1903
Total charge passed (Coloumbs)	**663.48**	**5251.77**	**3292.65**

F. Water Absorption

Water Absorption test was conducted as per ASTM C642-1981. This test was carried out for cubes of Reference D (D-1); TRC with AR glass fibre mesh of five layers, and TRC with Aramid fibre mesh of five layers. In total 9 number of specimens were casted with a standard cube size specimen of 70.6mm for the determination of percentage of water absorption at 28 days. After curing, the specimens were dried in the oven at the controlled temperature of 110°C for 72 hours and the space between the specimens was maintained at least 25mm as shown in Fig 8.6. After oven dried, the specimens were allowed to cool for 24 hours in an air tight box. The weight of each specimens was noted (W_d). Then, the specimens were immersed in water for 30 hours. The weight of the wet specimens was further noted (W_w). The percentage of water absorption was calculated by the formula:

Table 12: Percentage of water absorption for the specimens.

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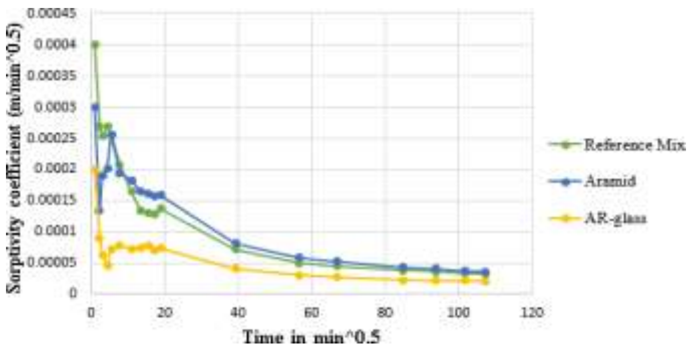
S.No.	Test Specimens	Weight of oven dried sample (W1) kg	Weight after immersion (W2) kg	Percentage of water absorption (%)
1	Reference D	0.719	0.754	4.57
2	D-AR glass fibre mesh 5 layers	0.765	0.789	4.213
3	D-Aramid fibre mesh 5 layers	0.738	0.778	4.88

G. Sorptivity

Sorptivity test was conducted as per ASTM C1585-2020. In total 6 number of specimens were casted with a standard cube size specimen of 70.6mm of reference D, AR-glass fibre mesh and aramid fibre mesh with 5 layers for the determination of rate of absorption at 28 days. The specimens are oven dried at 110ºC for 72 hours. After oven dried, the specimens are placed at room temperature for 24 hours to cool down. The sides are applied with water repellant and the weight of the specimens is noted. The specimens are then placed in a tray and allowed to touch the water at a level of 2mm (Fig. 8.7) and maintain it for the duration of test. The specimens weighed after wiping the excess water at the bottom at 1 minute interval up to 30 minutes for the period of 7 days.

Table 13: Sorptivity coefficients of the specimens.

S.No	Test Specimens	Average $m/min^{0.5}$	Min, value $m/min^{0.5}$	Max, value $m/min^{0.5}$	SD $m/min^{0.5}$
1	Reference D	0.000148	0.000032	0.000401	0.000108
2	D-AR glass fibre mesh 5 layers	0.000061	0.000021	0.000200	0.000042
3	D-Aramid fibre mesh 5 layers	0.000136	0.000036	0.000301	0.000081



IV. CONCLUSIONS

- Compressive strength of cement mortar specimens arrived at 28 days for all 27 mixes was varied from 45.40MPa to 91.91MPa.
- Maximum compressive strength of about 87.5MPa was achieved when 15% of fly ash and 13% of silica fume was added in the total binder of cementitious matrix composition in Mix-26 from experimental results.
- Mix-3 with 27% of fly ash and 10% of silica fume in total binder content resulted in compressive strength of about 82MPa.
- Maximum compressive strength of about 91.91 MPa was attained for mix proportions arrived from statistical method and it was about 1.05 times higher when compared to the other 27 mixes.
- The predicted combination for all the factors based on Taguchi analysis to achive maximum compressive

stregth are Cement Content = 980 kg/m^3, Fly Ash = 233 kg/m^3, Silica Fume = 210 kg/m^3, Super plasticizer = 2 kg/m^3, Silica Sand (0 – 0.25 mm) = 118 kg/m^3 and Quartz Sand (0.6 – 1.2 mm) = 325 kg/m^3.

- By considering the quantity of cementitious materials used, Mix-3 was proportioned with 1.62 times higher cementitious materials when compared to Mix-1. However, Mix- 1 develops comparable compressive strength of about 0.94 times as that to that of Mix-3. Hence, Mix-1 was considered as economical mix that develops comparable compressive strength as that to that of Mix-3 and recommended for further studies.
- Compressive strength of TRC specimens with AR-glass and aramid fibre meshes of 3, 4, 5, and 6 layers at 7, 28, and 56 days was varied from 31.06 to 61.98 MPa, 51.16 to 98.05 MPa and 55.10 to 99.05 MPa respectively.
- Based on experimental results, TRC specimens of Mix-3 type-1 aramid fibre meshes of 5 layers resulted in maximum compressive strength of about 99.05MPa and it was about 10.17%, 5.97% and 4.27% higher than AR glass meshes at 7, 28 and 56 days respectively.
- Mix-3 with type-1 aramid fibre mesh of 5 layers resulted in higher compressive strength of about 10.17%, 5.97%, and 4.27% than AR glass meshes at 7, 28, and 56 days respectively. In case of Aramid fibre mesh TRC specimens, rate of compressive strength produced at 28 days was about 63% and 99% when compared to 56 days. It can be inferred that rate of compressive strength development after 28 days was not significant.
- Water absorption was reduced by about 7.8% and increased by 6.78% respectively for TRC with AR-glass and aramid fibre mesh reinforcement than reference mix.
- Sorptivity of TRC with aramid fibre mesh was higher up to 12.52% when compared to that of reference mix. Increase in sorptivity may be due to slightly hygroscopic nature of aramid fibre mesh. Whereas AR-glass fibre mesh reinforcement reduced the sorptivity up to 42.86% when compared to that of reference mix.
- Weight loss due to acid attack was about 5.44% and 7.64% for TRC with AR-Glass fibre mesh and Aramid fibre mesh at 56 days is attained when compared to reference mix.
- Residual compressive strength of TRC with AR-Glass and Aramid fibre mesh due to acid attack were also reduced by about 35% and 20% when compared to reference mix, respectively.

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