REVISTAMATÉRIA V.29 N.3
ISSN 1517-7076 articles 20240125, 2024

Performance of RC beams developed with ECC layer and AR glass fiber mesh under flexural loading

Ravi Prakash Thangaraj[1], Balaji Shanmugam[1]

[1]Kongu Engineering College, Department of Civil Engineering. 638060, Perundurai, Erode, TamilNadu, India.
e-mail: civil.raviprakash@gmail.com, ktravi.civil@kongu.edu, er.shbalaji@gmail.com

ABSTRACT

Textile reinforced concrete (TRC) is an innovative technology increasingly utilized for various applications involving thin concrete composite panels. This experimental study investigates the use of fly ash as a supplementary cementitious material in the production of cementitious mortar, enhanced by the addition of 20% silica fume by weight of cement to improve compressive strength. The research incorporates fibers of Polyvinyl Alcohol (PVA), basalt, and polyester with varying volume fractions into the composites to mitigate cracking in the concrete. Additionally, Alkali-Resistant glass fiber mesh was integrated into the cementitious composites in varying layers to create thin TRC laminates. Specimens were cast and tested to determine their compressive, tensile, and flexural strengths. The study identified the optimal fiber volume fraction for hybrid fibers, with PVA fiber at 2% demonstrating superior performance due to its excellent tensile strength and high modulus of elasticity, making it the reference mix. Hybridization with basalt and polyester fibers at different volume fractions was also explored. Results indicated that increasing fiber content and the number of layers significantly enhanced the strength, toughness, and energy absorption of the composite elements. Increasing of fiber volume fraction in terms of mesh, give much improvement in the matrix.

Keywords: ECC; PVA fiber; Polyester fiber; Basalt fiber; AR Glass fiber mesh; Mechanical properties.

1. INTRODUCTION

Concrete is a structural element most frequently and widely used material all over the world and day by day new techniques are emerging to improve their properties. Concrete is an artificial stone, it is a mixture of fine aggregate, coarse aggregate, cement and water. It is brittle in nature, weak in tension strong in compression. To increase the tension strength of reinforcements are provided at different rod size as required. In this developing world in concrete mix is added with fibers now a days. This can change the behavior of concrete and increase the property of concrete and increase the crack resistance [1]. Using of fiber in concrete reduces the weight of structure, and also increases the property of concrete. Quality and strength of concrete depends upon the mixture and materials used [2].

Fiber reinforced concrete is mixture of cement, aggregate and discontinuous fibers of different sizes. Reinforcing fiber are of different types namely steel fiber, glass fiber, Polyvinyl alcohol fiber, polymer fiber, natural fiber, nano fiber etc. for production of fiber reinforced concrete. The shape of fiber and size also various from one another [1]. Fiber reinforced is a geometric shaped mesh for the penetration of cement into the structures, it is planar shaped structure. The mesh cells have different shapes as rectangular, square, diamond, triangle, and other [3]. In olden days there were not given more importance to fiber reinforcing and also was limited, but in these days fiber reinforced concrete is given more significant attention has been increased due to advantages repair and retrofit of structures.

The most common fiber used for ECC among all the researchers was Poly vinyl alcohol fibers. The PVA fiber is produced through the polymerization process of vinyl acetate, resulting in polyvinyl acetate, which is subsequently transformed into powdered PVA and extruded into fiber form. With its high modulus of elasticity and tensile strength, PVA fiber finds application in thin composite elements. And also it have a good interfacial bond with cement matrix, which gives much more flexural strength in the specimens [4, 5]. Several mineral admixtures were added to the ECC mixes with combination of fibers gives some better results [6]. And also use of hybrid fibers gives much better results in flexural and impact strength [7].

Textile reinforced concrete finding new application for reinforcement of structural parts. There are different types of fiber such as glass, basalt, carbon as others were used. Textile reinforced concrete is a

Corresponding Author: Ravi Prakash Thangaraj Received on 23/03/2024 Accepted on 10/06/2024

DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0125

combination of cement matrix and textile fibers. It is becoming most promising used in construction due to its greater advantages like minimal concrete covering, high corrosion resistance, light weight etc. [8]. The use of textile reinforced concrete is a strengthening technique in construction field, these structures are used as a repairing structural element, lightweight structures, facade elements, thin-walled elements [9]. As many fibers available glass fiber is chosen in our specimen because of high strength and high modulus of fiber, glass fiber is used instead of steel reinforcement.

Increasing number of textile layer increases flexural strength of concrete [2]. Flexural strength of concrete depends upon the type of reinforcing roving. Textile reinforced concrete of different textile fiber shows different flexural strength. Textile reinforcement shows higher load bearing capacity and increase in flexural strength [10]. Use of hybrid textile fibers like carbon and glass in laminates reduces crack width and spacing. And also increases flexural ductility [11].

Application of textile woven materials in concrete is not so popular yet, but it gives much result in the performance of building materials. Usage of textile woven mesh inside the thin specimens increase the flexural strength of panels by certain percentage and also the layers influence the strength parameters. The thickness of the specimen also plays a major role in determining flexural strength [12]. Addition of steel fiber mesh inside the thin composite panel has been widely researched and developed many results, but in addition to those small fibers added has recently developed with combination ECC gives much results [13].

In standard condition flexural strength of cementitious composites mortar have negligible increase, it has found that use of Poly Propylene (PP) recycled fiber shows maximum strain before failure and gives maximum post flexural failure [14]. New tensile strength configuration developed to find out the mechanical strength and micro structural analysis for engineered cementitious composites [15]. Increase in ratio of reinforcing increases the flexural strength. Using AR glass fiber as a reinforcement increases ultimate load, decreases deflection of specimen, AR glass fiber provides intermediate strength and brittle behavior compared to carbon fiber [2].

The composite samples reinforced with PVA consistently exhibited the highest levels of absorbed energy across all layer configurations. This superiority can be attributed to PVA's effective bonding properties between the textile and matrix, facilitated by its multifilament structure. Furthermore, as the number of layers increased, there was a notable enhancement in impact strength observed, particularly evident in the AR Glass and PVA reinforced standard cured series [16]. Polyethylene fabric is a low cost and commercially available material. Based on the results obtained it may be utilized in mass to improve load resistance [17]. The type of fabric and fibers used in ECC have reviewed and presented for the different mechanical properties [18]. The use of polypropylene, steel, glass and basalt fibers with same mix proportions used in high strength fiber reinforced concrete improves mechanical properties and arrest cracks [19]. Silica fume with different varying percentages from 0% to 15% combined with chopped basalt fibers show better improvement in mechanical properties [20].

Concrete possesses advantageous qualities such as workability, durability, and mechanical strength, rendering it a suitable material choice amidst the array of construction materials available [21]. Concrete is a composite material which has lower tensile strength and higher compressive strength [22]. Textile reinforced concrete exhibits an increased compressive strength and increased durability [23]. Flexural performance is increased by certain percentage by increasing thickness of ECC layer in concrete by adding PVA and polypropylene fibers [24]. Tensile specimens casted with a glass fiber mesh at middle having different thickness of mortar layer of 6 mm, 8 mm, 10 mm and 12 mm have been studied and results showed that up to 10 mm show the increase of strength [25]. Nowadays a geopolymer based matrix are replaced with ordinary cement combined with mini basalt rods to improve the matrix [26]. The use of glass woven fibers and unidirectional fabrics in fiber composites improves the flexural strength based on percentage and position of fibers [27].

In this study, a new technique was proposed to produce textile reinforced composites using short fibers. In this study, AR glass fiber textile mesh was used as reinforcement in the composites combined with hybrid fibers. During the study, varying percentages of fibers were used to produce ECC. In this research, three types of fiber materials were used and AR glass fiber mesh is used for textile reinforcement to produce thin cementitious composites. The objective of this investigation is to assess the bending capabilities of composite thin plates constructed utilizing a blend of hybrid fibers and AR glass fiber meshes via the four-point bending test. Samples, shaped in a rectangular configuration with dimensions of 520 × 100 × 15 mm, were manufactured for experimentation. Additionally, the impact of several critical variables including textile type, reinforcement ratio, and fiber dosage was examined. For the direct-tensile test, dog bone specimens were casted and tested to find the direct tensile strength of the composites. The influences of fiber volume and textile layers in composites were investigated. The hybridization of fibers significantly improves the mechanical properties of ECC.

2. EXPERIMENTAL INVESTIGATION

2.1. Materials and its properties

To produce the cementitious mortar, Ordinary Portland Cement of grade 53 (priya cement) was used in this research work. The chemical composition of cement was shown in Table 1. The physical properties of the cement are obtained conforming to IS: 12269 – 2013 are shown in Table 2. The cement was free from any lumps and fresh. Class F-type fly ash which is taken from nearby mettur thermal power station is used as supplementary cementitious material for reducing hydration process inside the concrete. The chemical composition of fly ash is given in Table 3. To improve the strength in the matrix, about 20% of silica fume is added to the mortar The various properties of silica fume are given in Table 4. The fine aggregate used as M-sand taken from local which is well graded conforming to Zone-II which is conforming to IS: 383 – 1970. The various properties of fine aggregate are given in Table 5.

2.2. Water

Fresh water with a pH value of 7 available from local sources according to IS: 456-2000 is used for mixing and curing.

Table 1: Chemical composition of cement.

INGREDIENTS	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Other
WEIGHT %	22.3	6.44	1.58	64.53	2.4	1.45	1.3

Table 2: Physical properties of cement.

PHYSICAL PROPERTIES	VALUE
Specific gravity	3.12
Standard consistency	29%
Initial setting time	140 min
Final setting time	220 min
Compressive strength	55 MPa

Table 3: Chemical composition of fly ash.

INGREDIENTS	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Other
WEIGHT %	54.2	29.03	7.95	5.6	1.68	0.24	1.3

Table 4: Chemical composition of silica fume.

INGREDIENTS	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Other
WEIGHT %	91.40	0.09	–	0.95	0.75	–	1.3

Table 5: Properties of fine aggregate.

PHYSICAL PROPERTIES	VALUE
Specific gravity	2.85
Fineness modulus	2.51
Water absorption (%)	0.65
Bulk density (kg/m^3)	1450

2.3. Chemical admixture

Conplast SP430 super plasticizing admixture with sulphonated naphthalene polymers produced by Fosroc Chemicals India Private Limited is used. The optimum dosage of Conplast SP430 to meet specific requirements will be found out by number of trials. High Range Water Reducing Admixture was utilized to enhance the workability property and rheological characteristics of the mixture, aiming for an enhanced dispersion of fibers. The chemical admixture is identifiable by its brown liquid coloration.

2.4. Fibers

PVA (polyvinyl alcohol), polyester and basalt chopped fibers are used in length as 12 mm for preparing specimens in different fiber volume fractions. The properties of PVA fibers, basalt fibers and polyester fibers from the supplier are given in Table 6. Using short PVA fibers offers a distinct advantage over other fiber types in controlling crack growth and achieving strain-hardening behavior under tension. As Polyester fiber has low self-weight, it reduces the specimen weight and shows high impact strength. Figure 1 shows the images of PVA, Basalt and Polyester fibers of 12 mm length and Figure 2 shows the SEM images of fibers. PVA fiber increases flexural strength, high tensile strength, high modulus of elasticity, crack resistance and resistance to corrosion.

Table 6: Physical properties of fibers.

TYPE OF FIBER	DIAMETER (D) (μm)	LENGTH (L) (mm)	TENSILE STRENGTH (MPa)	ELONGATION (%)	YOUNG'S MODULUS (GPa)	DENSITY (g/cm^3)
PVA	40	12	1600	7	42.8	1.3
Basalt	16	12	2800	4	90	2.68
Polyester	30	12	480	30	4	1.31

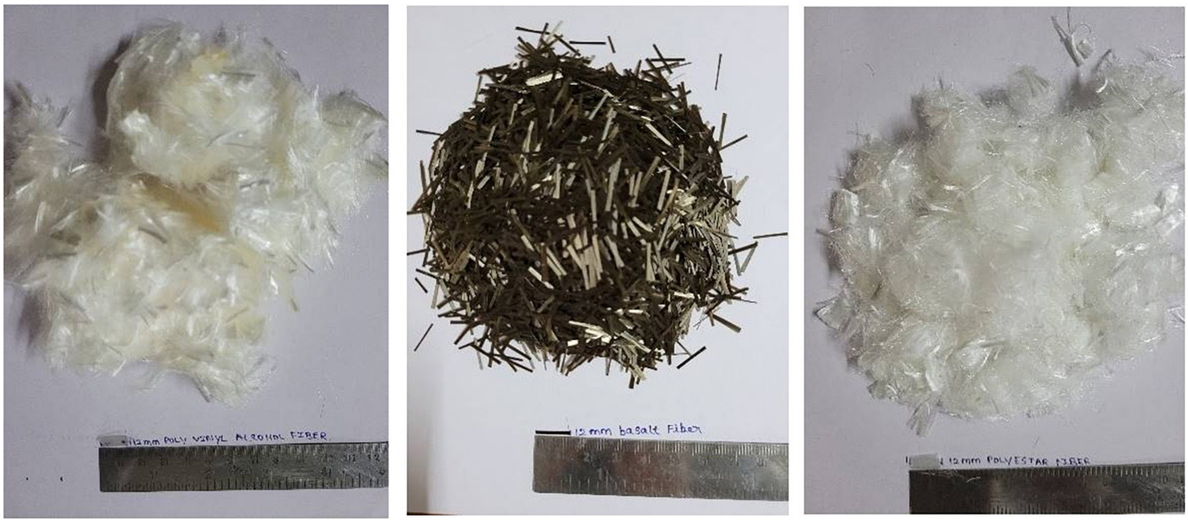

Figure 1: Morphology of fiber.

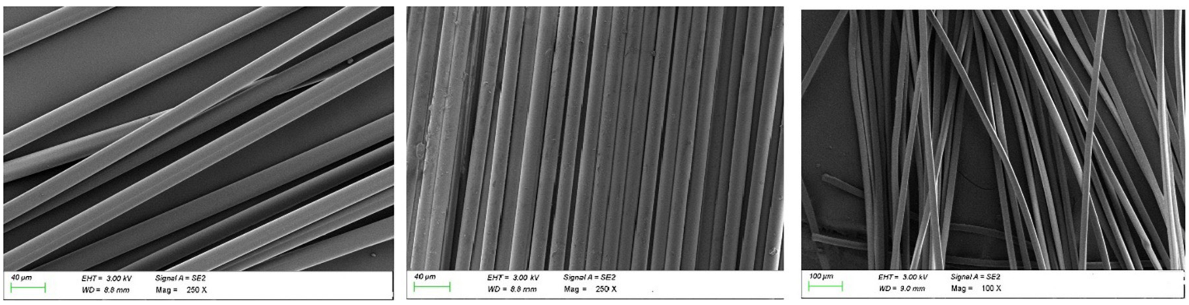

Figure 2: Scanning electron microscope images of fibers.

In this study, Alkali Resistant glass fiber mesh is used as reinforcement in different layers for preparing cementitious laminates. AR-glass fiber is resistance to high alkali levels in cement. The properties of AR glass fiber mesh are mentioned in Table 7, and Figure 3 shows AR-glass fiber mesh.

2.5. Mix proportions

In this experimental study, various mix proportions for engineered cementitious composites given in Table 8 and conventional concrete given in Table 9 were adopted. In this study, the different fiber volume fraction was taken to find out the strength parameters. Before casting, materials are tested to know the quality and then the materials are used for casting. After the material collection and testing, totally 24 combinations of mixes were casted for different types of specimens with different ratios of fiber and super plasticizer specimens were casted as shown in Figure 4. And different layers of meshes were used for producing textile reinforced laminates. At the first stage, the mould is made with appropriate dimension as mentioned above. Mould is cleaned and oiled. Second step is to insert AR-glass fiber mesh of two layers as Figure 5 shows, mesh is placed at a distance of 4 mm from the outer cover and vibration is given using nozzle vibrator. Figure 6 shows the placement of AR glass fiber mesh in ECC mixes in different layers in tension zone.

2.6. Mixing, casting and curing procedures

The mixing of the mortar is very important for casting of specimens. Sometimes the fibers will not uniformly disperse in the mixing of materials will lead to the balling effect. To avoid that, a proper mixing procedure sequence is followed for preparing specimens are shown in Figure 7. First cement, Fine aggregate, Fly ash and silica fume were weighed separately and added together in a pan mixer. The pan mixer is set to run for 128 r/min for two minutes to ensure proper mixing of cementitious materials. And then, water is added to the mix of about 75% and remaining 25% water is mixed with the super plasticizer and added slowly to the mix. After adding the water, mixer is set to run about two minutes in slow rate at 128 r/min speeds and after that set to run at high rate at 128 r/min speed for about two minutes. Subsequently, the fibers were uniformly incorporated into the

Table 7: Properties of AR glass fiber mesh.

TEXTILE TYPE	NOMINAL SPACING (mm)	YOUNG'S MODULUS (GPa)	TENSILE STRENGTH (MPa)	STRAIN/%	MASS (g/m^2)	DENSITY (g/cm^3)
AR glass fiber mesh	5 × 5	72	2500	3.6	145	2.46

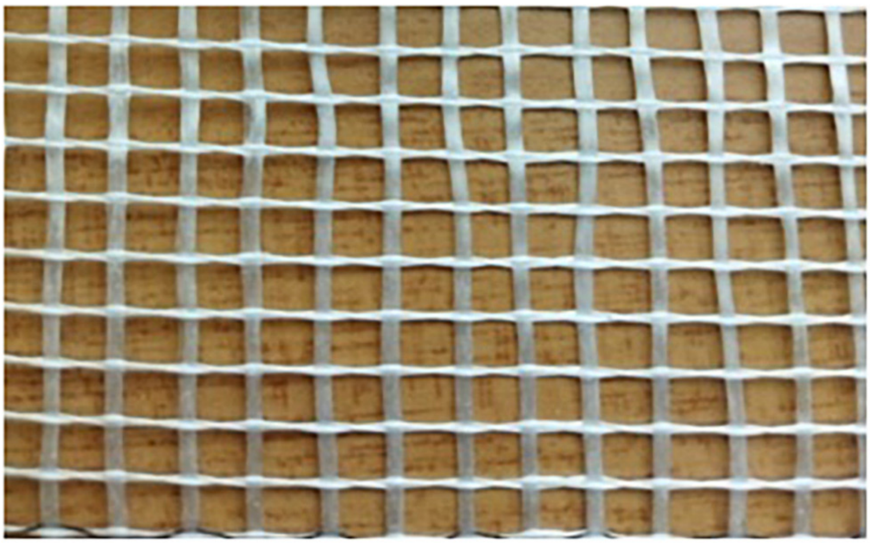

Figure 3: AR-glass fiber mesh.

Table 8: Mix proportions for ECC mixes.

MIX ID	CEMENT	SILICA FUME	FINE AGGREGATE	WATER/ BINDER RATIO	SUPER PLASTICIZER [%]	FIBER VOLUME FRACTION IN %		
						PVA	BASALT	POLYESTER
M1	1	0.20	0.7	0.35	1.8	–	–	–
M2	1	0.20	0.7	0.35	1.8	2	–	–
M3	1	0.20	0.7	0.35	1.8	–	2	–
M4	1	0.20	0.7	0.35	1.8	–	–	2
M5	1	0.20	0.7	0.35	1.8	0.5	1.5	–
M6	1	0.20	0.7	0.35	1.8	1.5	0.5	–
M7	1	0.20	0.7	0.35	1.8	1.0	1.0	–
M8	1	0.20	0.7	0.35	1.8	0.5	–	1.5
M9	1	0.20	0.7	0.35	1.8	1.5	–	0.5
M10	1	0.20	0.7	0.35	1.8	1.0	–	1.0

Table 9: Mix proportions for conventional concrete.

MATERIAL	CEMENT	FLY ASH	SILICA FUME	FINE AGGREGATE	COARSE AGGREAGATE	WATER	SUPER PLASTICIZER
kg/m^3	276.02	118	177	715.47	1131.46	5.91	276.02

Figure 4: Preparation of mortar cubes and dog-bone specimen.

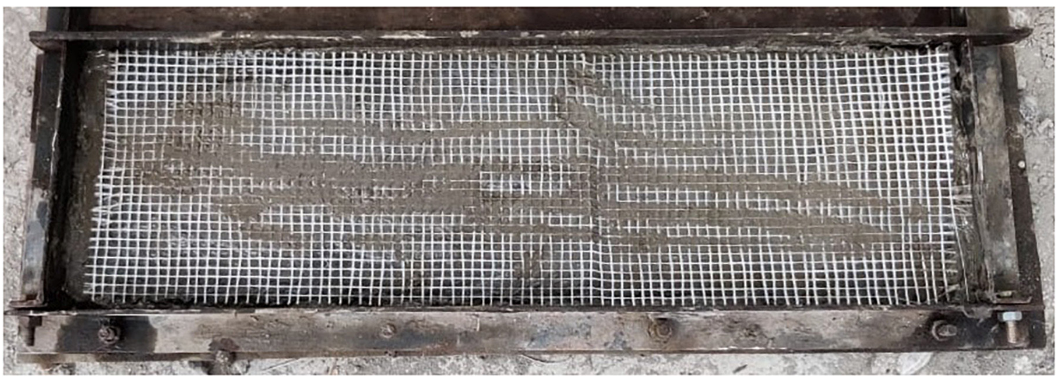

Figure 5: AR glass fiber mesh placed in laminate plate.

Figure 6: AR glass fiber mesh placed in ECC layered beam.

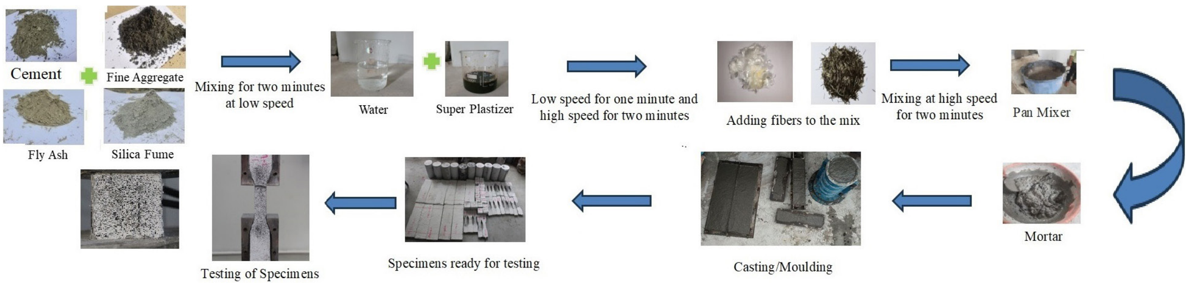

Figure 7: Sample preparation procedure.

pan mixer and blended at a mixing speed of 180 rotations per minute for duration of 5 minutes, ensuring their homogeneous dispersion within the mortar. The resultant fresh mixtures were then poured into respective molds and left to cure under ambient conditions before being demolded after a 24-hour period.

3. TEST METHODS

3.1. Compressive strength test

For the above mixes, the compressive strength test was conducted for the mortar cubes of size 70.7 mm × 70.7 mm × 70.7 mm as per IS: 4031 (Part 6) – 1988 standard sizes. Mortar cubes were casted for different fiber volume fractions. The test was conducted for 7, 14 and 28 days. The compressive strength was varied for different fiber volume fractions for different fibers. From the results, the increase of PVA fibers adversely affects the strength values up to 2% volume fraction. Figure 8 shows the setup of compression testing machine of capacity 1000 kN capacity make by EIE instruments, Pune.

3.2. Direct tensile strength test

Direct tensile strength test was conducted for dog bone specimens of size with cross section 330 mm × 60 mm × 30 mm with a gauge length of 80 mm. The specimens were casted for different fiber volume fraction and cured for 28 days. Figure 9 shows the setup of direct tensile testing machine make by EIE instruments, Pune.

3.3. Flexural strength test

Flexural testing serves as an indirect method for measuring the tensile strength of specimens. The flexural strength assessment is conducted through a four-point bending test for laminates. Specimen had the dimension size of 520 mm × 150 mm × 25 mm layered with textile fiber mesh. The warp yarns of slab are placed longitudinal section for the tensile load. The flexural test setup of four-point bending test is, illustrated in Figure 10.

Figure 8: Compressive strength test.

Figure 9: Dog bone specimen dimensions and direct tensile testing machine setup.

Load is applied beneath upside down. Testing specimen consisting of steel rods at top and bottom, it is placed at a distance of 400 mm of bottom steel rollers, upper steel rollers of distance 200 cm center to center distance. Before start of test, it is compulsory to mark the specimen to locate the position of rollers. After cleaning place, the specimen in machine making use of marking to the longitudinal axis of machine. The load is applied at the rate of 400 kg/min, applied the load until specimen fails record the maximum load applied.

3.4. Flexural strength behaviour of ECC layered AR glass fiber mesh reinforced concrete beams

A test setup model for the beam is represented in Figure 11. Spandrel beams are placed at a distance of L/3 from the two ends of the beam, to transfer the loads produced by the loading frame. The static loadings were applied and the deflections were measured at the mid-section till the ultimate failure occurred. The load carrying capacity of all the beams tested were calculated. The reinforced concrete beams undergo a four-point load test across their effective span of 1800 mm, adhering to standard procedures and conducted at room temperature. These concrete beams are designed with under-reinforced sections, measuring 2100 mm in length, with cross sections of 150 mm × 100 mm. Reinforcement detailing for the beam having 2nos of 8 mm diameter provided at bottom in tension zone and 2nos of 6 mm diameter provided at top as a hanger bar in compression zone and two-legged 6 mm diameter bars spaced at 100 mm centers for vertical stirrups. During the casting process, the ECC mixes are first placed within the mold with a thickness of 30 mm. Subsequently, conventional concrete is added after an hour to enhance the bonding between the layers and prevent coarse aggregate from penetrating the ECC layer. Special attention is paid to external compaction during the concrete layer application. Throughout the mixing process of ECC, measures are taken to prevent the thixotropic effect of fibers, as discussed earlier. Figure 5 depicts the arrangement for the four-point load test conducted on the beam. A push-pull hydraulic jack with a capacity of 100 kN is employed to apply the load, beneath which a load cell is positioned to measure the load exerted on the beam. Linear variable differential transformers (LVDT) are placed at three points beneath the beam's load point and mid-span, connected to a data acquisition system along with the load cell. Readings

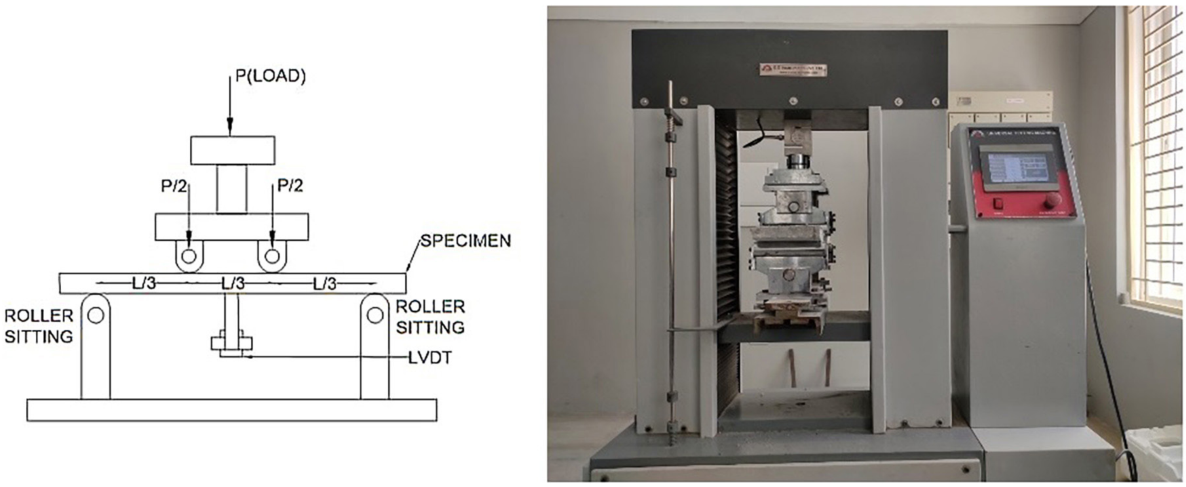

Figure 10: Test setup for flexural testing machine.

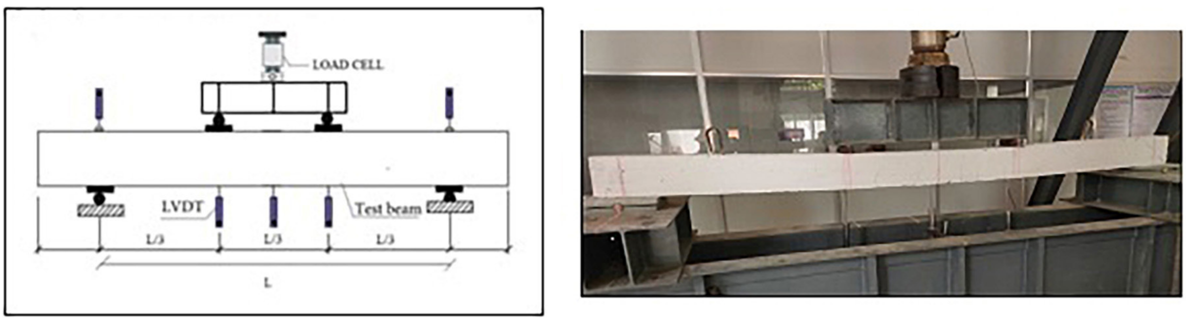

Figure 11: Test setup for ECC beam flexural testing machine.

and data are recorded and stored using a computer. The flexural test provides parameters such as the load-deflection curve, energy absorption of the section, and displacement ductility. The energy absorption of the section is computed by determining the area between the yield points and breaking point on the load-deflection curve. Displacement ductility is defined as the ratio between the ultimate deflection and the yield deflection of the beam.

4. RESULTS AND DISCUSSIONS

4.1. Compressive strength test

The compressive strength of various ECC mixes are shown in the Figure 12. The strength parameters are influenced based on the fiber volume percentage varying from 0.5% to 2.5%. And the results are arrived based on 3 days, 7 days, 14 days and 28 days of curing compressive strength. From the experimental results, compressive strength of PVA fiber (0.5 to 2.5%) mixes for the 28 days of curing shows the results of 48.4 MPa, 50.7 MPa, 51.2 MPa, 52.4 MPa and 48.7 MPa respectively. And for the Basalt fiber (0.5 to 2.5%) mixes for the 28 days of curing shows the results of 50.6 MPa, 52.3 MPa, 54.3 MPa, 55.6 MPa and 51.8 MPa respectively. And for the polyester fiber (0.5 to 2.5%) mixes for the 28 days of curing shows the results of 46.8 MPa, 47.7 MPa, 48.5 MPa, 49.3 MPa and 47.2 MPa respectively. Figure 13 shows the Failure pattern of cube specimen and Table 10 shows the compressive strength, standard deviation and coefficient of variation at 28 days.

Comparing with the control specimens, it was observed that the specimens with PVA fiber volume fractions of 0.5% to 2.5% with an interval of 0.5% exhibited increased percentages of 5.9%, 10.2%, 11.3%, 13.17%, and 6.5%, respectively. Similarly, specimens with basalt fiber volume fractions of 0.5% to 2.5% with an interval of 0.5% showed increased percentages of 10%, 13%, 16.2%, 16.21%, and 12.16%, respectively. Furthermore, specimens with polyester fiber volume fractions of 0.5% to 2.5% with an interval of 0.5% displayed increased percentages of 2.7%, 4.6%, 6.18%, 7.7%, and 3.6%, respectively. The hybrid specimen of optimum percentages i.e., PVA1.5% & B0.5%, PVA0.5% & B1.5%, and PVA1.0% & B1.0%, showed an increase percentage of 21%, 17.8% and 13.5% respectively. And for PVA1.5% & PE0.5%, PVA0.5% & PE1.5%, and PVA1.0% & PE1.0%, showed an increase percentage of 3.6%, 8.6% and 9.3% respectively. The specimen with fiber volume fraction of 2.5% showed decreased compressive strength all the mixes of three fibers. This may due to the absorption of water by a high accumulation of fiber content. Basalt specimens gave good results when compared to PVA fiber, polyester and hybrid fiber mixes. Percentage increase in compressive strength was effective with fiber hybridization when compared with control specimens. Upon analyzing the outcomes of hardened cementitious composites, it was observed that there was a notable increase in the concentration of basalt fiber, while the presence of PVA fiber was relatively reduced within the hybrid blends, consequently enhancing the compressive strength [28]. In real-world scenarios, the dispersion of fibers is impacted by numerous factors such as the flow properties of the matrix, manner of placement, attributes of the fibers (including length, diameter, and volume proportion), as well as the geometry of the structure [29].

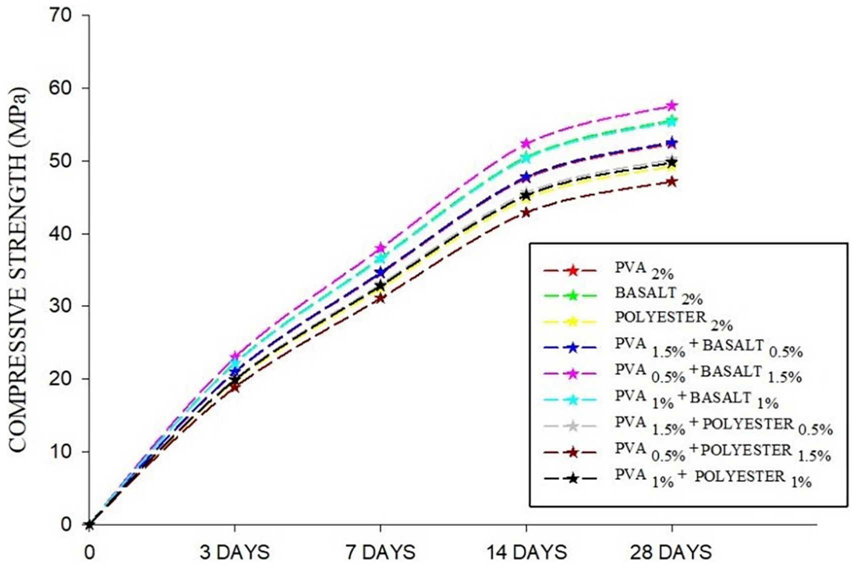

Figure 12: Compressive strength test results of ECC mixes.

Table 10: Compressive strength, standard deviation and coefficient of variation at 28 days.

SPECIMEN ID	% OF FIBER CONTENT	AVERAGE COMPRESSIVE STRENGTH (MPa)	STANDARD DEVIATION (MPa)	COEFFICIENT OF VARIATION (%)
Control specimen	0	48.10	1.09	2.31
PVA	2	47.73	1.26	2.65
Basalt	2	50.76	1.05	2.09
Polyester	2	46.26	1.02	2.23
PVA + Basalt	0.5 + 1.5	54.29	1.20	2.23
	1 + 1	51.55	1.14	2.23
	1.5 + 0.5	46.26	1.02	2.23
PVA + Polyester	0.5 + 1.5	48.80	1.08	2.23
	1 + 1	49.20	1.08	2.23
	1.5 + 0.5	48.10	1.09	2.31

Figure 13: Failure pattern of cube specimen.

4.2. Direct tensile strength test

By adding fibers to the mix, the brittle matrix gains the ability to endure tensile loads, which are then transferred to the fibers, consequently boosting the tensile strength of the composites. Basalt fiber having high tensile strength when compared to the other two fibers, the tensile strength is marginally increased when compared with PVA fiber due the strength reduction coefficient [30]. When combining PVA with basalt fibers in ECC mix can result in increasing tensile strength and strain capacity. Figure 14 shows the Failure pattern of cube specimen and Figure 15 illustrates the results of the direct tensile strength tests conducted on ECC mixes. From the experimental results, direct tensile strength of PVA fiber (0.5 to 2.5%) mixes for the 28 days of curing shows the results of 5.8 MPa, 6.3 MPa, 6.6 MPa, 6.8 MPa and 6.9 MPa respectively. And for the Basalt fiber (0.5 to 2.5%) mixes for the 28 days of curing shows the results of 5.9 MPa, 6.3 MPa, 6.6 MPa, 6.9 MPa and 5.6 MPa respectively. And for the polyester fiber (0.5 to 2.5%) mixes for the 28 days of curing shows the results of 4.9 MPa, 5.2 MPa, 5.4 MPa, 5.6 MPa and 4.8 MPa respectively. ECC specimen of basalt and PVA of 2% showed an increase of 23.18% and 22.50% in comparison with control specimen. Polyester fibers exhibited lower tensile strength compared to PVA and basalt fiber specimens. Incorporating a fiber ratio exceeding 2% in ECC led to decreased water content, compromised cement bonding, and affected properties like strain hardening.

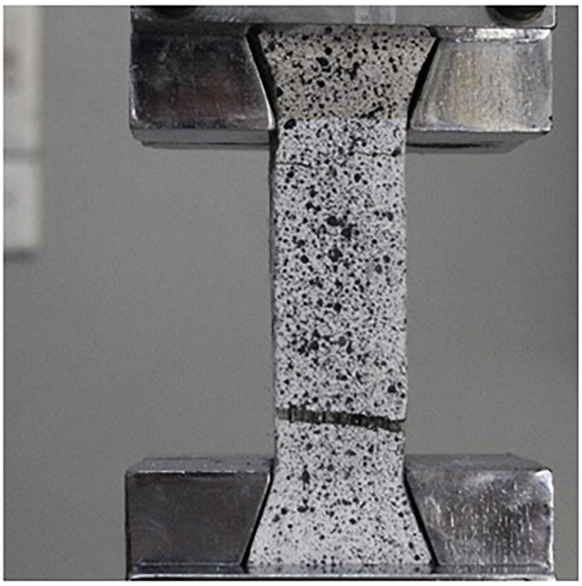

Figure 14: Failure pattern of dog-bone specimen.

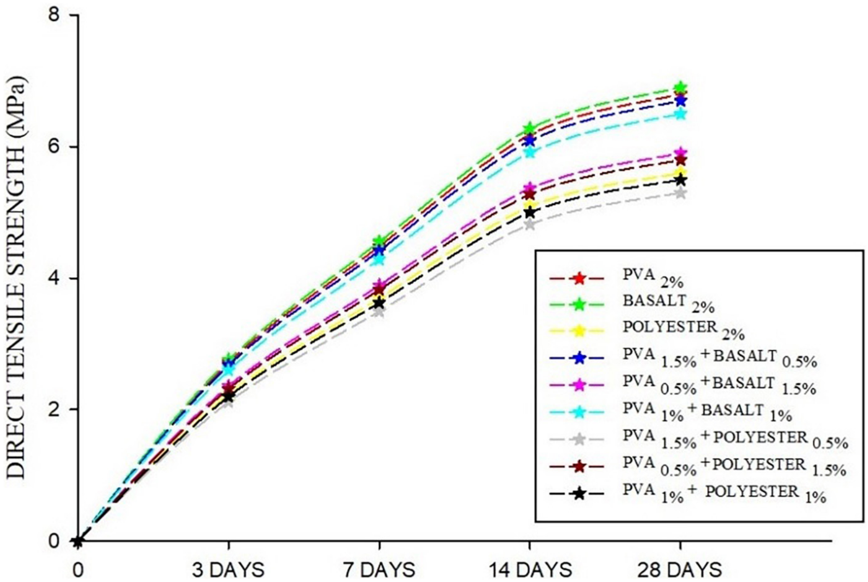

Figure 15: Direct tensile strength test results of ECC mixes.

4.3. Flexural strength of laminates

Three different fibers of Polyvinyl Alcohol fiber, Basalt fiber, Polyester fiber are used in different percentage fraction and AR-glass fiber mesh is used as reinforcement material for thin laminates. Polyvinyl Alcohol fiber and Polyester fiber of size 12 mm of both fiber fraction ratio of 0.5%, 1%, 1.5%, 2% & 2.5% of mix ratio. In order to find out the flexural strength of laminates, different types of slab specimens with different types of fiber percentage fraction of three different types of fibers are used. In this additionally glass fiber mesh is added in the thin laminates having two layers at middle of the specimen. ECC mixes of hybrid fibers having PVA 1.5% and 0.5% of polyester & fibers having PVA 0.5% and basalt of 1.5% shows better flexural performance in thin laminates, so that for the above mixes glass fiber mesh is placed in two layers.

At first laminates is casted without any fibers and have obtained the results so as to compare with textile reinforced concrete. Thin laminates having polyvinyl alcohol fiber exhibits higher flexural strength compared to Polyester. Fibers of shorter length show higher strength where it acts as bridge for mesh. Polyester fiber slab has an advantage that it reduces the crack length and also Polyvinyl Alcohol reduce the crack length. AR-glass fiber acts as the reinforcement in slab as it shows higher strength since AR-glass fiber has its own higher strength properties. Increasing number of layers of AR-glass fiber mesh has constant increase in flexural strength. The Flexural strength of the laminates were determined as per IS: 516 – 1959 (Reaffirmed 2004) by using the Flexure testing machine and the results were shown in Figure 16. Specimen with fiber volume fractions of 2% for PVA, Polyester and Basalt are compared with conventional specimen (CS) and results obtained are shown in figure. Results showed that for PVA, Polyester and Basalt having increased percentage of 10.79%, 3.06% and 1.04% respectively. Specimen with PVA 1.5% and 0.5% of polyester fiber volume fractions without fiber mesh and with 2 layers of mesh showed an increase percentage of 5.75% and 9.21% respectively, whereas for Specimen with PVA 0.5% and 1.5% of basalt fiber volume fractions without fiber mesh and with 2 layers of mesh showed an increase percentage of 15.81% and 18.92% respectively. Figure 17 shows the failure pattern of laminate specimen.

4.4. Flexural behaviour of ECC layered beam with fiber mesh

The table displays the experimental results for all specimens casted with PVA, polyester, and basalt fibers. Hybrid fibers with glass fiber mesh also shown in the table. Table 11 presents the characteristics of load deflection values, encompassing parameters such as initial cracking, yield point, ultimate strength, and failure point. The table provides data on the first crack load (Pcr), yield load (Py), and ultimate load (Pu) for all mixes. It also includes deflection values at first crack load (δcr), yield load (δy), and ultimate load (δu). The yield load corresponds to

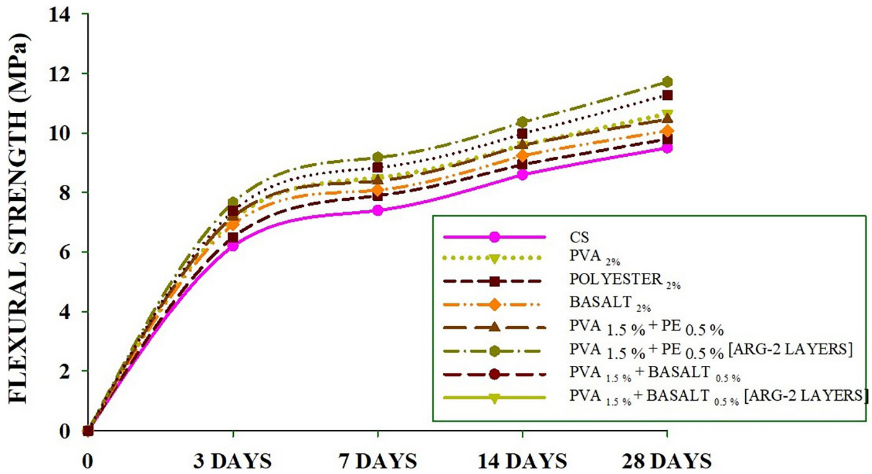

Figure 16: Flexural strength test results of ECC mixes.

Figure 17: Failure pattern of laminate specimen.

the yield point of the steel reinforcement, while the ultimate load represents the maximum sustained load by the structure beyond the yield load. In Figure 18, load-deflection curves for various beams are depicted. Figure 19 illustrates the flexural behavior of ECC layered with AR glass fiber mesh reinforced beams under ultimate loading. The glass fiber meshes with two layers are positioned at the bottom of the beam, with a cover of 10 mm for the ECC layer across various mixes. The beams show the better performance with flexural and deflection. For all the beams, an ECC layer shows better results when compared with the conventional specimen. Until reaching

Table 11: Flexural test results for conventional, ECC mixes and ECC mixes with fiber mesh.

BEAM ID	FIRST CRACK LOAD (kN)	DEFLECTION @ FIRST CRACK (mm)	YIELD LOAD (kN)	DEFLECTION @ YIELD LOAD (mm)	ULTIMATE CRACK LOAD (kN)	DEFLECTION @ BREAKING LOAD (mm)
CB	5.25	0.42	10.65	0.89	20.5	25.0
M1	5.87	0.38	11.86	1.1	21.9	34.1
M2	6.2	0.34	12.6	0.81	24.6	31.5
M3	5.72	0.31	11.67	0.63	24.9	29.9
M4	6.85	0.28	14.25	0.75	25.5	29.1

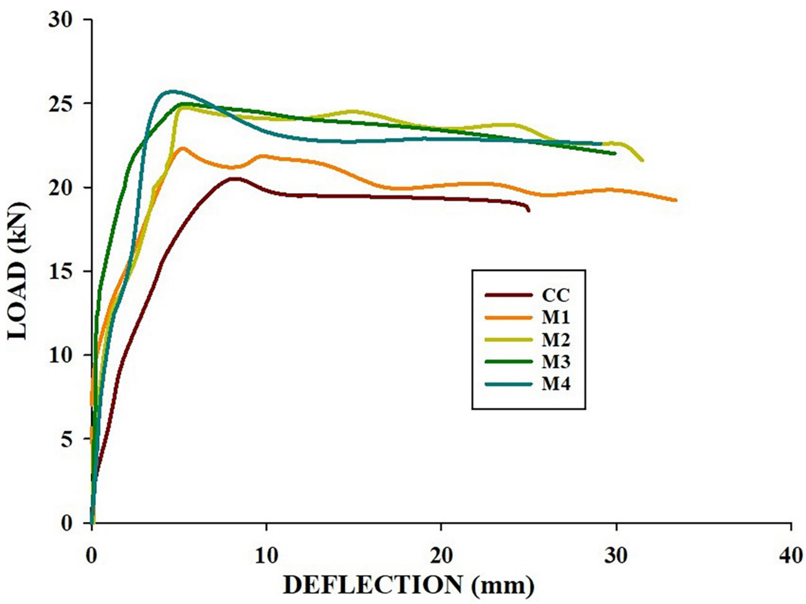

Figure 18: Flexural strength test results for ECC and AR glass fiber mesh layered beams.

Figure 19: Failure pattern of ECC layered beam with fiber mesh.

Table 12: Energy absorption and displacement ductility of ECC with glass fiber mesh beams.

BEAM ID	ENERGY ABSORPTION (kN.mm)	DISPLACEMENT DUCTILITY
CB	441.63	28.09
M1	661.56	31.00
M2	706.34	38.89
M3	686.5	47.46
M4	644.1	38.80

the yield stage, all beams exhibited comparable performance under flexure, with the occurrence of the first crack observed across all mixtures within this yielding phase. The crack formation in the beam was observed through visual inspection. After yielding, numerous smaller cracks emerged on the tension side of the beam, contributing slightly to alterations in the structure's strength, resilience, and overall performance. The experimental findings indicate a notable enhancement in beams incorporating ECC layers combined with AR glass fiber mesh. Mix M1 represents the conventional concrete specimen and M2 represents the PVA 1.5% + PE 0.5% hybrid mix, M2 represents PVA 1.5% + PE 0.5% with 2 layers of AR glass fiber mesh, M3 represents PVA 0.5% + B 1.5%, M4 represents PVA 0.5% + B 1.5% with 2 layers of AR glass fiber mesh. For the beams having ECC mix with PVA 0.5% and Basalt 1.5% performed better in more loading capacity, where PVA 1.5% and polyester 0.5% show better ductility behaviour. As number of layers increases the deflection behavior was also improved.

Energy absorption pertains to a material or structure's ability to soak up energy without undergoing substantial deformation or failure. It serves as a key metric for evaluating resilience and durability, especially in scenarios involving impacts or dynamic loads. Enhanced energy absorption signifies superior resistance to damage and heightened performance when subjected to various loading conditions. Energy absorption and displacement ductility were assessed for ECC beams reinforced with glass fiber mesh are given the Table 12. In contrast, PVA with a volume fraction of 1.5% and Polyester with a volume fraction of 0.5% demonstrated significant enhancements in energy absorption and ductility characteristics. The displacement ductility of the M3 mix reached 47.46, marking a 40% increase compared to conventional concrete. In comparison, the layered beams of M1 mix, M2 mix, and M4 mix exhibited displacement ductilities of 9.38%, 27.7%, and 27.6%, respectively.

5. CONCLUSION

The primary focus of this study was to conduct experimental investigations into the compression, direct tensile and flexural strength of cementitious composites reinforced with textile fibers. Based on the certain limitations like fiber volume percentage, layers of AR glass fiber mesh, mesh size and specimen size, the following results were concluded based on the experimental results arrived:

1. Specimen with PVA fiber of fiber volume fraction of 2% showed an increased percentage of 13.17%, 32.35%, 10.79% in compressive strength (cube), tensile strength and flexural strength respectively. Specimen with polyester fiber of fiber volume fraction of 2% showed an increased percentage of 7.7%, 17.85%, 3.06% compressive strength (cube), tensile strength and flexural strength respectively. Specimen with baslat fiber of fiber volume fraction of 2% showed an increased percentage of 18.17%, 33.33, 1.04% in compressive strength (cube), tensile strength and flexural strength respectively.
2. Specimen with hybrid fiber mix of PVA 1.5% and PE 0.5% showed good results in all mechanical properties. PVA 0.5% and Basaslt 1.5% shows higher compressive strength and PVA 1.5% and Basalt 0.5% shows higher tensile strength.
3. The flexural strength with specimens of 2 layers of AR glass fiber mesh with hybrid volume fractions gave good results. The incorporation of fibers led to a notable enhancement in the strength of the concrete, as they effectively bridged the gaps when subjected to loading conditions on the structural members.
4. Flexural behaviour of Hybrid fiber reinforced ECC with AR glass fiber mesh show better deflection behaviour. By increasing number of layers AR-glass fiber mesh flexural strength has constant increase. Textile fiber reinforced cementitious composites exhibits greater flexural strength compared to conventional specimens.

6. ACKNOWLEDGMENTS

The authors wish to acknowledge Department of civil engineering, Kongu Engineering College, Perundurai, Tamil Nadu for the facility and support extended for the research work.

7. BIBLIOGRAPHY

[1] DAS, S., HABIBURRAHMANSOBUZ, M., TAM, V.W.Y., *et al.*, "Effects of incorporating hybrid fibres on rheological and mechanical properties of fibre reinforced concrete", *Construction & Building Materials*, v. 262, pp. 120561, 2020. doi: http://doi.org/10.1016/j.conbuildmat.2020.120561.

[2] DU, Y., ZHANG, X., ZHOU, F., *et al.*, "Flexural behavior of basalt textile-reinforced concrete", *Construction & Building Materials*, v. 183, pp. 7–21, 2018. doi: http://doi.org/10.1016/j.conbuildmat.2018.06.165.

[3] VOLKOVA, A., PAYKOV, A., SEMENOV, S., *et al.*, "Flexural behavior of textile-reinforced concrete", *MATEC Web of Conferences*, v. 53, pp. 01016, 2016. doi: http://doi.org/10.1051/matecconf/20165301016.

[4] KHAN, M., ABBAS, Y., FARES, G., "Review of high and ultrahigh performance cementitious composites incorporating various combinations of fibers and ultrafines", *Journal of King Saud University-Engineering Sciences*, v. 29, n. 4, pp. 339–347, 2017. doi: http://doi.org/10.1016/j.jksues.2017.03.006.

[5] LOH, Z.P., MO, K.H., TAN, C.G., *et al.*, "Mechanical characteristics and flexural behaviour of fibre-reinforced cementitious composite containing PVA and basalt fibres", *Sadhana*, v. 44, n. 4, pp. 1–9, 2019. doi: http://doi.org/10.1007/s12046-019-1072-6.

[6] KANDASAMY, Y., THANGAVEL, B., SUKUMAR, K.K., *et al.*, "Strength properties of engineered cementitious composites containing pond ash and steel fiber", *Matéria (Rio de Janeiro)*, v. 29, n. 1, pp. e20230277, 2024. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0277.

[7] KRISHNARAJA, A.R., ANANDAKUMAR, S., JEGAN, M., *et al.*, "Study on impact of fiber hybridization in material properties of engineered cementitious composites", *Matéria (Rio de Janeiro)*, v. 24, n. 2, pp. e12347, 2019. doi: http://doi.org/10.1590/s1517-707620190002.0662.

[8] ELAVENIL, S., KNIGHT, G., "Impact response of plates under drop weight impact testing", *Daffodil International University Journal of Science and Technology*, v. 7, n. 1, pp. 1–11, 2012. doi: http://doi.org/10.3329/diujst.v7i1.9580.

[9] LI, T., ZHANG, Y., DAI, J.-G., "Flexural behavior and microstructure of hybrid basalt textile and steel fiber reinforced alkali-activated slag panels exposed to elevated temperatures", *Construction & Building Materials*, v. 152, pp. 651–660, 2017. doi: http://doi.org/10.1016/j.conbuildmat.2017.07.059.

[10] ZHANG, T., WANG, B., LU, X., *et al.*, "Flexural properties of textile-reinforced concrete with nonorthogonal grids", *Polymers*, v. 14, n. 23, pp. 5185, 2022. doi: http://doi.org/10.3390/polym14235185. PubMed PMID: 36501580.

[11] YOU, J., PARK, J., PARK, S.-K., *et al.*, "Experimental study on the flexural behavior of steel-textile-reinforced concrete: Various textile reinforcement details", *Applied Sciences (Basel, Switzerland)*, v. 10, n. 4, pp. 1425, 2020. doi: http://doi.org/10.3390/app10041425.

[12] KIM, S.H., LEE, S.H., "Study on flexural strength of textile-reinforced mortar panel with tensile force of glass fiber mesh", *Textile Science and Engineering*, v. 55, n. 6, pp. 373–380, 2018.

[13] SHANNAG, M.J., ZIYYAD, T.B., "Flexural response of ferrocement with fibrous cementitious matrices", *Construction & Building Materials*, v. 21, n. 6, pp. 1198–1205, 2007. doi: http://doi.org/10.1016/j.conbuildmat.2006.06.021.

[14] FRANCIOSO, V., MORO, C., CASTILLO, A., *et al.*, "Effect of elevated temperature on flexural behavior and fibers-matrix bonding of recycled PP fiber-reinforced cementitious composite", *Construction & Building Materials*, v. 269, pp. 121243, 2021. doi: http://doi.org/10.1016/j.conbuildmat.2020.121243.

[15] TAHMOURESI, B., NEMATI, P., ASADI, M.A., *et al.*, "Mechanical strength and microstructure of engineered cementitious composites: A new configuration for direct tensile strength, experimental and numerical analysis", *Construction & Building Materials*, v. 269, pp. 121361, 2021. doi: http://doi.org/10.1016/j.conbuildmat.2020.121361.

[16] DASKIRAN, E.G., DASKIRAN, M.M., GENCOGLU, M., "Experimental investigation on impact strength of AR Glass, Basalt and PVA textile reinforced cementitious composites", *European Journal of Environmental and Civil Engineering*, v. 26, n. 6, pp. 2037-2056, 2022. doi: http://doi.org/10.1080/19648189.2020.1749940.

[17] TSESARSKY, M., PELED, A., KATZ, A., *et al*., "Strengthening concrete elements by confinement within textile reinforced concrete (TRC) shells - Static and impact properties", *Construction & Building Materials*, v. 44, pp. 514–523, 2013. doi: http://doi.org/10.1016/j.conbuildmat.2013.03.031.

[18] THANGARAJ, R.P., SHANMUGAM, B., "A review paper on mechanical properties of flexural and impact test on textile reinforced engineered cementitious composites", *Materials Today: Proceedings*, v. 50, pp. 2160–2169, 2022. doi: http://doi.org/10.1016/j.matpr.2021.09.443.

[19] SARADAR, A., TAHMOURESI, B., MOHSENI, E., *et al*., "Restrained shrinkage cracking of fiber-reinforced high-strength concrete", *Fibers (Basel, Switzerland)*, v. 6, n. 1, pp. 12, 2018. doi: http://doi.org/10.3390/fib6010012.

[20] SADRMOMTAZI, A., TAHMOURESI, B., SARADAR, A., "Effects of silica fume on mechanical strength and microstructure of basalt fiber reinforced cementitious composites (BFRCC)", *Construction & Building Materials*, v. 162, pp. 321–333, 2018. doi: http://doi.org/10.1016/j.conbuildmat.2017.11.159.

[21] NASSANI, D.E., "Experimental and analytical study of the mechanical and flexural behavior of hybrid fiber concretes", *Structures*, v. 28, pp. 1746–1755, 2020. doi: http://doi.org/10.1016/j.istruc.2020.10.014.

[22] CHANDRA, V.B., CHARI, K.B., RAO, V.R., "The comprehensive analytical investigation on blended cement concrete beams with glass fibers under flexural loading", *Materials Today: Proceedings*, v. 33, pp. 587–592, 2020. doi: http://doi.org/10.1016/j.matpr.2020.05.498.

[23] SANJEEV, J., NITESH, K.S., "Study on the effect of steel and glass fibers on fresh and hardened properties of vibrated concrete and self-compacting concrete", *Materials Today: Proceedings*, v. 27, pp. 1559–1568, 2020. doi: http://doi.org/10.1016/j.matpr.2020.03.208.

[24] SHANOUR, A.S., SAID, M., ARAFA, A.I., *et al*., "Flexural performance of concrete beams containing engineered cementitious composites", *Construction & Building Materials*, v. 180, pp. 23–34, 2018. doi: http://doi.org/10.1016/j.conbuildmat.2018.05.238.

[25] JOHN, S.K., NADIR, Y., GIRIJA, K., *et al*., "Tensile behaviour of glass fibre textile reinforced mortar with fine aggregate partially replaced by fly ash", *Materials Today: Proceedings*, v. 27, pp. 144–149, 2020. doi: http://doi.org/10.1016/j.matpr.2019.09.135.

[26] FURTOS, G., PRODAN, D., SAROSI, C., *et al*., "Mechanical properties of minibars™ basalt fiber-reinforced geopolymer composites", *Materials (Basel)*, v. 17, n. 1, pp. 248, 2024. doi: http://doi.org/10.3390/ma17010248. PubMed PMID: 38204101.

[27] FURTOS, G., SILAGHI-DUMITRESCU, L., MOLDOVAN, M., *et al*., "Influence of filler/reinforcing agent and post-curing on the flexural properties of woven and unidirectional glass fiber-reinforced composites", *Journal of Materials Science*, v. 47, n. 7, pp. 3305–3314, 2012. http://doi.org/10.1007/s10853-011-6169-1.

[28] ÖZKAN, Ş., DEMIR, F., "The hybrid effects of PVA fiber and basalt fiber on mechanical performance of cost effective hybrid cementitious composites", *Construction & Building Materials*, v. 263, pp. 120564, 2020. doi: http://doi.org/10.1016/j.conbuildmat.2020.120564.

[29] KANG, S.T., LEE, B.Y., KIM, J.-K., *et al*., "The effect of fibre distribution characteristics on the flexural strength of steel fibre-reinforced ultra high strength concrete", *Construction & Building Materials*, v. 25, n. 5, pp. 2450–2457, 2011. doi: http://doi.org/10.1016/j.conbuildmat.2010.11.057.

[30] CHOI, J.-I., LEE, B.Y., "Bonding properties of basalt fiber and strength reduction according to fiber orientation", *Materials (Basel)*, v. 8, n. 10, pp. 6719–6727, 2015. doi: http://doi.org/10.3390/ma8105335. PubMed PMID: 28793595.