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Ductile Concrete Using Engineered Cementitious Composites

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Abstract- This paper deals to improve conventional property of normal concrete. Ductile property of normal concrete can be improved by using PVA fibers in place of coarse aggregate and cement partially replaced by fly ash. For these purpose concrete cubes, cylinders, beams and slabs are experimentally investigated. This paper also focuses on significant pattern of cracks developed during testing of specimens. The micro-crack pattern of this concrete shows the ductile behavior of bendable concrete. The result is a moderately low fiber volume fraction (<2%) composite which shows extensive strain-hardening with strain capacity of about 3 to 5% compared to 0.01% of normal concrete.

Keywords Engineered cementitious composite ,ECC, ECC Concrete , PVA FIBERS.

1. Introduction

Concrete consisting of cement, water, fine and coarse aggregates are widely used in civil engineering constructions. Though making concrete is convenient and inexpensive, its brittle behaviour upon tensile loading is one of its undesirable characteristics so that leads to the development of fiber reinforced cementitious composites to improve this deficient. The brittle behaviour of concrete is due to the fast growing of single crack consequences to the sudden failure of the specimen. This kind of failure mode is resulted from a low ultimate strain around 0.01% and a sudden failure without warning. In order to improve the behavior of concrete, fiber reinforced concrete is made by adding discrete short fibers into the concrete matrix. Fibers which are currently used include steel, glass, carbon and polymer fibers. Development of FRCs started in the 1 970s. By that time, only glass fiber and steel fiber were investigated. During the past 10 years, polyvinyl alcohol (PVA) fiber has been introduced in the production of FRC, resulting to a new composite, which exhibits a pseudo ductile behaviour similar to that of steel and is called ñengineered cementitious compositesò.

ECC developed in the last decade, may contribute to safer, more durable, and sustainable concrete infra-structure that is cost-effective and constructed with conventional construction equipment. With two percent by volume of short fibers, ECC has been prepared in ready-mix plants and transported to construction sites using conventional ready-mix trucks.

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 plate yielding. Extensive inelastic deformation in ECC is achieved via multiple micro-cracks, with widths limited below 60εm (about half the diameter of a human hair). This inelastic deformation, although different from dislocation movement, is analogous to plastic yielding in ductile metals such that the material undergoes distributed damage throughout the yield zone. The tensile strain capacity of ECC can reach 3-5%, compared to 0.01% for normal concrete. Structural designers have found the damage tolerance and inherent tight crack width control of ECC attractive in recent full-scale structural applications. The compressive strength of ECC is similar to that of normal to high strength concrete .The aim of research work is to study ductile behavior of concrete, crack resistance capacity & concrete should give warning before its failure. Normal concrete is brittle in nature while ECC is ductile in nature, due to this property; it has wide applications & wide future scope in various fields. The Figure1.Shows the typical behavior of ECC-ECC Concrete.

The development of fiber reinforced concrte material has undergoes a number of phases. In the 1960, research by romualdi and cowoekers(Romualdi and Batson, 1963; Romualdi and Mandel,1964) demonstrate the effectivenesss of short steel fibers in reducing the brittleness of concrete. This development has continued with expansion to a variety of other fibers such as glass, carbon, synthetics, natural fibers and in recent years hybrids that combine either different fiber types or fiber lengths. The continuously enhanced knowledge of fiber reinforcedment effectiveness has resulted in structural design recommendations by RILEM TC 162-TDF (Vandewalle et al., 2003)

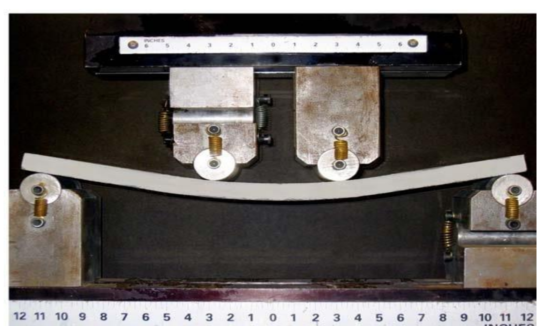

Figure1. Bendable Concrete

2. Objective

1..To check tensile strength and compression strength of ECC bendable concrete.
2. To study behavior of ECC bendable concrete under flexure
3. To check the ductility of the concrete
4. To study the effect of sand, super plasticizer & PVA fibers on the behavior of ECC-Bendable concrete.

3. Ingredients Of Ecc Concrete

ECC Concrete is homogenous mixture of Cement, sand, fly ash, water, an optimal amount of fibers and small amount of admixtures . In the mix coarse aggregates are deliberately not used because property of ECC Concrete is formation of micro cracks with large deflection. Coarse aggregates increases crack width which is contradictory to the property of ECC Concrete.

3.1 Cement

Ordinary Portland cement (OPC) ï 53 grade (Ultratech Cement) was use.

3.2 Sand [Fineaggregate]

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. soil containing more than 85% sand-sized particles.. Sand is used ingredients of mortar and concrete and for polishing and sandblasting. The weight varies from 1,538 to 1,842 kg/m^3, depending on the composition and size of grain. The fine aggregate obtained from river bed of Koel, clear from all sorts of organic impurities was used in this experimental program. The fine aggregate was passing through 4.75 mm sieve and had a specific gravity of 2.68. The grading zone of fine aggregate was zone III as per Indian Standard speciýcations.

3.3. Fly Ash

Fly ash used was pozzocrete dirk 60. In RCC construction utilization of fly ash has been prosperous in reducing heat generation without loss of strength, and providing supplemental fines for compaction.

3.4. Super Plasticizer

Super plasticizer used is Melamine Formaldehyde Sulphonate. This is utilized to control rheological properties of fresh concrete.

Table No 1 Properties of super plastisizers

Brand Name	SUPERCON 100
Color	White
Solid Content	20%
PH	8-8.5%
Viscosity	10-12 cps

3.5 PVA Fibers

PVA (PolyVinylAlcohol) fiber has high strength and modulus of elasticity (25 to 40 Gpa) compared to other general organic fiber which widely used for cement reinforcing. Fiber elongation is about 6-10%. The tensile strength of fiber is 880-1600 Mpa

Table No 2 Specification of PVA Fibers

Type	Alcoholysis %	ASH %	pH Value	Viscosity, mPas	Sodium Acetate %	Volatiles
17-99	99.8	2.8	7-10	22-28.9	6.8	7.0
05-99	99.5	.7	5-7	5-6	2.1	7.0
20-99	99.5	0.7	7.0	46-50	2.1	7.0
22-99	99.5	0.7	7.0	51-56	2.1	7.0
2499	99.5	0.7	7.0	56	2.1	7.0

One of the remarkable characteristics of PVA fiber is strong bonding with cement matrix. The layer of $Ca(OH)_2$ called ITZ(Interfacial transition zone) round PVA fiber is formed as white part, and in case of PP, this layer is not observed. It is known that PVA is easy to make complex cluster with metal hydroxide. It is assumed that Ca+ and OH- ions in cement slurry are attracted by PVA and makes $Ca(OH)_2$layer. It seems reasonable to think that $Ca(OH)_2$ layer plays important role for bonding strength. Figure 2.shows images of surface for coarse PVA fiber after single fiber pull-out test. This image implies that surface of PVA fiber is peeled by $Ca(OH)_2$ layer and this phenomena is related to strong bonding between PVA fiber and cement matrix.

Figure2. PVA Fiber

3.6 Water

Potable Water is suited for concrete mix. Water should be free from acids, oils, alkalis, vegetables or other organic Impurities. Soft waters also affect on strength of concrete.

4. Ecc Mix Design

The mix design of grade M25 was used. The mix design for ECC Concrete is basically based on Micromechanics design basis. 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. However itô s based on pull test to be carried on the PVA fibers, which is not possible in the laboratory. Hence the ideal mix proportion given in the literature of ECC-ECC Concrete was used as the guidelines to determine the proportion of various constituents in the concrete.

Sr. no.	Mix Design	No. of Cubes
01	1:0.8004:1.1996 PAV-1% Superplastisizer-1040.47 ml/bag Water/cement ratio-.3048	6
02	1:0.9:1.1 PAV- 1.2% Superplastisizer- 1040.47 ml/bag Water/cement ratio-.3048	6
03	1:1:1 PAV- 1.2% Superplastisizer- 600 ml/bag Water/cement ratio-.33	6
04	1:0.9:1.1 PAV- 1.2% Superplastisizer- 600 ml/bag Water/cement ratio-.3118	6

5. Casting of ECC bendable concrete

Once the mix design was finalized, the mixing was carried out. The mixing of bendable concrete was carried out by using hand mixing. Add sand, cement, 50% of fly ash & 50% water &super plasticizer. Add slowly remaining quantity of fly ash, water &super plasticizer. Once the homogenous mixture is formed, add the PVA fibers slowly. Mix all the constituents till the fibers are homogenously mixed in the matrix.

During the placing of fresh concrete into the moulds, tamping was done using Tamping rod. After placing the concrete into the moulds, vibrations were done using a table vibrator. After vibration operation, the leveling of concrete was done on the surface of the concrete. Leveling is the initial operation carried out after the concrete has been placed & compacted.

6. Curing Of Concrete Specimen

After leaving the fresh concrete in the moulds to set overnight, the concrete specimens in the moulds were stripping. The identification of concrete specimens was done. After 24 hours, all the concrete specimens were placed into the curing tank with a controlled temperature of 25 ^{0}C in further for 28 days for the hardened properties test of concrete.

7. Testing Of Concrete

This deals with Tests and testing procedure for fresh & hardened concrete specimen. Investigations are carried out by testing cubes, beams, slabs and cylinders for 7, 21, 28 days. Cubes and cylinders were tested on Compression Testing Machine (CTM) and beams and slabs were tested on Universal Testing Machine (UTM).

7.1.Workability Test Of Fresh Concrete

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 & the degree to which it resists segregation.

Slump test is used to determine the workability of fresh concrete.The apparatus & equipment used for the slump test & the procedure of the test according to IS 7320-1974

7.2 Testing On Hardened Concrete Specimens

The testing for the strength if concrete is very important in the civil works.. There are compression test, split tensile test and flexural test conducted on hardened concrete. All the procedure used was according to the Indian Standard Code.

7.2.1 CRUSHING TEST- [TEST ON CUBES]

Compression test is the most common test used to test the hardened concrete specimens because the testing is easy to make. The specimens used in compression test were the cube of 150×150×150 mm.

Apparatus and test Procedure of compression testThe apparatus and equipments used in compression test were according to IS: 509-1959 and is shown in figure

Figure3. Compression Test

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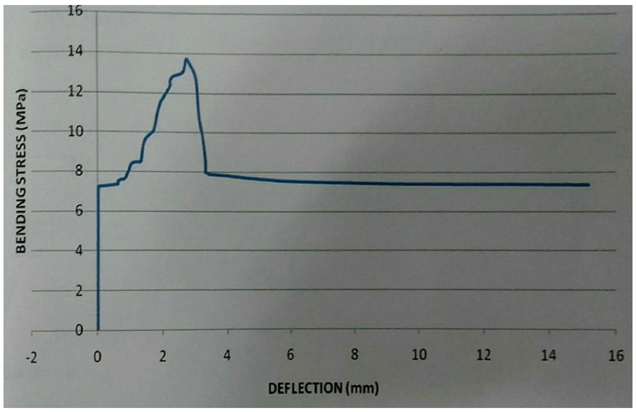
7.2.2 Flexure Test- [Test On Beams]

The flexural strength test was carried out on UTM on the beam specimen

Three specimens shall be tested each at the end of three and seven days. If the line of rupture occurs in the middle third, the modulus of rupture is given by equation.

$F_{cr} =$ [illegible]

In case line of rupture lies outside the middle third at a



distance ‘a’ from the support up then modulus of rupture is given by

$F_{cr} =$ [illegible]

The Graph1Show the behavior of ECC Concrete in flexure.

Graph No 1: Bending stress Vs Deflection

From the graph it is clear upto 7 Mpa the beam does not undergo any deflection. Once the bending stress of 7.5 Mpa is reached the specimen starts undergo deflection. But the increase in deflection with the stress is very less until the max. bending stress of 13.9 Mpa is reached. After which the bending stress goes on decreasing due to decrease in load carrying capacity such that the bending stress 8 Mpa is reached after which at constant bending stress the specimen undergoes excessive deflection(15mm) until the specimen fails

Figure4. Flexural behavior of Beam

7.2.3. Split Tensile Test [Test On Cylinders]

The split tensile test was carried out on the cylinder at the age of 7 & 28 days respectively using CTM. Apparatus and Test Procedure of Indirect Tensile Test The following apparatus and equipments used in the indirect tensile test are according to IS : 5861-1970.

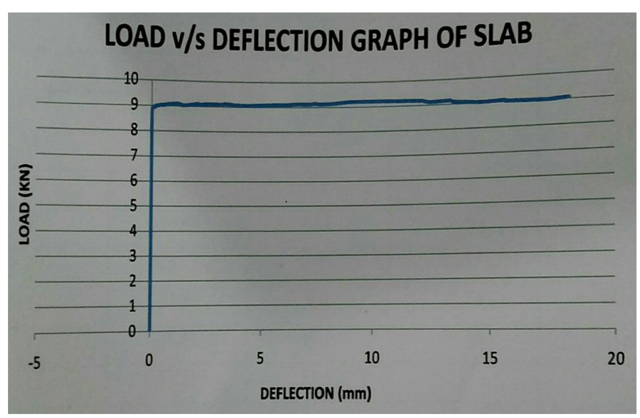
The no. of cylinders casted for conventional as well as ECC Concrete is 9.The 6 cylinders were tested for Split tensile test.

Figure 5. Split Tensile Test

7.2.4 Two point Bending Test On Slab

ECC bendable concrete is characterizes by the bending property i.e. high curvature bebore actual bending. In order to investigate this bending property two point bending test was carried out on the slab of thickness 20mm.

The load deflection graph of slab shows that up to 90. kN the slab does not undergo any deflection. At 9.0 Kn the crack is developed at the bottom face of the slab, after which the load remains nearly constant with slight variation but the slab undergoes excessively deflection up to 18.2 mm after which the slab fails.



The Graph 2: Load Vs Deflection of Slab

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Figure 6. Deflected Shape of Slab Under Two point Bending

8. Conclusion

According to test results, the beam is withstanding high load and a large deformation without succumbing to the brittle fracture typical of normal concrete, even without the use of steel reinforcement.

Conventional concrete is brittle in nature where as ECC has an appreciable ductility. Flexurle strength of ECC is 60% more than convential concrete, though compressive strength of ECC and convential concrete is nearly same.

Split tensile strength of ECC is about 32% more than conventional concrete.

The cost of ECC is nearly two to three times that of conventional concrete per cubic yard which depends on availability of fibers, fly ash. However initial construction cost savin can be achieved through smaller structural member size, reduced or eliminated reinforcement elimination of other structural protective system. The advantages offered by ECC over conventional concrete become even more compelling.

Also use of fly ash leads to less environmental impact because disposal of fly ash is serious issue, hence Eco Friendly

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