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Strengthening of PCC Beam Using ECC

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Abstract **—** An experimental study carried out on the flexural behaviour of plain cement concrete. This present experimental investigations deals with the comparison study of normal PCC beams and strengthening of PCC beams by Near Surface Mounting (NSM) technique using Engineered Cementitious Composite (ECC) and the validation of results with FEM model using ANSYS. A total of ten PCC beams are casted and are tested under a two point loading. The test specimen has an overall depth (D) of 0.2m, width (b) of 0.1m, span (L) 0.7m and an effective span (L_{eff}) of 0.6m. Two point static loads were applied to the specimen and displacements are measured to collapse of the specimen. The structural responses of PCC beams are primarily dependent on the degree of the interruption of the natural load path. Also respective load vs. deflection graphs are drawn and compared. The strength gain caused by the ECC strengthened PCC beams are to be compared with the normal PCC beam. From the study it was found that the specimen with externally bonded ECC was found very effective in upgrading the flexural strength of PCC beams.

Key words - *PCC*, ECC, Flexural strengthening

1. Introduction

Plain Cement Concrete is a construction material generally used as binding materials. PCC is concrete without reinforcement or reinforced only for shrinkage or temperature changes. PCC possesses a high compressive strength and is not subjected to corrosive and weathering effects. PCC can be easily handled and moulded into any shape. The term plain concrete is used to describe any concrete mass used without any strengthening materials. PCC is a material used to build a wide range of structures, ranging from residential homes to bridges.

Plain concrete is a non-homogeneous mixture of coarse aggregate, sand and hydrated cement paste. The physical properties of plain concrete are very similar to stone and include the ability to withstand great pressure. Plain concrete beams are inefficient as flexural members because the tensile strength in bending (modulus of rupture) is a small fraction of the compressive strength. As a consequence, such beams fail on the tension side at low loads long before the strength of the concrete on the compression side has been fully utilized.

In terms of material constituents, ECC utilizes similar ingredients as fibre reinforced concrete (FRC). It contains water, cement, sand, fibre, and some common chemical additives. Coarse aggregates are not used as they tend to adversely affect the unique ductile behaviour of the composite. A typical composition employs w/c ratio and sand/cement ratio of 0.5 or lower. Unlike some high performance FRC, ECC does not utilize large amounts of fibre. In general 2% or less by volume of discontinuous fibre is adequate, even though the composite is designed for structural applications. ECC can be regarded as a family of materials with a range of tensile strength and ductility's that can be adjusted depending on the demands of a particular structure.

ECC also represents a family of materials with different functionalities in addition to the common characteristics of high tensile ductility and fine multiple cracking. Self consolidating ECC is designed for large-scale on-site construction applications. High early strength ECC (HES-ECC) is designed for applications which require rapid strength gain such as transportation infrastructure that needs fast reopening to the motorist public.

Light-weight ECC (LW-ECC) is designed for applications where the dead load of structural members must be minimized. Green ECC (G-ECC) is designed to maximize material greenness and infrastructure sustainability. Self-healing ECC (SH-ECC) emphasizes the functionality of recovering transport and mechanical properties after experiencing damage.

ECC using local material ingredients have been successfully produced in various countries, including Japan, Europe, and S. Africa, in addition to the US. To successfully develop local versions of ECC, a good understanding of the underlying design approach is helpful.

"A parametric study on the flexural behavior of plain concrete beams strengthened by externally bonded plates" by R V Balendran, et al., (2001). In this paper an experimental study carried out on the flexural behavior of plain and composite beams are discussed in this paper. The composite beams were composed of plain concrete beams strengthened by Steel or Carbon Fiber Reinforced Plastic (CFRP) plates, externally bonded to their tension faces. The effects of four parameters; namely, plate thickness, beam size, concrete strength and adhesive type on the moment capacity, deflection and failure mode of composite beams were studied. The results of the study showed that the moment capacity and stiffness of the beams increased through plate bonding. Those bonded with CFRP plates performed better than the corresponding beams bonded with steel plates, in terms of moment capacity and stiffness. It was also found that plate thickness and beam size had significant impact on the flexural strength, stiffness and failure mode of composite beams. However, the effect of concrete grade and adhesive type on these properties was generally less significant.

"Experimental Evaluation of Retrofitted Concrete Beams Using CFRP and GFRP" by P. Polu Raju, et al., (2001). This paper discussed about Upgraded loading requirements; damage by accidents and environmental conditions, rectification of initial design flaws, change of usage can be achieved by retrofitting. The solutions adopted are generally based on successful prior practice. It is necessary to take a decision whether to demolish a distressed structure or to restore the same for effective load carrying system. Many a times, the level of distress is such that with minimum restoration measure the building structure can be brought back to its normalcy and in such situation, retrofitting is preferred. One of the techniques of strengthening of the RC structural members is through confinement with a composite enclosure. FRP material, which are available in the form of sheet, are being used to strengthen a variety of RC elements to enhance the flexural, shear, and axial load carrying capacity of these elements. The proposed technique consists of applying Glass Fiber Reinforced polymer (GFRP) & Carbon Fiber Reinforced polymer (CFRP) to the bottom surface and sides of the concrete beam (PCC & RCC) to increase its stiffness and flexural strength. This study clearly demonstrated the effectiveness of the proposed technique in retrofitting of reinforced concrete beam.

"Engineered Cementitious Composites for Structural Applications" by Dr. A. W. Dhawale et al. This paper suggests the need for developing a new class of FRCs which has the strain-hardening property but which can be processed with conventional equipment. It is demonstrated that such a material, termed engineered cementitious composites or ECCs, can be designed based on micromechanical with strain capacity of about 3 to 5% compared to 0.01% of normal concrete. The result is a moderately low fiber volume fraction (<2%) composite which shows extensive strain-hardening.

"Engineered Cementitious Composite for repair of Initially cracked concrete beams" by A.M. Anwar et al. This paper discussed about the current research addresses engineered Cementitious Composites (ECC) as a new alternative for retrofitting demaged concrete beams.Twenty one plain concrete beams with pre-defined artificial cracks were prepared and repaired using different combinations of Ecc alone or together with carbon Fiber Reinforced Polymers (CFRP) .The study showed that replacement ot the inferior layer from the bottom of the deteriorated beams with a thin layer of ECC could be able to restore the beam to a condition better than its original state.Moreover,the repair with ECC was found effective in enchancing the member ductlity as well.It was also shown that pasting CFRP directly over ECC substrate resulted in shear failure rather than the undesirable interfacial debonding mode of failure that typically occurs in case of concrete substrates.

2. OBJECTIVES

The objectives of the project are in the form of the following things:

- To increase the load carrying capacity of PCC beam by using ECC.
- To increase the flexural strength and ductility of plain cement concrete.
- To evaluate the performance of strengthened plain cement beams by using engineered cement composites.
- To reduce ultimate deformation under shear failure mode.

3. EXPERIMENTAL INVESTIGATION

3.1 MATERIAL TESTING

Material testing was conducted to investigate the properties of the materials such as cement, fine aggregate and coarse aggregate which are used for casting the specimens. Various laboratory tests were performed and the test results obtained were compared with the Indian Standard values. The test results are tabulated below.

Table 1 Properties of Material

S.no	Name of Test	Experimental value	Codal value
1	Specific gravity of cement	3.14	IS:4031(Part3)1988 Range-3.15
2	Standard consistency of cement	32%	IS:4031(Part-4)-1988 Penetration 5-7mm
3	Initial setting time of cement	35 min	IS 12269-1987 Not < than 30 mins clause 5.3
4	Final setting time of cement	425 min	IS 12269-1987 Not >than 600mins clause 5.3
5	Average Compressive strength test of cement mortar cube 28days	54 N/mm^2	Not < 53 N/mm^2 as per IS 12269 – 1987
6	Specific gravity of F.A	2.66	IS: 2386(Part-3)1963. Range(2.6-2.7)
7	Sieve analysis of F.A	FM=2.78	IS:2386(Part-1)1963 Medium sand 2.6-2.9
8	Water absorption test on F.A	0.917%	IS:2386(Part-3)1963 Range < 2%
9	Specific gravity test for C.A	2.66	IS:2386(Part-3)1963 Range-2.6-2.85
10	Water absorption test for C.A	0.4%	IS:2386(Part-3)1963 Range-0.4-0.5%

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11	Sieve analysis of C.A	FM=7.51	IS:2386(Part-1)1963
12	Impact test of C.A	7.1%	IS:2386(Part-4)1963 Range-7-12.5%

3.2 PROPORTIES OF FRESH AND HARDENED CONCRETE

The properties of the fresh and hardened concrete are being found in order to find the slump value, flow percentage, compressive strength and split tensile strength of the concrete for the M30 grade of concrete for which the mix design ratio is being calculated. The results have been tabulated below.

Table 2 Properties of fresh concrete

S.No	Properties	Concrete
1	Slump value	1.77
2	Flow percentage	2.64%

Table 3Compressive strength results in N/mm^2

Specimen	Control concrete	
	7days	28days
1	23.46	31.77
2	24.35	32.22
3	22.88	30.88
Average	**23.56**	**31.62**

Table 4 Split tensile strength results in N/mm^2

Specimen	Control concrete	
	7days	28days
1	2.36	4.13
2	2.44	4.21
3	2.64	4.17
Average	**2.48**	**4.17**

4. PLAIN CEMENT CONCRETE BEAM

The size of the PCC beam being adopted is of length (l) 0.7m, depth (d) 0.2m and width (b) 0.1m. The details are represented in fig.1. The PCC beams are being casted and tested under the static loading condition. The beams are to be strengthened using ECC.Strengthened beams are to be tested under the static loading condition. The strengthening of beams done by NSM technique by various dimension.

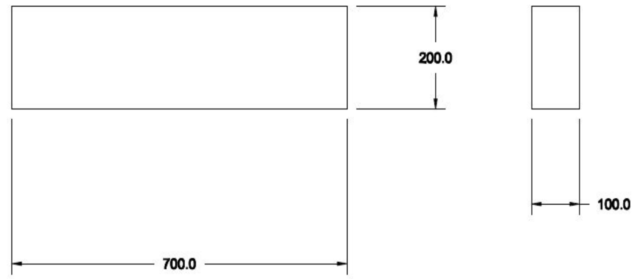

FIG 1 PCC BEAM

5. STRENGTHENING MATERIAL

Engineered cementitious composites

Constituents of ECC

- OPC 53 grade
- Fly ash
- Silica sand
- PVA fiber
- Super plasticizer
- Water

5.1 OPC 53 GRADE CEMENT

53 grades OPC is a higher strength cement to meet the needs of the consumer for higher strength concrete. As per BIS requirements the minimum 28 days compressive strength of 53 grade OPC should not be less than 53Mpa.For certain specialized works, such as pre-stressed concrete and certain items of precast concrete requiring consistently high strength concrete, the use of 53 grade OPC is found very useful.53 grade OPC produces higher – grade concrete at very economical cement content. In concrete mix design, for concrete M-20 and above grades a saving of 8 to 10% of cement may be achieved with the use of 53 grade OPC.

Fig 2 OPC 53 grade

5.2 FLY ASH

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash that does not rise is called bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata. Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify rapidly while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 300 µm.

Fig 3 Fly ash

5.3 SILICA SAND

Sand consists of small grains or particles of mineral and rock fragments. Although these grains may be of any mineral composition, the dominant component of sand is the mineral quartz, which is composed of silica (silicon dioxide).Other components may include aluminium,feldspar and iron – bearing minerals. Sand with particularly high silica levels that is used for purposes other than construction is referred to as silica sand or industrial sand. Silica sand is one of the most common varieties of sand found in the world. It is used for a wide range of applications, and can be purchased from various suppliers throughout the world. Silica sand is used in industrial processing, to make glass, as fill, and to create molds and castings.

Fig 4 Silica sand

5.4 PVA FIBRE

PVA fiber has high tensile strength and flexibility ,as well as high oxygen and aroma barrier properties.PVA has a melting point of 230 °C and 180 -190 °C (356 – 374 degrees Fahrenheit) PVA is close to incompressible.the possions ratio has been measured to between 0.42 and 0.48.PVA fibres are very high – performance reinforcement fibers for concrete and mortar.PVA fibers are well suited for a wide variety of applications because of their superior crack-fighting properties,high modulus of elasticity,excellent tensile and molecular bond strength and high resistance to alkali,UV,chemicals,fatigue and abrasion.PVA fibers are unique in their ability to create a molecular bond with mortar and concrete that is 300% greater than other fibers.

Table 3.18 Properties of PVA fibre

PROPRETY	RANGE
Fiber length	12mm
Fiber diameter	0.04mm
Tensile strength	1600Mpa
Elastic modulus	40Gpa
Rupture strain	7%
Aspect ratio	300

Fig 5 PVA fibre

5.5 SUPERPLASTICIZER

GLENIUM B233 is a high performance super plasiticizer based on poly carboxy ether and is an admixture of a new generation based on modified poly carboxylic ether.The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required.

Fig 6 Glenium B233

Table 5 Specimen Details

S.No	WIDTH AND THICKNESS OF ECC
1	20mm and 100mm
2	40mm and 100mm
3	2 strips,20mm and 20mm
4	2 strips,20mm and 40mm
5	2 strips,30mm and 30mm
6	2 strips,40mm and 30mm
7	Single strip ,25mm and 25mm
8	Single strip,50mm and 25mm

5. TESTING PROCEDURE

The PCC beams are tested under the loading frame. The testing procedure for the all the specimen is

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same. First the beams are cured for a period of 28 days and then being tested under the two point loading condition. The load is transmitted through a load cell and the load is being spreader to the beam at two points using a spreader beam. The specimens placed over the two steel rollers bearing leaving 50 mm from the ends of the beam. One dial gauge is used for recording the deflection of the beam and is placed at the centre of the beam. The purpose of this research is to investigate the flexural behaviour of Plain cement concrete beams with strengthened PCC using ECC. The result being obtained is used to produce the load vs deflection curve.

FIG 7 Testing of Beam Specimen

6 CONCLUSIONS

According to the various results of the investigation, the structural application ECC improves the load carrying capacity of PCC beams compared normal PCC beams.The deflection of the beams also increased. Evaluated the performance of strengthened plain cement beams by using engineered cement composites.

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