Mechanical Characteristics of Glass Fiber Reinforced Engineered Cementitious Composites

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***Abstract*— Confining concrete elements with fibre reinforced polymer (FRP) is proven to be an efficient technique in improving the dilation and axial performance of concrete columns. However, its effectiveness is reduced significantly for non-circular columns. In addition, a few drawbacks of using FRP, such as brittleness of FRP sheet and poor performance of the epoxy resins at high or low temperatures, have been found in recently year. This paper presents a feasibility investigation of a newly developed strengthening system, Glass fibre textile reinforced engineered Cementitious composite (ECC). The Parameters such as Split Tensile Strength, Axial Load Carrying Capacity, Ultimate Strength, Effective Confinement Ratio and Axial Strain Ratio were Investigated.. The experimental results revealed that the new strengthening system has significantly enhanced the load carrying capacity and ductility of square concrete columns compared to the unconfined specimens and the specimens confined with textile reinforced mortars (TRM); the axial compressive strength increased in the range of 54%-77% for the new strengthening system compared to 41% for the TRM system. The results also shown that ECC itself could be used as a new retrofitting material in column confinement.**

***Index Terms*— Cement, Glass fibers, Fiber Reinforced Concrete, Engineered Cementitious Composite, Epoxy Coated Layer, Glass Fiber Composite**

I. INTRODUCTION

Glass Fiber Reinforced Engineered cementitious composites (ECC) are the type of reinforcement in which the usual steel bars are replaced by Glass fiber, however concrete is brittle, and its toughness decreases with its increasing strength, which may lead to cracking in structures. ECC were developed due to advantages in toughness and energy absorption capacities. The ultimate tensile strain of ECC is nearly 1-8%, whereas that of normal concrete is only about 0.01%. GFR is a cementitious based material where reinforcement consists of high strength on corrosive textile fabrics. This may lead to unexpected brittle failure and structural collapse in a earthquake. Glass fiber composites mainly oriented in columns circumferential direction have proven to be an effective retrofit technique.

Concrete is the most popular construction material because of its special properties such as versatility, durability and easy to handle, due to these special properties more than 11.4 billion tons of concrete consumed annually worldwide. Ordinary Portland cement, though costly and energy intensive is the most widely used ingredient in the production of concrete mixes. The creation of ECC is mainly motivated on micromechanical interactions that occur between ingredients and way of processing. Interaction occurs between fibers and matrix is recognized as key factor which governs ECC behavior, resulting in interfacial zone modification techniques to design desired properties.

Fiber ruptures in ECC are prevented and pull-out of fiber from matrix is achieved using suitable mineral admixtures. Micromechanical interaction recounts macroscopic properties of the microstructure of composite, and forms spine for ECC material design theory. GFRECC is used worldwide to improve the tensile strength and axial load carrying capacity of concrete column. Strengthening of columns using ECC as a confinement layer and increases the structural integrity. It reduces the plastic shrinkage and brittle failure. It can also provide confinement as well as stay-in – place formwork for new constructions.

II. METHODOLOGY

The Main Objectives of the investigation are:

1. To study the mix design aspects of the GFR (Glass fiber reinforcement).
2. To evaluate the first crack stress, Strain Ratio, Confinement Effectiveness Ratio and Ultimate Strength of GFRECC
3. To evaluate the axial load carrying capacity.
4. To evaluate the crack pattern and comparing ECC with conventional concrete and circular column showing the performance of GFRECC.

A. Materials:

Ordinary Portland Cement of 53 Grade was used in this Investigation as a main Ingredient of Concrete. Fly ash obtained from thermal power stations is extensively used in RCC construction these days. This Investigation mainly Focuses on using Class – C Fly-ash as a Substitute. Natural River Sand is used as a Fine Aggregate and Coarse Aggregate of Size 16 - 20 mm are used.

B. PVA Fiber:

PVA Fibers (polyvinyl alcohol) are high-performance reinforcement fibers for concrete and mortar. PVA fibers are well-suited for a wide variety of applications because of their superior crack-fighting properties, high modulus of elasticity, excellent tensile and molecular bond strength, and high resistance to alkali, UV, chemicals, fatigue and abrasion. The Fibers which are Used in this investigation are of 12 mm in length and white in colour.

Table -1: Properties of PVA Fiber

Fi b er	Tensile Strength	Young's Modulus	Diameter	Length	Specific Gravity	Shape
P V A	1600 MPa	66 GPa	39µm	12mm	1.3	Straight

C. Other Chemical Agents Used:

Fosroc Brand super plasticizer is used as water reducing agent in the ECC matrix which reduces the water demand and increases the workability. Super plasticizers are used to control rheological properties of fresh concrete. An Epoxy Resin was used to coat the Fiber Matrix which is Clear Cast Epoxy Resin.

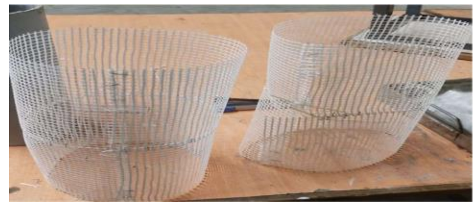

Fig 1. Glass Fiber Confinement Layer

III. MIX DESIGN

Mix proportioning is done for M 20 Grade according to the guidelines of IS – 10262: 2019. The detailed mix proportions for ECC mix are as follows.

Table -2: Mix Proportions for ECC

Mix	cement	sand	Fly ash	Water	Super plasticizer	PVA Fiber %
ECC based matrix	547 kg/m^3	438 kg/m^3	656 kg/m^3	312 liters	17.31	2%

Fig 2 Specimen with ECC Matrix

IV. RESULTS AND DISCUSSIONS

A. Split Tensile Strength:

Initially, take the wet specimen from water after 7, 28 of curing; or any desired age at which tensile strength to be estimated. The split rigidity is figured as takes after split tensile strength (Mpa) = $2p/\pi Dl$

Table -3: Split Tensile Strength

Mix	Glass Fiber	Split tensile strength (N/mm^2)	
		7 Days	28 Days
1	0.5%	1.41	3.4
2	1%	2.83	3.92
3	2%	2.60	3.57
4	3%	2.43	3.52

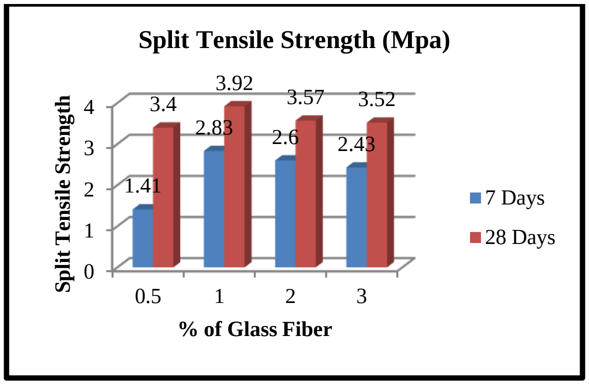

Fig. 3 Split Tensile Strength

B. Ultimate Strength of Specimens:

The Ultimate Strength of specimens is calculated by analyzing the axial load carrying capacity of the confined and unconfined cylindrical Specimens. The variation of Ultimate strength was shown below Table 4.

Table -4: Ultimate Strength of GFRECC Specimens

S.NO	Axial Load Carrying Capacity(kN)		Ultimate Strength (N/mm²)	
	P_{CO}	P_{CC}	f_{co}	f_{cc}
1	250	-	14.14	-
2	-	300	-	16.9
3	-	320	-	18.1
4	-	400	-	22.6
5	-	450	-	25.4

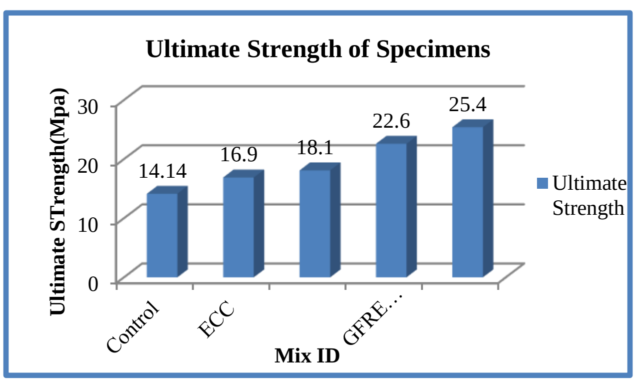

Fig. 4 Variation of Ultimate Strength

Table -5: Split Tensile Strength of Concrete

B. Stress Strain Behaviour of Specimens:

For Each Specimen, Axial Stresses and Strains were determined. The Confinement Effectiveness Ratio and Axial Strain ratio were calculated for Each Mix. In the case of column confinement effectiveness, the group C-E-GFRECC was about 25.4% more effective than the normal mortar group C-ECC.

Table 5. CER and ASR of Specimens:

Group	ε_{co} (μm/m)	ε_{cc} (μm/m)	fco (Mpa)	fcc (Mpa)	Confinement Effectiveness Ratio (fcc/fco)	Axial Strain Ratio ($\varepsilon_{cc}/\varepsilon_{co}$)
Control	347	-	14.14	-	-	-
C-ECC	-	65.6	-	16.9	1.20	0.1890
C-GFRECC 1	-	18.51	-	18.1	1.28	0.053
C-GFRECC 2	-	47.3	-	22.6	1.60	0.136
C-E-GFRECC 1	-	56	-	25.4	1.80	0.161

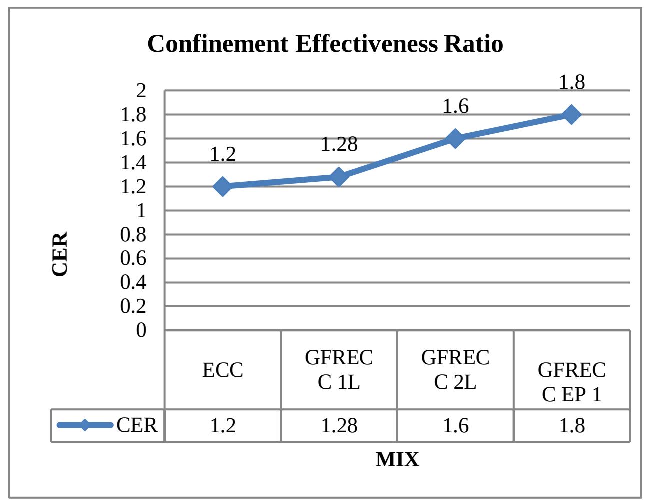

Fig 5. Confinement Effectiveness Ratio of GFRECC

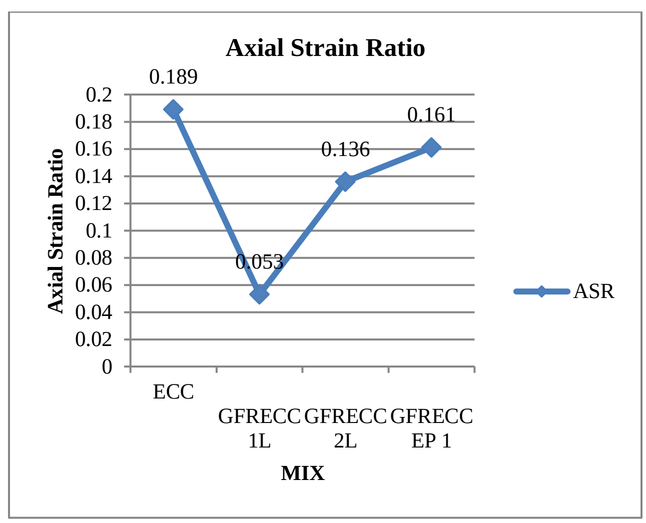

Fig 6. Axial Strain Ratio of GFRECC

V. CONCLUSIONS

1. The inorganic material, such as cement or ECC bonded well to the substrate concrete material, no deboning failure between concrete core and confinement layer was observed.
2. Under axial load condition, the load carrying capacity and ductility of square concrete column confined by ECC material were enhanced significantly with an increase of 92.5% compared to the unconfined specimens and specimens confined by traditional TRM system (41% increase).
3. This enhancement was slightly lower for the specimens confined by fibre textile reinforced ECC, where the load carrying capacity was increased in the range of 54.5%- 77.2%.
4. The proposed column confining technique was verified to be effective in improving the load carrying capacity and ductility of square concrete column.
5. ECC or Glass fibre textile reinforced ECC has a potential to modify and confine non-circular concrete column with considerable improvement in both failure pattern and load carrying capacity.
6. It Was observed that the maximum Split tensile strength achieved at 1% of Glass Fiber i.e.,3.92 Mpa.
7. The Axial Load Carrying capacity was Gradually increased for the Trials with Glass Fiber Composite Layer. The Maximum Load carrying Capacity of 450 kN was observed for the Mix with GFRECC – Epoxy Coating.
8. The Ultimate Strength of ECC Composite Specimens was increasing with the Confinement Layer addition to the Specimens.
9. The Maximum Confinement Effectiveness Ratio was observed for the Mix GFRECC Epoxy which is 1.8 and for ECC which is 1.2.
10. In the case of column confinement effectiveness, the group C-E-GFRECC was about 25.4% more effective than the normal mortar group C-ECC.
    The Axial Strain Ratio is calculated by observing the stress strain behaviour of specimens. The Maximum Axial Strain Ratio was observed for the Mix ECC.

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