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Experimental Investigation Of Engineered Cementitious Composite

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Abstract: Traditional concrete is considered a ceramic, brittle and rigid. It can suffer catastrophic failure when strained in an earthquake or by routine overuse. ECC acts more like metal than glass and also more flexible than conventional concrete. In order to achieve the unique properties of strain hardening in traditional concrete, it is studded with specially-coated reinforcing fibers that hold it together which will give a new class of ultra-ductile fiber reinforced cementitious composites developed for applications in the large material volume usage, cost sensitive construction industry. Traditional concrete fractures and can't carry a load at 0.01 % tensile strain but ECC remains intact and safe to use at tensile strains up to 5%. This study suggests the need for developing a new class of FRCs which has the strain-hardening property. It is demonstrated that Engineered Cementitious Composites can be designed based on micromechanical properties with strain hardening capacity of about 3 to 5% compared to 0.01% of normal concrete. The main objective of this study is to increase the tensile properties of flexural member with the application of Poly Vinyl Alcohol (PVA) fibres of moderately low fiber volume fraction about 2% composite which shows extensive strain-hardening.

Keywords: Engineered cementitious composite, PVA fibres, micromechanics, strain hardening

I. INTRODUCTION

This study presents current scenario about various active research that are taking place around the world on study of behavior of Engineered Cementitious Composites (ECC) by incorporating Polyvinyl Alcohol (PVA) and other kinds fibers and by using various mineral ad-mixtures. Engineered Cementitious Composites is mainly designed based on paradigm of micro-mechanical interaction with exceptional strain capacity of about 3 to 5% compared to 0.01% of normal concrete. The volume fraction of the fiber used is also less than 2 percent and showing an extensive strain hardening behaviour of the composites.

NEED FOR STUDY

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 behaviour, resulting in interfacial zone modification techniques so as to design desired properties. Fiber ruptures in ECC are prevented and pull-out of fiber from matrix is achieved by the use of suitable mineral admixtures. Thus Polyvinyl alcohol (PVA) fibre tends to rupture instead of pull-out in a cementitious matrix due to the strong chemical bonding to cement hydrates and the slip-hardening response during pull-out. In order to achieve strain-hardening behaviour at the composite level, the micromechanical models suggest that the bond should be lowered to an optimal range.

OBJECTIVE OF STUDY

The objectives of this study are:

- ✓ To determine the effect of Engineered Cementitious Composite in flexural members with and without polymer fibre under static loading.
- ✓ To optimize the amount of fibre used for Engineered Cementitious Composite.
- ✓ To compare the strength of concrete mix with and without fibre.

SCOPE OF THE STUDY

ECC acts more like metal than glass and more flexible than traditional concrete. Traditional concrete is considered a ceramic, brittle and rigid. It can suffer catastrophic failure when strained in an earthquake or by routine overuse. It is studded with specially-coated reinforcing fibers that hold it together. ECC remains intact and safe to use at tensile strains up to 5%. Traditional concrete fractures and can't carry a load at 0.01 % tensile strain. Today, builders reinforce concrete structures with steel bars to keep cracks as small as possible. But they're not small enough to heal, so water and deicing salts can penetrate to the steel, causing corrosion that further weakens the structure.

II. LITERATURE REVIEW

Victor C Li et al. (2012) carried out experimental study to improve the fibre distribution by adjusting the mixing sequence. With the standard mixing sequence, fibres are added after all solid and liquid materials are mixed. The undesirable plastic viscosity before the fibre addition may cause poor fibre distribution and results in poor hardened properties. With the adjusted mixing sequence, the mix of solid materials with the liquid material is divided into two steps and the addition of fibres is between the two steps. In this paper, the influence of different water mixing sequences was investigated by comparing the experimental results of the uniaxial tensile test and the fibre distribution analysis. The result was concluded that compared with the standard mixing sequence, the adjusted mixing sequence increases the tensile strain capacity and ultimate tensile strength of ECC and improves the fibre distribution.

Yu Zhu et al. (2012) carried out an experimental study to develop a kind of green ECC with high tensile ductility and strong enough matrix strength, especially at early age. A series of investigations was carried out to evaluate mechanical properties and drying shrinkage of ECC with 70% combination mineral admixtures of flyash and ground granulated blast furnace slag. Four ECC mixtures with constant W/B of 0.25 are prepared with combined inclusion of fly ash and SL as constant cement replacement level of 70%. The laboratory measurements are carried out, including direct tensile test, four-point bending test, and compressive strength and drying shrinkage. The experimental results show that ECC with combination mineral admixtures can achieve strain hardening behaviour, tensile capacity of ECC can be more than 2.5% at 90 days. Meanwhile, compared to ECC only with fly ash, slag and fly ash can effectively increase compressive strength of ECC, especially at early age. Incorporating SL into matrix can slightly increase drying shrinkage of ECC. However, among four ECC mixtures, ECC with 30% SL and 40% FA presents the lowest drying shrinkage at later ages.

Jun Zhang et al. (2013) carried out an experimental study on the potential applications of the fibre reinforced engineered cementitious composite with characteristic of low drying shrinkage (LSECC) in concrete pavements for the purpose of eliminating joints that are normally used to accommodate temperature and shrinkage deformation. It was found that a composite slab containing both plain concrete and LSECC, with steel bars at the LSECC/concrete interface, and designed construction procedures, it is possible to localize the tensile cracks into the LSECC strip instead of cracking in adjacent concrete slab. The crucial problem that interfacial failure in composite slab was prevented by using reinforcing bars across the interfaces. Due to the strain-hardening and high strain capacity of the LSECC, the overall strain capacity and the integrity of the composite slab can be significantly improved. The temperature and shrinkage deformations can be accommodated by adequate selection on the length ratio of LSECC strip and concrete slab.

Yu Zhu et al. (2014) carried out experimental study to investigate the mechanical properties of ECC produced by high volume mineral admixtures which are fly ash, slag and silica fumes. Emphasis of this study is placed on building the correlation between compressive strength and the parameters obtained in load–deflection curves of 12 different ECC mixtures in binary and ternary system of binder materials with different mineral admixtures (FA, SL and silica fume) and to build the correlation between compressive strength and durability of ECC. The water-binder materials ratio (W/B) is kept at 0.25 for various ECC mixtures. The replacement levels of different mineral admixtures in all ECCs in binary systems of binder materials are 50%, 60%, 70% and 80%, respectively (FA + cement and SL + cement). In ternary system (FA + SL + cement and FA + SF + cement), the total replacement of mineral admixtures is 70%, the ratios of FA/SL and FA/SF are different in ECC mixture proportions. The toughness behaviour and compressive strength of 12 different ECC mixtures are firstly measured by four point bending test and compressive strength test, respectively. The results indicate that the compressive strength has an inverse relationship with deflection, toughness index and fracture energy, respectively; but the compressive strength have an direct proportional relation with flexural strength, first cracking load, and peaking load, respectively. Additionally, in the binary system of binder materials, the ductility of ECC can be obviously improved by introducing high volume fly ash and slag replacing the cement, respectively. However, the compressive strength of ECC with fly ash and slag can reduce 40% and 14%, respectively. For the ternary system of binder materials with replacement 70% of cement, the combination of fly ash and slag can keep not only the excellent ductility of ECC, but also enough stronger matrix strength. Meanwhile, the combination of fly ash and silica fume only increase the compressive strength, but weaken the toughness of ECC.

Tahir Kemal Erdem (2014) carried out experimental work to study size effect on the residual properties of ECC was investigated on the specimens exposed to high temperatures up to 800°C. Cylindrical specimens having different sizes were produced with a standard ECC mixture. Changes in pore structure, residual Compressive strength and stress–strain curves due to high temperatures were determined after air cooling. Standard ECC mixture (M45) with a fly ash-cement ratio (FA/C) of 1.2 by mass was used in this investigation which was prepared in a standard mortar mixer at water to cementitious material ratio of 0.27. Experimental results indicate that despite the increase of specimen size, no explosive spalling occurred in any of the specimens during the high temperature exposure. Increasing the specimen size and exposure temperature decreased the compressive strength and stiffness. Percent reduction in compressive strength and stiffness due to high temperature was similar for all specimen sizes.

III. MATERIALS

CEMENT

Ordinary Portland Cement (OPC) is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and plaster. It consists of a mixture of oxides of calcium, silicon and aluminium. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay and grinding this product (called clinkers) with a source of sulphate (most commonly gypsum). The ordinary Portland cement is classified into three grades. There are 33, 43 and 53 grade cement depending upon the strength of the cement at 28 days. We have used Cement used in the investigation was 53 grade ordinary Portland cement.

Figure 1: Ordinary Portland Cement

Test	Result	As per IS 4031-1998
Consistency	120/300	-
Initial setting time	40 minutes	Not less than 30 min.
Specific gravity	3.11	3.15

Table 1: Properties of OPC

FINE AGGREGATE

Fine aggregate is the inert or chemically inactive material, most of which passes through a 4.75 mm IS sieve and contains not more than 5 per cent coarser material. They may be classified as follows:

- ✓ Natural sand: Fine aggregate resulting from the natural disintegration of rocks and which has been deposited by streams or glacial agencies.
- ✓ Crushed stone sand: Fine aggregate produced by crushing of hard stone.
- ✓ Crushed gravel sand: Fine aggregate produced by crushing of natural gravel.

The fine aggregates serve the purpose of filling all the open spaces in between the coarse particles. Thus, it reduces the porosity of the final mass and considerably increases its strength. Usually, natural river sand is used as a fine aggregate. However, at places, where natural sand is not available economically, finely crushed stone may be used as a fine aggregate.

Figure 2: Fine aggregate

Test	Result	As per IS 4031-1998
Fineness Modulus	3.07	Grading zone II
Specific Gravity	2.61	2.6-2.8

Table 2: Properties of Fine Aggregate

COARSE AGGREGATE

Construction aggregate, or simply "aggregate", is a broad category of coarse particulate material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geo-synthetic aggregates. Aggregates are the most mined material in the world. Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. Due to the relatively high hydraulic conductivity, values are compared to moist soils. Maximum coarse aggregate size used is 20 mm and the minimum coarse aggregate size used is 12 mm.

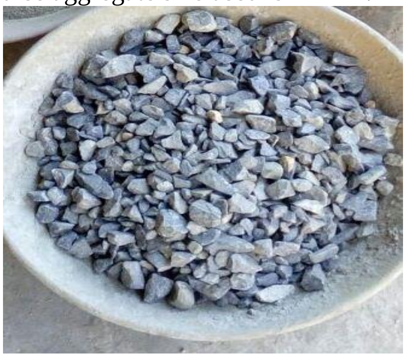

Figure 3: Coarse aggregate

Test	Result	As per IS 4031-1998
Specific Gravity	2.78	2.6-2.85
Fineness Modulus	7.3	6.5-8

Table 3: Properties of Coarse Aggregate

WATER

Potable water was used in the experimental work for both mixing purposes. It is the key ingredient, which when mixed with cement, forms a paste that binds the aggregate together. The water causes the hardening of concrete through a process called hydration. Hydration is a chemical reaction in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products. The role of water is important because the water to cement ratio is the most critical factor in the production of 'perfect' concrete. Too much water reduces concrete strength, while too little will make the concrete unworkable. Water cement ratio of 0.45 is adopted for this study.

SUPERPLASTICIZER

The superplasticizer used for casting the beam to reduce the water content and to increase the workability is Varaplast SP50. It is a chloride free, Superplasticising admixture based on selected synthetic polymers. It is supplied as a brown solution which is instantly dispersible in water. It can provide very high level of water reduction and hence major increase in strength can be obtained coupled with good retention of workability to aid placement. These can provide self-leveling concrete practically eliminating the need for vibration during placing. Water reduction by using Varaplast SP50 gives higher strengths without cement increase or workability loss which reduces porosity giving improved water impermeability. Specific Gravity of Superplasticizer is 1.22 at 25° C. Optimum level for the application of Varaplast SP50 is 0.50 - 1.0 litres/100 kg cementitious material for flowing concrete and 0.80 - 1.50 litres/100 kg cementitious material for high strength concrete.

POLY VINYL ALCOHOL FIBER

The high performance fiber reinforced cementitious composite is characterized by the presence of fibers in a less quantity compared to FRC. Generally the fiber used in ECC is PVA, One of the remarkable characteristics of this fiber is capable of strong bonding with cement matrix. The layer of $Ca(OH)_2$ called as Interfacial transition zone is formed round PVA fiber and is formed as white part, and in case of poly propylene, and glass it is not observed . It is known PVA makes complex cluster with the metal hydroxide of cement matrix.

REINFORCING STEEL

The steel reinforcement which have been used is of grade Fe500 strength. Main reinforcement has 10mm diameter whereas stirrups has 6mm diameter bars. Stirrups of 6mm diameter has been placed in 100 mm spacing. Design of steel reinforcement follows IS 456 recommendation.

Figure 4: Reinforcing Steel

IV. MIX DESIGN

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour.

STIPULATIONS FOR CONCRETE MIX PROPORTIONING

Grade designation - M_{30}
Type of cement - OPC 53 grade
Maximum nominal size of aggregate - 20mm
Minimum Cement content - 310 kg/m^2
Maximum free water content ratio - 0.45
Exposure condition - Normal
Placing condition - Heavily reinforced section
Degree of workability - medium
Slump - 50(mm)
Degree of supervision - Good
Type of aggregate - Crushed angular aggregate

TEST DATA FOR MATERIALS

Cement used - OPC53 grade confirming IS12269
Specific gravity of cement - 3.11
Specific gravity of fine aggregate - 2.61
Specific gravity of coarse aggregate - 2.78

MIX PROPORTIONS FOR TRIAL 1

Cement - 380 kg/m^3
Water - 160 litre or 160 kg/m^3

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Fine aggregate - 707.77 kg/m^3
Coarse aggregate -1232.374 kg/m^3
W/C ratio - 0.45

V. EXPERIMENTAL PROGRAMME

CASTING

Castings of the specimens were done after preparation of materials and weighing of materials. Beam were casted on mould of size of 500mm x 100mm x 100mm. For casting of reinforced and plain beam, the required number of steel bars were cut from the bundle and kept ready. The required cover to the reinforcement was provided. The beam mould was filled with concrete in three layers. The concrete was well compacted with the help of tamping rod. All specimens were moist cured by placing it in water tank for 28 days.

Figure 5: Casting of Beam

TYPES OF BEAM	CEMENT (kg/m^3)	AGGREGATE (kg/m^3)		WATER (litres)
		FINE	COARSE	
CONVENTIONAL BEAM	380	747.9	1220.4	160
ECC BEAM WITH FIBRE WEIGHT OF 2%	372.4	747.9	1220.4	160

Table 4: Concrete Mixture Design

SPECIMEN DETAILS	Nos	WEIGHT (kg)
CONVENTIONAL REINFORCED BEAM	2	11.625
REINFORCED ECC BEAM	2	11.528

Table 5: Details of specimens casted

CURING

Curing is the maintenance of a satisfactory moisture content and temperature in concrete for a period of time immediately following placing and finishing so that the desired properties may develop. The need for adequate curing of concrete cannot be overemphasized. Curing has strong influence on the properties of hardened concrete, proper curing will increase durability, strength, water-tightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicers. Exposed slab surfaces are especially sensitive to curing as strength development and freeze-thaw resistance of the top surface of a slab can be reduced significantly when curing is defective. When Portland cement is mixed with water, a chemical reaction called hydration takes place. The extent to which this reaction is completed influences the strength and durability of the concrete. Freshly mixed concrete normally contains more water than is required for hydration of the cement. However, excessive loss of water by evaporation can delay or prevent adequate hydration.

The surface is particularly susceptible to insufficient hydration because it dries first. If temperatures are favorable, hydration is relatively rapid the first few days after concrete is placed. It is important for water to be retained in the concrete during this period, that is, for evaporation to be prevented or substantially reduced. With proper curing, concrete becomes stronger, more impermeable, and more resistant to stress, abrasion, and freezing and thawing. The improvement is rapid at early ages but continues more slowly thereafter for an indefinite period. The strength of concrete gains with age for different moist curing periods and the relative strength gains of concrete cured at different temperatures.

Figure 6: Curing of beam

TESTING PROCEDURE

Concrete is quite strong in compression and weak in tension. Hence in most of the design of concrete structures its tensile strength is ignored. However at certain situations like water retaining and pre stressed concrete structures the tensile strength of concrete is essential requirement. A direct application of pure tensile stress is difficult. An indirect way is adopted by measuring the flexure strength of beam.

The flexural Testing was performed for seven days and twenty eight days curing. Before testing, the beams were white washed to obtain the clear picture of cracks under different stages of loading. The dimension of each specimen should be noted before the testing. The specimen shall then be placed in a machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould. The specimen shall be supported on 40 mm diameter roller with 400 mm span for 100 mm size specimen.

The load shall be applied through two similar rollers mounted at the third points of the supporting span that is spaced at 200 mm or 133 mm c/c. The spacing of the two load

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application points at top of specimen is 200 mm for a specimen size of 150 mm x150 mm x 700 mm and or 130 mm for 100 mm x 100 mm x 500 mm. The axis of the specimen shall be carefully aligned with the axis of loading device. The load is applied without shock at a rate of 4 KN/minute for 150 mm specimen and 1.8 KN/minute for 100 mm specimen. The load shall be increased until the specimen fails and the maximum load applied to the specimen during the test shall be recorded.

Figure 7: Flexure testing machine

Figure 8: Dial Gauge

VI. RESULTS AND DISCUSSIONS

Flexural members with and without fibers were tested in Flexural testing machine with two point loading. Specimens showed some flexural failure and support failure. In view of the results so far achieved, fiber incorporated beam have their flexural capacities were good enough to use. It has moderately low fiber volume fraction of about 2% PVA Fibers which is randomly oriented in the mix. ECC beam have lesser dead weight due to replacement of the cement with PVA fibers of about 0.8%.

The strain capacity of ECC beam under service load was a higher than those of an equivalent conventional beam. The result shows extensive strain-hardening in ECC beam, with strain capacity of about 3 to 5% compared to 0.01% of conventional concrete. The property of very strong compression yet comparably weak tensile nature of cement concrete resulted in development of Engineered Cementitious Composite due to the property of strain hardening. It has resulted in unique and distinctive properties of self-healing, high, tensile strength and ductility where tensile strength is almost 500 times that of standard concrete.

If the line of rupture occurs in the middle third, the modulus of rupture is given by

$$F_{cr} = \frac{PL}{bd^2}$$

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

$$F_{cr} = \frac{3P \times a}{bd^2}$$

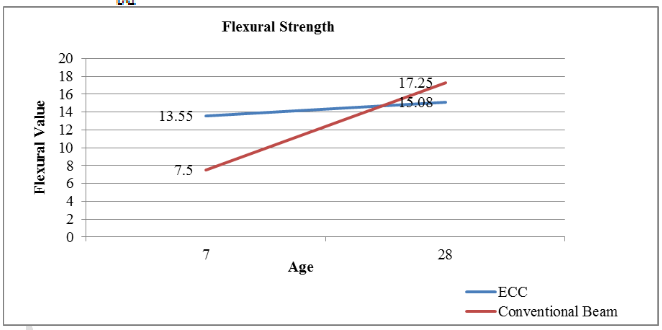

Figure 9: Flexural Strength vs Age

The graph depicts the flexural behavior of conventional and ECC beam at different ages. This shows almost same flexural capacity for both the beam. Flexural load testing was carried out to know the failure pattern of the structural beam. Conventional beam shows load failure at 28 days i.e., the line of rupture lies within the middle third of the span of the beam. But, all other beam shows support failure i.e., the line of rupture lies outside the middle third of the span.

Conventional beam shows less flexural strength initially but its value eventually increases towards 28 days testing. The ECC beam depicts gradual increase in flexural strength starting from 7 day to 28 days.

VII. CONCLUSION

This study deals with the structural performance of flexural beam with and without Polyvinyl Alcohol Fibers has been carried out and mix design has been formulated as per IS code recommendation. Experimental investigation of Flexural beam has been carried out in flexural testing machine and the following conclusion has been drawn out.

- ✓ Due to the fact, that the structural behavior of this new class of fibre reinforced concrete casted flexural member reveals high strain hardening behavior in comparison with conventional beam.
- ✓ The result is a moderately low fiber volume fraction of about 2% composite which shows extensive strain-hardening, with strain capacity of about 3 to 5% compared to 0.01% of normal concrete.
- ✓ The beam is withstanding high load and a large deformation without succumbing to the brittle fracture typical of normal concrete.

- ✓ Due to the property of very strong in compression yet comparably weak in tensile nature of cement concrete resulted in development of Engineered Cementitious Composite.
- ✓ It has resulted in unique and distinctive properties of self-healing, high, tensile strength and ductility where tensile strength is almost 500 times that of standard concrete.
- ✓ This technology is very prospective in modern construction and perhaps future of civil engineering belongs to this new kind of concrete.

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