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Effect of Textile reinforced Engineered Cementitious Composite as Concrete Column Confinement

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Abstract

Concrete structures with fiber reinforced polymers (FRP) improve the dilation and axial performance of concrete columns. However, there are few drawbacks of using FRP, such as brittleness of FRP sheet and poor performance of the material at high temperatures, have been found in recent years. But basalt fiber textile reinforced engineered cementitious composite (ECC) can be used as it's substitute in order to overcome all the drawbacks of FRP. Textile-reinforced mortar (TRM) is a type of reinforced mortar in which the usual steel reinforcing bars are replaced by textile materials. Instead of using a metal cage inside the concrete, this technique uses a fabric cage inside the same.

Keywords: *Fiber Reinforced Polymer, Engineered Cementitious Composite, Textile Reinforced mortar.*

1. Introduction

Concrete is the most popular construction material, with more than 11.4 billion tons of concrete consumed annually worldwide. It has been reported that 2.2 billion tons of cement was produced in the year 2005. It was estimated that each ton of cement produced generates an equal amount of carbon dioxide, a major contributor for greenhouse effect and global warming. Ordinary Portland cement, though costly and energy intensive is the most widely used ingredient in the production of concrete mixes.

Unfortunately, production of cement itself involves emission of large amounts of carbon dioxide into the atmosphere, a major contributor for greenhouse effect and global warming. Hence, it is inevitable either to search for another material or partly replace it by an alternate material. For example, Pozzolana is a natural or artificial material containing silica in a reactive form. It may be a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value. Pozzolana, in finely divided form and in the presence of moisture, reacts with calcium hydroxide at ordinary temperature and form compounds possessing cementitious properties.

In past few years, confining concrete structures with fiber reinforced polymer (FRP) is proven to be an efficient technique in improving the dilation and axial performance of concrete columns. However, a few drawbacks of using FRP, such as brittleness of FRP sheet and poor performance of the material at high temperatures have been found in recent years. In an attempt to alleviate the problems arising from the use of epoxies, researchers have suggested the replacement of organic matrix (epoxy resins) with inorganic (mortar) matrix. The penetration and impregnation of fiber sheets, in this case, has been very difficult due to the size of the granules in the mortar Even a fine mortar cannot impregnate fiber bundles as resins do. Improved bond conditions between fibers and matrix in mortar-based composite materials were achieved when continuous fiber sheets were replaced by textiles. Textile-based composite materials have been studied extensively during the last two decades, since they can be used for the construction of new prefabricated structural elements or for the strengthening of existing structures.

Textile Reinforced Mortar (TRM) is low-cost, friendly for manual workers, fire resistant, compatible with concrete and masonry substrate materials, and can be applied on wet surfaces or at low temperatures. For all these reasons, the use of TRM is progressively becoming more attractive for the strengthening of existing structures, in parallel to the widely used FRP. Although the first applications of TRM systems were in concrete elements, strengthening of typical or historical masonry structures with TRM seems to be very promising, considering the limitations of FRP systems. Finding compatible matrix for concrete column confinement attracts many interests recently. Among many investigations, the innovation of engineered cementitious composite (ECC) opens up new opportunities. ECC is a high-performance material made of a cementitious-based matrix reinforced with discrete PVA fibers. Engineered Cementitious Composite commonly known as ECC, developed in the last decade may prove a safer, more durable, and sustainable concrete material which is environmentally friendly, cost-effective and constructed with conventional construction equipment. Only with less than two percent by volume of short fibers, ECC has been developed these days. ECC is ductile in nature. Under flexure, normal concrete fractures in a brittle manner. In contrast, very high curvature can be achieved for ECC at increasingly higher loads, much like a ductile metal yielding. The tensile strain capacity of ECC can reach between 3 and 5 percent compared to 0.01 percent for normal concrete. Structural designers have found the damage tolerance and inherent tight crack width control of ECC. This behavior of strain hardening is attracting its potentiality in structural applications. It has wide applications and scope in various fields of Civil Engineering.

2. Materials and Methodology

Textile Reinforced Engineered Cementitious Composite mix involves the uses of Basalt fiber, Cement, Fly ash, fine aggregates, super plasticizers, Polyvinyl Alcohol Fibers and water.

Basalt fiber textile is a material made from extremely fine fibers of basalt, which is composed of the mineral's plagioclase, pyroxene, and olivine. It is similar to fiberglass, having better physic mechanical properties than fiberglass, but being significantly cheaper than carbon fiber with the size of25×25 mm was used; the weft and wrap were formed by monofilaments. The mechanical properties of basalt fiber density of 120 g/m^2 and tensile strength of 658.7 MPa.

Cement is a binder, a substance use for construction that sets, hardens, and adheres to other materials to bind them together. Fine aggregates are accumulation of grains of mineral matter derived from the disintegration of rocks. Usually, commercial sand is obtained from river beds or from sand dunes originally formed by the action of winds. The most useful commercial sands are silica sands, often above 98% pure.

The fine aggregates, passing through 4.75 mm sieve with a specific gravity of 2.60 to 2.68 are being used by the various researchers. The grading zone of fine aggregates was zone III as per Indian Standard specification.

Fly ash obtained from thermal power stations is extensively used in RCC construction these days. It reduces heat evolution without loss of strength. It also provides additional fines for compaction. Replacement levels of primary class fly ash have ranged from 30 to 75 percent by solid volume of cementitious material. The principal function of a fly ash is to occupy void space which would otherwise be occupied by cement or water. There will not be any acquisition cost for the fly ash but transportation cost is usually estimated.

PVA fibers possess similar characteristics as those of reinforcing materials. They have high modulus of elasticity, high durability, high tensile strength and greater bonding strength with concrete matrix. These are also some of the desirable properties of any cementitious composites. PVA fiber has high strength and modulus of elasticity of 25 to 40GPa. Fiber elongation is about 6 to 10 percent. The tensile strength of fiber is 880 to 1600MPa. One of the remarkable characteristics of PVA fiber is strong bonding with cement matrix. A layer of Calcium Hydroxide (CaOH2) is formed around the PVA fiber during hydration which is most important for bond strength. This is due to fact that Ca+ and OH- ions in cement slurry are attracted by PVA and makesCaOH2 layer.

Table 1. PVA Fiber Specifications

Fiber	Tensile Strength	Young's Modulus	Diameter	Length	Specific Gravity	Shape
PVA	1600 MPa	66 GPa	39μm	8 mm	1.3	Straight

Super plasticizers are used to control rheological properties of fresh concrete. Super plasticizers are additives to fresh concrete which help in dispersing the cement uniformly in the mix. This is achieved by their deflocculating action on cement agglomerates by which water entrapped in the groups of cement grains is released and it is available for workability. Super plasticizer increases slump from 5cm to 20cm without addition of water. They can reduce water up to 15 to 20 percent and hence decrease water to cement ratio by same amount. This results in increase in strength and other properties like density, water tightness. Where thin sections are to be cast, super-plasticizer can increase workability to pumpable level and almost no compaction is required. The permeability of concrete is a guide to its durability. The use of super plasticizer increases workability maintaining low water to cement ratio. The coefficient of permeability of cement paste reduces considerably with the reduction in water to cement ratio. Thus, super plasticizer can be used effectively to improve the properties of concrete and avoid defects like honeycombing. Melamine based Super plasticizer and Polycarboxylate Ether (PCE) based Super plasticizer are being used to assess their effectiveness in improving durability.

Water fit for drinking is generally considered fit for making cementitious composites. Water should be free from all sorts of impurities. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement

2.1. Mix design

Mainly three specimen's types are to be casted and materials required for each specimen is based on the type of specimen and mix ratio. Size of specimen – 300mm height X 150 mm diameter.
Following are the specimen types:

- SPECIMEN Type-1-Plain cement concrete.
- SPECIMEN Type-2-Engineered Cementitious Composite in the outer region with PCC as Core.

- SPECIMEN Type-3-Basalt textile with ECC in the outer region with PCC as core.

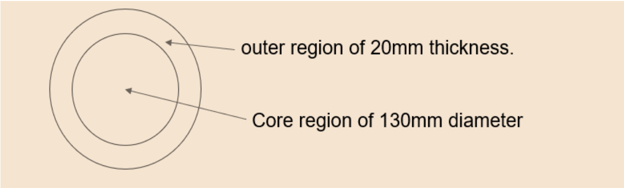

Fig.1 Plan of specimen

The specimens consist of plain concrete as core region with textile reinforced engineered cementitious composite as it's composite. Materials required for preparation of core region of specimen which comprises of plain cement concrete and materials required for preparation of ECC as confinement region around core region is taken in to consideration based on the required mix designs.

2.1.1 Mix design for core region

Materials are mixed for preparation of core region of the specimen with two mix ratios low grade concrete (M20 grade) and medium grade concrete (M40 grade).M20 grade mix ratio- 1:1.5:3(cement: fine aggregate: coarse aggregate). M40 Grade Concrete Parameters for mix design M40: Grade Designation = M-40 Type of cement = O.P.C-43 grade Fine Aggregate = Zone-II Sp. Gravity Cement = 3.15 Fine Aggregate = 2.61 Coarse Aggregate (20mm) = 2.65 Coarse Aggregate (10mm) = 2.66 Minimum Cement (As per contract) = 400 kg / m^3 Maximum water cement ratio (As per contract) = 0.45. Hence Mix details per m^3 Cement = 400 kg Water = 160 kg Fine aggregate = 660kg Coarse aggregate 20 mm = 1168 kg

2.1.2 Mix design for ECC

ECC consists of cement, fly ash, fine aggregate, PVA fibres, super plasticizers, water in the following proportions

Table 2 Composition of ECC

Mix	Cement	Sand	Fly ash	Water	Super Plasticizer	PVA Fibre % Volume
ECC based matrix	1	0.8	1.2	0.58	0.0055	2%

2.2. Casting of specimens

A total of 6 short concrete columns with a height of 300 mm and diameter of 150 mm should be casted using two batches called Batch 1 and Batch 2. Low compression strength mix (M20 grade concrete) was used in the first batch and moderate compressive strength mix (M40 grade concrete) was used in the second batch (batch 2) as core material. Each batch contained Specimen type 1 - Plane cement concrete only. Specimen type 2 - PCC as core confined with 20 mm thick ECC material only. Specimen type 3- PCC as core confined with 20 mm thick basalt textile reinforced ECC (For columns confined with textile reinforced ECC or mortar, about 140 mm overlap of fibers was considered to avoid premature fiber textile failure resulted from debonding).

In the case of Specimen type-1, plain cement concrete is of required mix ratio according to the type of batch is placed in the oil lubricated cylinder mould, and demoulding it after a period of 24 hours' time and the specimens were cured until 28 days.

In the case of Specimen type-3, the confinement layer was manufactured according to the following procedures: Mould work, which included the use of steel cylinders and PVC tubes. PVC tubes were mounted into the steel cylinders creating moulds to cast tube specimens with the thickness of 20 mm, height of 300 mm and outer diameter of 150 mm, application of a bidirectional basalt grid to have a cylindrical shape with the diameter of 130 mm and overlap of 140 mm that was located in the gap between the steel cylinder and the PVC pipe

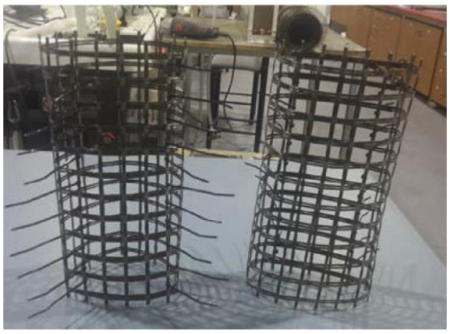

Fig.2 basalt grid

Fill the remaining portion confinement layer with ECC material. Pour the matrix into the mould around PVC pipe with continuous shaking by a rapper hummer as shown in Fig.

Fig.3 confinement layer casting

Removing the PVC pipe after 24 h to have a tube shape with a total diameter of 150 mm and thickness of 20 mm and lubricating the inner region of confinement layer with oil.

Fig.4 Removing of PVC Pipe

Fig.5 Removing of PVC Pipe

Fig.6 Removing of PVC Pipe

Fig.7 Lubricating the Inner Portion of Confinement Layer.

Application of concrete core of required mix proportion inside the ECC confinement layer; the specimens will be cured for 28 days.

Fig.8 Filling of core region with PCC

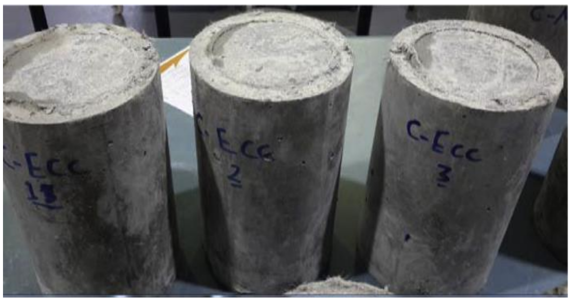

Fig.9 Filling of core region with PCC

Surface leveling execution using a saw cut to ensure uniform distribution load during test as shown in Fig. 1e.

Fig.10 Leveling of Specimen Surfaces

In the case of specimen type-2, the same procedures applied except for step (2).

3. Results and discussion

Table 3 Compressive strength test results.

Grade of specimen	Specimen type	fco (MPa)	fcc(MPa)
Low grade (M20 grade)	Specimen type-1	15.8	-
	Specimen type-2	15.8	23.66
	Specimen type-3	15.8	21.95
Medium grade (M40 grade)	Specimen type-1	32.2	-
	Specimen type-2	32.2	42.52
	Specimen type-3	32.2	38.75

f_{co} is the compressive strength of core region.
$f_{cc}$is the compressive strength of confinement layer.

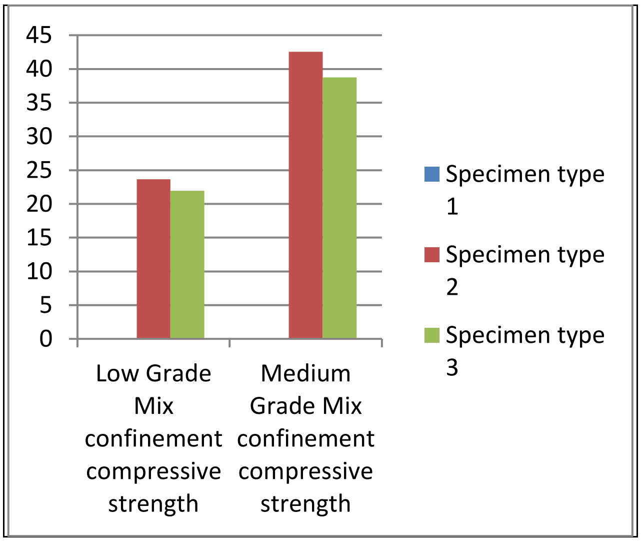

Fig.11 Compressive strength test results.

Table 3 and Figure 11 represents the compressive strength test values of low grade mix (M20 grade) and medium grade mix (M40 grade) specimens. The core strength of all specimen types of low grade mix (M20 grade) remains same i.e., 15.8 MPa and the confinement layer of each specimen changes due to the difference in use of materials as the confinement layer.

In Low grade mix specimens, Specimen type 1 doesn't contain a confinement layer so the confinement compressive strength is zero. Specimen type 2 contains ECC as the confinement layer of 20 mm thickness. The confinement compressive strength low grade mix specimen type 2 is 23.66 MPa which is higher than the core compressive strength of the specimen because the material used as confinement layer in low grade mix specimen type 2 is ECC, due to the composition of ECC i.e., cement, fly ash, fine sand, PVA fiber, Melamine based super plasticizer makes the confinement layer stronger than the core region and its self healing ability of inner cracks, high performance and etc., Specimen type 3 contains basalt textile reinforced ECC as the confinement layer of 20 mm thickness with basalt textile as reinforcement. The confinement compressive strength low grade mix specimen type 3 is 21.95 MPa which is higher than the core compressive strength of the specimen as the material used as confinement layer in low grade mix specimen type 3 is ECC, as the composition of ECC i.e., cement, fly ash, fine sand, PVA fiber, Melamine based super plasticizer, basalt fiber makes the confinement layer stronger than the core region due to its self healing ability of inner cracks, good performance at high temperature conditions and etc.,

The core strength of all specimen types of low grade mix (M20 grade) remains same i.e., 32.2 MPa and the confinement layer of each specimen changes due to the difference in use of materials as the confinement layer. In medium grade mix specimens, Specimen type 1 doesn't contain a confinement layer so the confinement compressive strength is zero. Specimen type 2 contains ECC as the confinement layer of 20 mm thickness. The confinement compressive strength low grade mix specimen type 2 is 42.52 MPa which is higher than the core compressive strength of the specimen as the material used as confinement layer in medium grade mix specimen type 2 is ECC, due to the composition of ECC i.e., cement, fly ash, fine sand, PVA fiber, Melamine based super plasticizer makes the confinement layer stronger than the core region and its self healing ability of inner cracks, high performance and etc., Specimen type 3 contains basalt textile reinforced ECC as the confinement layer of 20 mm thickness with basalt textile as reinforcement. The confinement compressive strength medium grade mix specimen type 3 is 38.75MPa which is higher than the core compressive strength of the specimen as the material used as confinement layer in low grade mix specimen type 3 is ECC, as the composition of ECC i.e., cement, fly ash, fine sand, PVA fiber, Melamine based super plasticizer, basalt fiber makes the confinement layer stronger than the core region due to its self healing ability of inner cracks, good performance at high temperature conditions and etc.,

In both low grade and medium grade specimens, the compressive strength of specimen type 2 is more than the specimen type 3 as the compressive strength of ECC material is more than the compressive strength of Basalt Textile reinforced ECC.

Table 4 Split tensile strength test results

Grade of specimen	Specimen type	Tensile strength(MPa)
Low grade (M20 grade)	Specimen type-1	2.5
	Specimen type-2	3.5
	Specimen type-3	3.7
Medium grade (M40 grade)	Specimen type-1	4.5
	Specimen type-2	5.7
	Specimen type-3	5.9

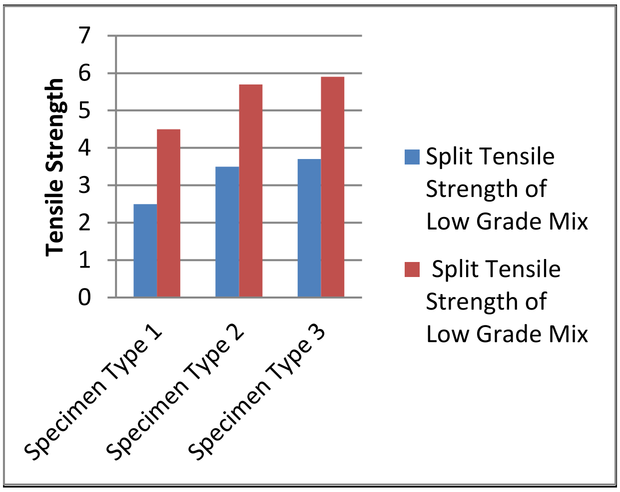

Fig.12 Split Tensile Strength Results

Table 4 and Figure 12 represents the Split tensile strength test values of low-grade mix (M20 grade) and medium grade mix (M40 grade) specimens.

In Low grade mix specimens, Specimen type 1 contains plain cement concrete of M20 grade, the tensile strength of specimen type 1 is 2.5 MPa. Specimen type 2 contains ECC as the confinement layer of 20 mm thickness. The tensile strength of low-grade mix specimen type 2 is 3.5 MPa which is higher than the tensile strength of low-grade mix specimen type 1, as ECC based confinement layer has self-healing ability of inner cracks, Specimen type 3 contains basalt textile reinforced ECC as the confinement layer of 20 mm thickness with basalt textile as reinforcement. The tensile strength low grade mix specimen type 3 is 3.7 MPa which is higher than the tensile strength of the other low grade mix specimens due to its composition, self-healing ability of inner cracks, good performance at high temperature conditions and etc.,

In Medium grade mix specimens, Specimen type 1 contains plain cement concrete of M40 grade, the tensile strength of specimen type 1 is 4.5 MPa. Specimen type 2 contains ECC as the confinement layer of 20 mm thickness. The tensile strength of medium grade mix specimen type 2 is 5.7 MPa which is higher than the tensile strength of medium grade mix specimen type 1, as ECC based confinement layer has self-healing ability of inner cracks and etc., Specimen type 3 contains basalt textile reinforced ECC as the confinement layer of 20 mm thickness with basalt textile as reinforcement. The tensile strength medium grade mix specimen type 3 is 5.9 MPa which is higher than the tensile strength of the other medium grade mix specimens due to its composition, self-healing ability of inner cracks, good performance at high temperature conditions and etc.,

3.1 Comparison of data

3.1.1 ECC Vs Cement Mortar

Table 5 Physical properties of ECC

Compressive strength (MPa)	First crack strength (MPa)	Ultimate tensile strength (MPa)	Ultimate tensile strain (%)	Young’ s modulus (GPa)	Flexural strength (MPa)	Density (g/cc)
20-95	3-7	4-12	1-8	18-34	10-30	0.95-2.3

Table 6 Physical properties of Cement Mortar

Compressive strength (MPa)	First crack strength (MPa)	Ultimate tensile strength (MPa)	Ultimate tensile strain (%)	Young’ s modulus (GPa)	Flexural strength (MPa)	Density (g/cc)
33-53	1-3	1-4	1-8	10-30	1-10	2.162

3.2.2 FRP Vs TRM

Table 7 Physical properties of FRP

Material	Tensile strength (MPa)	Elongation (%)	Young’ s modulus (GPa)	Coefficient of Linear expansion ($10^{-6}/^{o}c$)	Density (g/cc)
CFRP	600-3920	0.5-1.8	37-784	-9.0 – 0.0	1.50 – 2.10
GFRP	483-4580	1.2-5.0	35-86	6.0 - 10.0	1.25 – 2.50
AFRP	1720-3620	1.4-4.4	41-175	-6.0 – 2.0	1.25 – 1.45
BFRP	600-1500	1.2-2.6	50-65	9.0 – 12.0	1.90 – 2.10

Table 8 Physical properties of TRM

Material	Tensile strength (MPa)	Elongation (%)	Young's modulus (GPa)	Coefficient of Linear expansion (10^{-6}/ºc)	Density (g/cc)
Glass	1950 - 2050	3.0	72 - 85	4.9 – 5.1	2.5
Carbon	3620-6210	1.75	241 - 297	0.1 – 6.0	1.74 – 1.80
Basalt	3000 - 3500	3.1 – 4.6	85 - 87	2.9 – 8.0	2.65 – 3.5

4. Conclusion

The inorganic-based matrix, such as cement or ECC bonded well with the concrete material, no debonding failure between concrete core and confinement layer was observed.

1) The confining technique was verified to be effective in improving the load carrying capacity of concrete columns.
2) ECC confined specimens have more compressive strength compared to textile reinforced ECC and the tensile strength of textile reinforced ECC is higher than ECC confined columns.
3) ECC or basalt fiber textile reinforced ECC has a potential to confine circular columns with considerable improvement in load carrying capacity.
4) Maximum confined strength was provided by the specimens confined by ECC.ECC confined specimens have more compressive strength compared to textile reinforced ECC and the tensile strength of textile reinforced ECC is higher than ECC confined columns.

Future scope

ECC is an effective material which can be used as a confinement material for strengthening of structures. It can also be used0 for strengthening of damaged structures i.e., for repairing damaged structures such as cracks in dams, cracks in columns of structures, covering of eroded layers of roads and etc.,

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