A Literature Review on Engineered Cementitious Composites for Structural Applications

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***Abstract*-This paper presents facts about various research activities that are taking place around the world since the last one decade on development and study of behaviour of Engineered Cementitious Composites (ECC) using Polyvinyl Alcohol (PVA) fiber. Engineered Cementitious Composites can be designed based on micromechanical model with strain capacity of about 3 to 5% compared to 0.01% of normal concrete. The volume fraction of the fiber is less than 2 percent which shows extensive strain hardening behaviour of the composites.**

Keywords- ECC, PVA fibers, Micromechanics

1.0 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 green house 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 green house 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 the world of materials engineering, raw ingredients are shaped into a composite material through processing. Traditionally, raw ingredient selection is based on empiricism. In recent years, composite materials are systematically being designed. One such material is "Engineered Cementitious Composite (ECC)." Micromechanics can be a powerful tool to deliberately tailor the composite ingredients, such as fiber dimensions and surface coatings along with sand particle amount and size. In addition, knowledge of material processing and its effect on both fresh and hardened properties aid in composite design.

Engineered Cementitious Composite commonly known as ECC, developed in the last decade may prove a safer, more durable, and sustainable concrete material which is environmental 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 behaviour of strain hardening is attracting its potentiality in structural applications. It has wide applications and scope in various fields of Civil Engineering.

2.0 SCOPE AND BACKGROUND

Concrete is the most important construction materials used worldwide. Historically, structural designers have primarily relied on concrete to carry compressive loads. However, in real field conditions, concrete is also subjected to tensile stresses due to loading and environmental effects including shrinkage, chemical attacks and thermal effects. The tensile strength of concrete is only 10% of its compressive strength. The main shortcoming of the concrete is its brittle nature and as a result of its brittle nature cracking, damage and deterioration occurs and it requires repeated maintenance of the structural members [8].

High-strength concrete performs well under pure compression loading. However, many structures experience flexural and shear loading that invariably introduces tensile stresses into the material. In dynamic loading, compressive stress waves travelling through the thickness of a concrete element and approaching a free surface would reflect back as a tensile wave that results in high velocity debris ejected on the back side of the structure. No amount of steel reinforcement can prevent this type of failure mode involving concrete spalling and fragmentation since the reinforcement always require a concrete cover [13].

The conventional concrete will be subjected to a greater pressure before it breaks. A team lead by Victor Li has developed a new type of flexible concrete that bends under such pressure and can repair itself. The self-healing concrete develops many hairline fractures when bent, distributing the pressure over its area. The tiny cracks will seal themselves with calcium carbonate when exposed to rainwater and carbon dioxide. Professor Victor Li named this new flexible concrete as Bendable Concrete or ECC. It is a relatively new material with a number of benefits; including high ductility under uniaxial tensile loading and improved durability due to intrinsically tight crack width and also finds widespread use across the country since 2005 [10].

ECCs are a unique class of new generation high performance fiber-reinforced cementitious composites (HPFRCC) featuring high ductility and medium fiber content. Tensile strain capacity at a range of 3 to 5% has been demonstrated in ECC materials using polyethylene fibers and PVA fibers with fiber volume fraction not greater than 2% [4]. Self healing of cracked concrete is an often-studied phenomenon. Two strategies for the promotion of self-healing have proven promising. One approach focuses on the embedment of capsules that contain self-healing compounds within the concrete material, while the other relies on a continuous dispersion of self healing compounds intrinsic to the concrete matrix. The latter often referred to as autogenous healing as reported by Yingzi Yang [12].

It is like if you get a small cut on your hand, your body can heal itself. But if you have a large wound, your body needs help and it might need stitches etc. We have created a material with such tiny crack widths that it takes care of the healing by itself. Even if you overload it, the cracks stay small. "The flexible concrete bends but doesn't break." This was reported by Victor Li and Benjamin Wylie. [16] Within the community of Concrete Technology, stronger structures have been constructed during the last few decades with the development of high strength concrete of compressive strength up to 120 MPa. However, when a certain level of compressive strength is reached, the failure of structural elements will be dominated by brittle fracture in tension. This perceptive has lead to an expansion and development of concrete materials with high tensile ductility.

The concept of Integrated Structures and Materials Design (ISMD) combines the advantages of Materials Engineering with Structural Engineering for the purpose of better performance of the structures in respect of its safety and durability. Tensile strain capacities, micro-crack widths, self-healing of cracks are some of the parameters which govern the structural performance in terms of safety and durability. Cracking in concrete is a result of the combined effect of mechanical loading and environmental exposure. The presence of cracks in concrete not only causes distress but also reduces the resistance to penetration of aggressive agents like chlorides. Concentrated chloride exposure is one of the severe and aggressive environmental exposures which will be seen in coastal areas. Serious concrete deterioration has been reported and the general cause was noted to be cracks in concrete, which lead to the corrosion of steel reinforcement and subsequent spalling of the concrete. In addition to increased tensile strength, the tight micro-cracks of ECCs will prevent the ingress of water and other aggressive chemicals which helps in better performance of the structure in total [1].

Unlike concrete and conventional fiber-reinforced concrete (FRC) which shows unloading after matrix first cracking, ECC exhibits tensile-strain hardening behaviour achieved by sequential development of matrix multiple cracking. The tensile ductility of ECC is several hundred times that of normal concrete and crack width in ECC is self controlled and reaches a constant value (~60µm) after 1% elongation. It has been reported that ECC has lower water permeability and lower effective chloride diffusivity in the presence of micro-cracks when compared with cracked concrete in which the crack width is not self controlled and is usually in the range of several hundred micrometer to several millimeter [5].

While explaining the motivations for developing bendable concrete, Li reveals, it was a response to many of the major concerns we face every day in the Society. The things like climate change, infrastructure is experiencing more and more loads from extreme weather conditions. The concerns about environmental sustainability relating to the high energy and carbon dioxide emissions of producing cement. The production of cement is responsible for 5% of global greenhouse gas emission [3]. The infrastructure in many of the countries is not being in great shape and of course the economic crisis. All these problems make Society to go for alternate better materials for construction as reported by Victor Li.

3.0 OBJECTIVES

1 To investigate the ingredients of Engineered Cementitious composites (ECCs)
2 To investigate the Mix Design of ECCs
3 To investigate the wet properties of the ECCs
4 To investigate the strain hardening behaviour of the ECCs
5 To investigate the applications of the ECCs

4.0 INGREDIENTS OF ECC CONCRETE

ECC mix involves the uses of Cement, Fly ash, fine aggregates, High Range Water Reducers (HRWR), Polyvinyl Alcohol Fibers and water. Generally, coarse aggregates are not used in the mix design.

4.1 Cement: Portland cements are commonly characterized by their physical properties for quality control purposes. Some of the important physical properties are fineness, compressive strength, initial setting time and soundness.

Physical Properties

a. Fineness

Fineness or particle size of Portland cement affects hydration rate and thus the rate of strength gain. The smaller the particle size, greater will be the surface area-to-volume ratio. Thus, more area is available for water-cement interaction per unit volume. When the cement particles are coarser, hydration starts from the surface of the cement particle and leaves behind the unhydrate portion of the cement at its core. So the coarser particles may not be completely hydrated. This causes low strength and low durability. For high strength and high durability, high fineness is required. 33 Grade OPC (IS 269 – 1989), 43 Grade OPC (IS – 1989), 53 Grade (IS-12269-1987) are being used by the various Researchers.

b. Compressive Strength

The strengths can be affected by a number of factors like water cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, curing conditions, size and shape of specimen, loading conditions and age.

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Cement mortar strength is not directly related to concrete strength. Strength tests are done on cement mortars (cement + water + sand). The cement mortar consists of 1 part of cement, 3 parts standard sand and P/4 of water by weight. Where, P is the Normal consistency of the cement paste. Normal consistency is the water content of the cement paste and is expressed as a percentage by weight of dry cement. The value of P is usually varies between 26 percent and 33 percent. 33 Grade, 43 Grade and 53 Grade represent the compressive strength of the mortar cubes of 7 cm in MPa (N/mm^2) at the age 28 Days.

c. Setting Time

Cement paste setting time is affected by a number of factors like cement fineness, water-cement ratio, chemical content (especially gypsum content) and admixtures. Setting tests are used to characterize how a particular cement paste sets. Normally, two setting times are defined. They are

1. Initial set: Occurs when the paste begins to stiffen considerably.
2. Final set: Occurs when the cement has hardened to the point at which it can sustain some load. Setting is mainly caused by Tricalcium Aluminates (C_3A) and Tricalcium Silicate (C_3S)

d. *Soundness*

When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed expansion. Soundness is also defined as the volume stability of the cement paste. This expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). The cement paste should not undergo large changes in volume after it has set. However, when excessive amounts of free CaO or MgO are present in the cement, these oxides can slowly hydrate and cause expansion of the hardened cement paste. The expansion of the cement paste for Portland cement is limited to 10 mm as indicated by Le Chatelier's apparatus.

4.2 Fine aggregates (sand)

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.

4.3 Fly ash

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.

4.4 Polyvinyl Alcohol (PVA) fibers

PVA fibers possess similar characteristics as that 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 40 GPa. 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 ($CaOH_2$) 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 makes $CaOH_2$ layer.

4.5 Water

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.

4.6 Super-plasticizer

This is 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 superplasticizer 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 Superplasticizer and Polycarboxylate Ether (PCE) based Superplasticizer are being used to assess their effectiveness in improving durability.

5.0 UNIQUE PROPERTIES OF ECC

Important unique properties of ECC as reported by Victor Li are as listed below [17].

- Able to bend like a metal, non-brittle and up to 40 % lighter.
- 500 times more resistant to cracking.
- Reduces or eliminates steel reinforcement.
- Minimizes maintenance cost and reduces environmental impacts.
- Faster precast or on-site construction.

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6.0 APPLICATIONS OF ECC

ECC has found use in a number of large-scale applications in Japan, Korea, Switzerland, Australia and the U.S [18]. A few important applications are as reported below.

- The Mitaka Dam near Hiroshima was repaired using ECC in 2003. The surface of the then 60-year old dam was severely damaged, showing evidence of cracks, spalling, and some water leakage. A 20 mm-thick layer of ECC was applied by spraying over the 600 m^2 surface area.
- In addition during 2003, an earth retaining wall in Gifu, Japan, was repaired using ECC. Ordinary Portland cement could not be used due to the severity of the cracking in the original structure, which would have caused reflective cracking. ECC was intended to minimize this danger; after one year only micro cracks of tolerable width were observed.
- The 95 m Glorio roppongi high-rise apartment building in Tokyo contains a total of 54 ECC coupling beams (2 per storey) intended to mitigate earthquake damage. The properties of ECC give it superior properties in seismic resistance applications when compared to ordinary Portland cement. Similar structures include the 41-storey Nabeaure Yokohama Tower (4 coupling beams per floor).
- The 1 km long Mihara Bridge in Hokkaido, Japan was opened to traffic in 2005. The steel-reinforced road bed contains nearly 800 m^3 of ECC material. The tensile ductility and tight crack control behavior of ECC led to a 40% reduction in material used during construction.
- Similarly, a 225-mm thick ECC bridge deck on Interstate 94 in Michigan was completed in 2005, 30 m^3 of material was used, Both the University of Michigan and the Michigan Department of Transportation are monitoring the bridge in an attempt to verify the theoretical superior durability of ECC; after 4 years of monitoring, performance remained undiminished.

7.0 EXPERIMENTAL INVESTIGATIONS ON ECC

The mix design for ECC Concrete is based on Micromechanics design. The principle of Micromechanics is applied at the material constituent level which has a striking mechanical interaction among the fiber, mortar matrix, and fiber–matrix interface. Typically, fibers are of the order of millimeters in length and tens of microns in diameter and they may have a surface coating on the nanometer scale. The lengths of the PVA fibers used by various researchers vary between 8 mm and 12 mm. The diameter of the PVA fiber is 40µm. The ideal mix proportion given in the literature of ECC determines the proportion of various constituents in the concrete.

The tests on concrete are carried out to assess the various wet properties as well as hardened properties. The usual tests to assess the wet properties are Slump Test and Compaction factor test. The tests on hardened property include Crushing test on cube specimens,

Sabaa & Ravindrarajah (1999) had mentioned that workability is a very important property of concrete which will affect the rate of placement & the degree of compaction of concrete. Cement Association of Canada (2003) stated that the workability is the ease of placing, combining & finishing freshly concrete mixed and the degree to which it resists segregation. It is also mentioned in IS 7320-1974 that a slump less than 25mm will indicate a very stiff concrete and a slump more than 125mm will indicate a very runny concrete. [15]

En-Hua Yang et.al, in their study included four factors like Class C Fly ash ratio to Class F Fly ash ratio, water to binder ratio, amount of High-range water reducer and amount of Viscosity Modifying Admixture to investigate the composition effects on fresh and hardened properties of ECC. Among the four factors, water to binder ratio has the greatest effect on Plastic Viscosity. The plastic viscosity of fresh ECC has a significant impact on ECC tensile properties. The tensile strain and ultimate tensile strength of ECC were found to increase with the increase of plastic viscosity [7].

Dr. A. W. Dhawale and Mrs. V. P. Joshi in their research paper reported that Melamine based super plasticizer is the best plasticizer and hence chosen for the research work. Super plasticizer used was Melamine Formaldehyde Sulphonate. In the initial mix proportion workability was not achieved. Hence for second trial, the mix proportion was changed with PVA fiber percentage increased to 1.2% and water to cementitious material ratio was increased to 0.3048. In the third trial mix proportion plasticizer dosage was reduced to 600 ml/bag and water to cementitious material ratio was 0.33. For the forth trial mix proportion, super-plasticizer dosage of 600 ml/bag along with water to cementitious material of ratio 0.3118 was used. To achieve workability various trials were taken. However in order to increase the workability of concrete the water to cementitious ratio was increased to 0.35 for the subsequent trials [15]. The Mix Proportions of the research are shown in the Table 1.

The mixing of ECC concrete was carried out by using hand mixing. The procedure of hand mixing was as follows. Add sand, cement, 50% fly ash & 50% of water & superplasticizer. Add slowly remaining quantity of fly ash, water and superplasticizer. Once the homogeneous mixture is formed add the PVA fibers slowly. Mix all the constituents till the fibers are homogeneously mixed in the matrix

Table 1: Mix proportion

Sample	Mix proportion					
	Cement (PC)	Sand (FA)	Fly ash	HRWRA ml/bag	Fiber %	w/b*
Initial Mix	1.0	0.8004	1.1996	1040.47	1.0	0.2740
Second trial	1.0	0.9000	1.1000	1040.47	1.2	0.3048
Third trial	1.0	1.0000	1.0000	0600.00	1.2	0.3300
Fourth trial	1.0	0.9000	1.1000	0600.00	1.2	0.3118
*: Weight ratio of water-binder (cement + fly ash) material						

Mustafa Sahmaran and Victor Li in their investigation have given out the following materials and mix proportions for the following two ECC mixtures with Fly ash to Portland cement (FA/PC) of 1.2 and 2.2 by weight. This ratio was used in their investigation [9]. The ECC mixtures were prepared in a standard mortar mixer at a constant amount of cementitious material and constant water to cementitious material ratio of 0.27. High Range water Reducer was added to the mixture until the desired ECC characteristics in its fresh state were visually observed. The cement used was Ordinary Portland Cement and Fly ash used was Class F Fly ash. The PVA fibers of tensile strength 1620 Mpa and Elastic Modulus of 42.8 GPa were used in the mix proportion. The materials and mix proportion are shown in the Table 2.

Table 2: Materials and Mix proportion

Sample	Components, Kg/m^3							
	Cement (PC)	Sand (FA)	Fly ash	HRWRA	Water	Fiber	w/b*	FA/PC
ECC1	570	455	684	4.9	331	26	0.27	1.2
ECC2	386	448	847	3.7	327	26	0.27	2.2
*: Weight ratio of water-binder (cement + fly ash) material								

Crushing Test

From the above mix proportions, the observed compressive strengths at 7 days, 28 days and 90 days for ECC1 mix were 38.1 MPa, 50.2 MPa and 55.4 MPa respectively. Similarly for ECC2 Mix, observed values were 21.6 MPa, 36.3 MPa and 41.9MPa respectively.

Uniaxial Tensile Test and exposure to marine environments

After 28days of curing, the coupon specimens were pre-loaded to direct tensile strain before exposure to Sodium Chloride (NaCl) solution. For a preloading tensile strain of 0.5%, 1.0% and 1.5% the observed average crack widths were 36 µm, 44 µm and 50 µm for ECC1 and for ECC2, the observed values were 24 µm, 30 µm, and 28 µm respectively. The widths of cracks were measured using the Optical microscope.

Mustafa Sahmaran, Mohammed Lachemi and Victor C Li in their investigation have given out the following materials and mix proportions for the two mixtures, one with PVA fibers and another without PVA fibers [8]. The mix proportions are shown in the Table 3.

Table3: Mix proportions

Sample	Ingredients, Kg/m^3						
	Cement (PC)	Sand (FA)	Fly ash	HRWRA	Water	Fiber	FA/PC
ECC with PVA fiber	558	446	669	2.3	326	26	1.2
ECC without PVA fiber	558	446	669	2.3	326	---	1.2
*: Weight ratio of water-binder (cement + fly ash) material							

Crushing Test

From the above mix proportions, the observed compressive strengths at 14days, and 28 days for ECC with PVA mix were 39.2 Mpa and 62.5 MPa respectively. Similarly for ECC Mix without PVA fibers, observed values were 36.1 Mpa and 60.3 respectively.

Uniaxial Tensile Testing

The ECC with PVA fibers exhibited a strain capacity of 2.7% at 28 days with a tensile strength of 5.1Mpa and the residual crack width observed was 48µm.

Mustafa Sahmaran et.al in their study on ECC with PVA fibers of Nominal strength of 1620 Mpa, Young's Modulus of 42.8 GPa, Diameter 39µm and Length of 8mm have come out with the following mixture properties [6].

1. 7-day Compressive strength of 38.1 Mpa
2. 28-day Compressive strength of 50.2 Mpa
3. 7-day Tensile strain capacity of 3.48 %
4. 28-day Tensile strain capacity of 3.16 %
5. Corrosion mass loss of 2.5% at the end of 25 hours of accelerated corrosion exposure.
6. Corrosion mass loss of 5.3% at the end of 50 hours of accelerated corrosion exposure
7. Corrosion mass loss of 11.7% at the end of 75 hours of accelerated corrosion exposure

Li-Li Kan et.al., in their study on Self-healing characterization of Engineered Cementitious composite materials have come out with the following results [11]. The mix proportions are shown in the Table 4.

Table 4: Materials Composition

Sample	Components, Weight %						
	Cement	Sand	Fly ash	HRWRA	Water	Fiber	w/b*
ECC	27	22	33	0.4	16	1.3	0.267
*: Weight ratio of water-binder (cement + fly ash) material							

Uniaxial Tensile Testing and Self-healing product characterization

After preloading, specimens were subjected to wet-dry cycles consisting of submerging the ECC specimens in water at 20ºC for 24 hours followed by drying the specimens in air at 20ºC for 24 hours. For a preloading tensile strain of 0.3%, 0.5%, 1.0% and 2.0% at 90 days, the observed average crack widths were 14 µm, 13 µm, 15 µm and 18 µm respectively. The widths of cracks were measured using the Optical microscope.

Mo Li and Victor C Li in their study, incorporated 4 mm polystyrene beads in the preparation of High Early Strength Engineered Cementitious Composites (HES-ECC), to form a weak bond with the cementitious matrix to behave as an artificial flaw under tension. They were deliberately introduced into the mixture to control the initial flaw size and distribution to achieve a high density of microcracks during strain hardening stage and improve tensile ductility. The mix proportion of HES-ECC and the various properties are shown in the following tables [14]. Table 5 shows the Mix Proportions and Table 6 shows the Research Results.

Table 5: Mix proportion

Material	Cement	WATER	Sand	CA*	HRWRA	Fiber	AC**
HES-ECC	1.0	0.33	1.0	0.064	0.0075	0.02	0.04
CA*: Polystyrene beads as coarse aggregates							
AC**: Accelerating Admixture							

Table 6: Research Results

Age	Compressive strength (Mpa)	Young's modulus (Mpa)	Tensile strength (Mpa)	Tensile strain capacity (%)	Flexural strength/Modulus of rupture (Mpa)	Deflection at failure (mm)
7 days	47.5	20.6×10^3	5.56	3.52	13.55	9.91
28 days	55.6	23.2×10^3	5.68	3.47	15.08	9.91
60 days	56.8	23.8×10^3	5.79	3.52	-	-

M. Li and Victor C. Li in their study on three different repair materials have concluded that the concrete specimens show brittle nature, Steel Fiber Reinforced Concrete (SFRC) specimens show quasi-brittle nature. However, Engineered Cementitious Composites (ECC) exhibit ductile characteristics. The repair materials composition and properties at 28 days are shown in Table 7. The Young's Modulus of ECC is lower than the Concrete and SFRC because of the absence of coarse aggregates in its
Composition [2].

Table 7: Materials Composition and Properties at 28 days

Material	C	W	S	FA	CA	SP	V_f	ϵ_u	f_c (Mpa)	E (GPa)	Tensile Behaviour
Concrete	1.0	0.4	1.3	0	1.3	0.01	0	0.01	60	26	Brittle
SFRC	1.0	0.4	1.3	0	1.3	0.01	0.01	0.01	63	26	Quasi-brittle
ECC	1.0	0.53	0.8	1.2	0	0.03	0.02	3~5	62	20	Ductile
C: Cement; W: Water; S: Sand; FA: Fly ash; CA: Coarse Aggregates; SP: Super Plasticizer; V_f : Volume fraction of the fibers; ϵ_u: Tensile Strain Capacity; f_c: Compressive strength; E: Young's Modulus											

CONCLUSION

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 green house effect and global warming. Hence, it is inevitable either to search for another material or partly replace it by an alternate material. The various investigations carried out by several authors related to the development of Engineered Cementitious Composite (ECC) and its applications in the real field proves to be one of the best alternative and sustainable concrete materials of the future decades.

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