EXPERIMENTAL STUDY ON THE FLEXURAL BEHAVIOR OF COMPOSITE RC BEAMS HAVING AN ENGINEERED CEMENTITIOUS COMPOSITE LAYER AT THE BOTTOM

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Abstract: The primary aim of this research was to investigate the flexural behavior of composite reinforced concrete (RC) beams having an Engineered Cementitious Composite (ECC) layer at the bottom face. ECC is a mortar based composite reinforced material, which has improved properties of high ductility, tensile and flexural strength. For this purpose, four full scale composite RC-ECC beams and two RC control beams were casted and tested under third point bending in the straining frame. Two different ECC layers having thickness of 75 mm and 100 mm were used to study the effect of layer thickness. After careful test results, the average cracking load for the composite beams was increased by 32% and 70% and the average yield load increased by 11% and 19% for 75 and 100 mm layer of ECC respectively, as compared to RC Control beams. Similarly the average ultimate load for composite beams was found slightly decrease but the individual value was observed more. Furthermore the mid span deflection of the beams was observed to increase at crack load & yield load.

Keywords: ECC, PVA fibers, Fly ash, Deflection, Flexural Behavior

I. INTRODUCTION

Concrete is the most widely used construction material for infrastructure upgradation and development, throughout the world. But the brittleness nature of concrete makes its application limited. The inherent brittleness of concrete contributes to common failure modes such as bond splitting, cover spalling, core-crushing and steel buckling. Besides, the tensile strength of normal concrete is very low. Similarly, common durability problems exist in normal concrete. When cracks are created in normal concrete, it propagates until fractures occurs and water can then easily entered into the concrete to start corrosion of steel bars. Once corrosion get starts, the design life of the structure is reduced significantly. To overcome this deficiency, a lot of research has been carried out to enhance the properties of concrete especially in tension. One such example is the fiber reinforced concrete, in which different fibers (like steel, glass, rubber etc.) are added to enhance its properties [1], [2]. But still in fiber reinforced concrete the fibers used has two drawbacks i.e. lack of ductility and low modulus of elasticity [3], [4].

A significant proportion of current expenditure in the world is directed towards maintenance and upgrading of infrastructures. In Pakistan, such problems are even more serious due to the lack of regular maintenance of structures. In order to overcome these problems, a new material known as Engineered Cementitious Composite (ECC) has been developed by Victor Li in 1993 [5]. Engineered Cementitious Composite, which is also known as a flexible concrete. This is a type of fiber reinforced concrete in which the reinforcement is normally a short hair like fibers known as PVA (polyvinyl alcohol) fibers (Li 1998. 2001, 2003). ECC is normally a mixture of cement, sand, admixture, water and PVA fibers, having no coarse aggregates.

According to the knowledge of the present author, in Pakistan no work has been reported on ECC so far, and with such a wide range of applications in the field, it was highly desired to investigate the behavior of RC beams having an ECC layer at the bottom face through a series of careful experiments. In order to overcome the drawbacks in normal concrete, use of ECC layer at the tension side of RC beam was an economical solution. ECC has improved structural properties such as high ductility, light weight, self-healing, flat steady cracks development, High tenacity, high modulus, high tensile, compression and flexural strengths [6], [7], [8]. It was believed that a small layer (75-100 mm) of ECC will reduce cracking and increase ultimate load in flexure [9], [10], [11], [12], [13].

II. DETAILS EXPERIMENTAL

2.1. Materials Selection

The materials used to produce control concrete and ECC includes Ordinary Portland Cement, Fine aggregate, Coarse aggregate, steel rebar, Fly ash, PVA fibers, High range Water Reducer and water. A variety of tests were performed to determine the properties of these materials before using them in concrete.

2.1.1. Ordinary Portland cement

Ordinary Portland cement was used to prepare all specimens used in the research. Dry process was followed to determine the Fineness modulus of

cement. The fineness modulus was calculated as 4.5%, which is within the permissible limit. ASTM C-184 standard was followed to determine the fineness value of cement.

2.1.2. Fine Aggregate

Locally available fine aggregate was used in the specimen preparation. Sieve analysis of fine aggregate was completed as per ASTM C-136-04. The fineness modulus was calculated as 2.56, which is within the limits. The average grain size found in fine aggregate was 600 µm. Specific gravity of fine aggregate was found by using ASTM C-158. Specific gravity of Fine aggregate was calculated as "2.56".

2.1.3. Coarse Aggregate

Locally available coarse aggregate was used in preparation of all specimens. Sieve analysis was of coarse aggregate was accomplished following ASTM C-136-04. The maximum size was found 19 mm in the coarse aggregate. Bulk density was determined using ASTM C-166 and was calculated as 1631.96 kg/m^3.

2.1.4. Fly Ash

The locally available Type-F fly ash was used. The chemical analysis of the fly ash was performed in PCSIR laboratories Peshawar, the results for which are given in Table-1.

Table 1: Chemical composition of the fly-ash

Parameters	Results %
Silica as SiO_2	60.10
Aluminum as Al_2O_3	24.91
Iron as Fe_2O_3	06.76
Calcium as CaO	07.67
Magnesium as MgO	ND
Loss on Ignition (LOI)	01.03
Total	100.47

2.1.5. PVA Fibers

Polyvinyl alcohol fiber is a type of organic fiber used in the ECC mix. RECS 15x12PVA fibers were selected for the current research study Fig.1. These are fibers are specially manufactured by Kurarey Ltd Japan, for mortar based concrete and is extensively used in the field in Japan and USA.

These fibers have high modulus of elasticity with improved results in flexure. Further detail of the geometric and material properties is given in Table-2 as provided by the manufacturer.

Table 2: Different geometric and material properties of the PVA-fibers

S #	Parameters	Value	SPEC
1	Diameter (dtex)	14.4	15.0 ± 3.0
2	Length (mm)	12.0	12.0 ± 2.5
3	Tensile strength (MPa)	1456	1560 ± 325
4	Elongation (%)	5.7	6.5 ± 1.5

Fig.1. PVA fibers (RECS 15x12) used in ECC

2.1.6. Steel Bars

Deformed bars 13mm diameter were used in for the longitudinal reinforcement of the beams, whereas, 10 mm stirrups were placed @100mm c/c for the shear reinforcement. In order to make sure that beams fail in flexure, low-grade steel (40ksi) was used for longitudinal reinforcement and a high-grade steel of (60 ksi) was used for the shear reinforcement. The samples collected were tested for different tests to conform its properties as per ASTM A-615. The tests were conducted to find yield strength, ultimate strength, and percentage elongation and bend test

2.1.7. High Range Water Reducers

Chemical admixtures (high range water reducers) were used in the mixture of Engineered Cementitious Composite to achieve the desired workability. Therefore, chemrite AG-300 (commonly available high range super plasticizer in brown color) was used for this purpose. It is a third generation admixture normally used in free flowing concrete or self-compacting concrete. It reduced water content up to 25%, which resulted in higher strength. Its recommended dosage for fluid concrete is 1.0 – 2.5 % by weight of cement. After trial mixes on ECC to establish a correct dosage and to get the targeted slump, this admixture was used up to 2.5%. Chemrite AG-300 fulfills ASTM C 1017 standards for concrete admixtures.

2.2. Mix Design

After conducting necessary tests, mix design was done using ACI mix design method. Mix proportion were determined for a compressive strength of 27.59 MPa (4 ksi) control concrete used in control beams as well as composite beams. As per ACI mix design method, ratios for 27.59 MPa (4 ksi) control concrete were found to be 1:2:3 (cement, fine aggregate, coarse aggregate). Similarly, the ratio used for ECC was 1:1.2:0.8:0.78:0.025:0.02 (cement, fly ash, sand, water, HRWR, PVA). The ECC mix used in the research was derived from M-45 mix design [14], which was already used for large scale production in countries like USA and Japan [15], [16]. Trial mixes were prepared to achieve the desired workability of both materials.

The mix proportioning for control concrete and ECC are summarized in the Table-3.

Table 3: Mix proportions for control concrete and ECC (Kg/m^3)

Material	Cement	Fine aggregate	Coarse aggregate	Water	HRWR	Fibers
Control Concrete	387	773	1160	220	0	0
ECC	583	700	467	454	14.58	26

2.3. Specimen Casting

Six full-scale beams were casted; two RC control beams and four RC composite beams. The control concrete was used in control beams. Similarly, two RC composite beams were casted having 75 mm ECC layer thickness at the bottom face, while two RC composite beams were casted having 100 mm ECC layer thickness. The same control concrete were also used in the composite beams above ECC layer. In composite beams concrete was poured over ECC after final setting of ECC which was calculated as four hours. To check the physical properties of concrete and ECC, cylinders and small beams were casted to check compression, split tensile and flexural stresses of the materials. The dimensions for small beams were 750mm length and 150 mmx150 mm cross-section. The beams dimensions and reinforcement details for the full scale beams were adopted as shown in Fig.2.

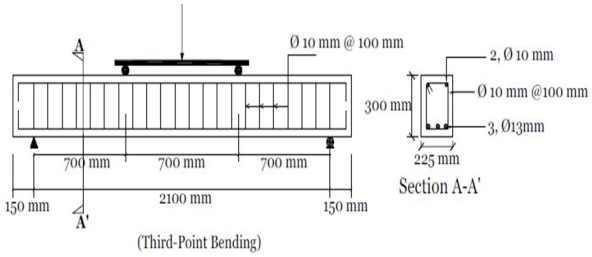


Fig.2. Schematic diagram of full scale tested beams

2.4. Workability Test

In order to check the workability of the mix, slump tests were performed. This was done by as per ASTM C-143 method by taking fresh concrete from the newly mixed batch of concrete. Slump value of 50 mm was noted for control concrete, which was in full compliance with mix design. Similarly, a slump value for ECC was calculated using Hyun-Joon Kong (2003) method. The ECC mortar was poured into the slump cone without any compaction, and the cone was then lifted allowing ECC to spread on the floor as shown in Fig.3. The slump for ECC was then calculated using Eq: (1).

$$\Gamma = (D_1 - D_0) / D_0 \geq 2.75 \qquad (1)$$

Where;

Γ = Deformability factor

D_1 = Average of two orthogonal diameters

D_0 = Diameter of the bottom of slump cone

The value of Deformability factor (Γ) was calculated as 2.76 inches which is within permissible limits.

Material	Cement	Fine aggregate	Coarse aggregate	Water	HRWR	Fibers
Control Concrete	387	773	1160	220	0	0
ECC	583	700	467	454	14.58	26



Fig.3. (a & b) Workability test for concrete and ECC

2.5. Density Test

Density of control concrete and ECC was determined as per ASTM C-138. The density of control concrete and ECC was found to be 2437 kg/m^3 and 2048 kg/m^3 respectively. As shown in Fig.4. due to the absence of coarse aggregate ECC is lighter than normal concrete.

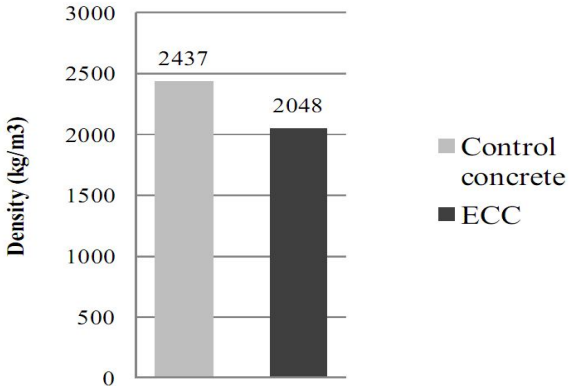


Fig.4. Density of concrete and ECC

2.6. Mechanical properties of concrete and ECC

It was important to know about the mechanical properties of concrete used for the full-scale beams in this research. Therefore, in order to determine the mechanical properties of concrete and ECC, a total of 30 cylinders and 18 small beams were casted. The cylinders and small beams were tested in UTM of 200 tons capacity as shown in Fig.5. The average values obtained for compressive strength, split tensile strength and flexural strength are drawn graphically in Fig.6.



Fig.5. (a, b & c) Compression, Split tensile and flexure test in UTM machine

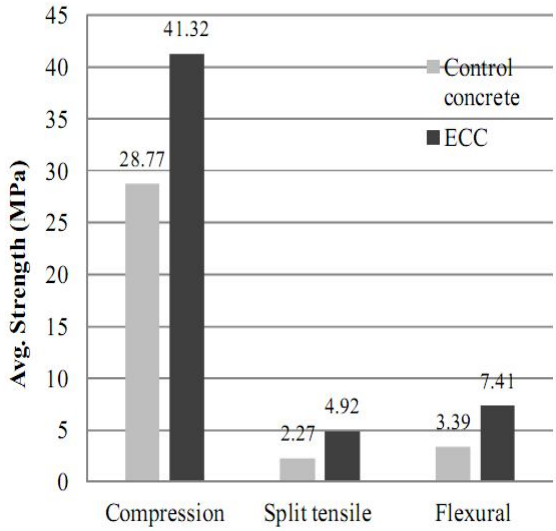


Fig.6. Data presentation for compression, split tensile and flexure strength of materials

III. RESULTS AND DISCUSSION

3.1. Load Deflection Curve

Full-scale beams were tested in straining frame of 200 kN capacity under third point bending as shown in Fig.7. In order to set a benchmark for comparison purposes, initially two reference beams of control concrete were tested. It was found that first crack appeared on 55.19 kN for RC control beam-1 and on 56.12 kN for RC control beam-2. The corresponding deformations were found to be 5.00 mm, 4.68 mm for the two RC Beams. The loading rate was kept slow as 0.017 mm/sec.

The loading rate was kept as slow as possible to study the actual behaviour of beams in flexure. Similarly, the yield load was noted as 107.21 kN for RC Control Beam-1 and 96.20 kN for RC Control Beam-2. The corresponding deformations were found 10.10 mm and 8.50 mm for the two RC Beams respectively. Similarly, the ultimate load was noted as 137.57 kN for RC control beam-1 and 116.71 kN for RC control beam-2. The corresponding deformations were found to be 49.79 mm and 30.07 mm for the two Beams respectively. These results are tabulated in Table-4 and Table-5. The load deflection curves for the two beams are illustrated in Fig.8. and Fig.9.



Fig.7. Full scale beam test set up

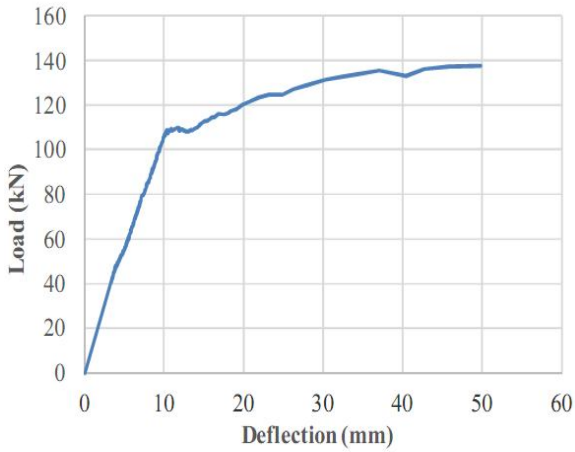


Fig.8. Experimentally obtained load-deflection curve RC control beam-1

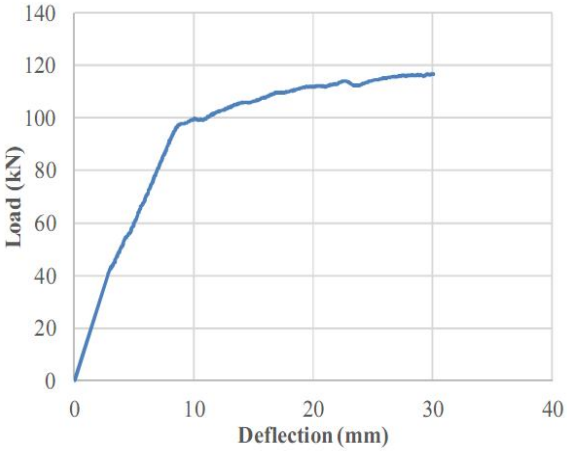


Fig.9. Experimentally obtained load-deflection curve RC control beam-2

In a similar way two RC composite beams having 75 mm ECC layer thickness at the bottom were tested in the straining frame. It was observed that first crack appeared on 74.06 kN for RC-ECC 75 beam-1 and 72.65 kN for RC-ECC 75 beam-2. These cracks were mostly found in the regions where control concrete was used. The corresponding deflections were found to be 6.42 mm and 8.08 mm for the respective two composite Beams. The average value of cracked loads with corresponding deformation in these composite beams was more as compared to RC control beams. At this stage the loading rate was kept the same as in RC control beams. Similarly, the yield load was noted as 118.35 kN for RC-ECC 75 beam-1 and 108.04 kN for RC-ECC 75 beam-2. The corresponding deformations were found to be 10.46 mm and 12 mm. The average values of yield loads with corresponding deformations values were higher as compared to control beams. Similarly, the ultimate load was noted as 127.61 kN for RC-ECC 75 beam-1 and 114.25 kN for RC-ECC 75 beam-2. The corresponding deformations were found 22.32 mm and 23.75 mm. These results are tabulated in Table-4 and Table-5. The load deflection curves for the two beams are illustrated in Fig.10. and Fig.11.

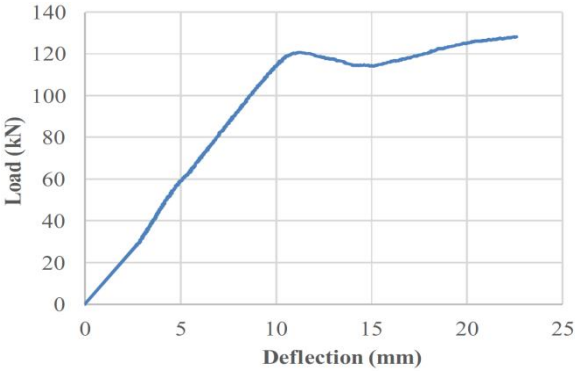


Fig.10. Experimentally obtained load-deflection curve-RC-ECC 75 beam-1

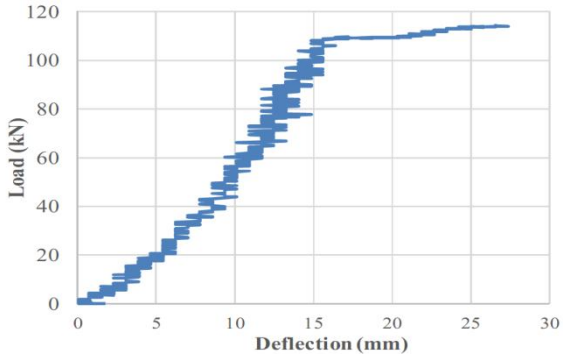


Fig.11. Experimentally obtained load-deflection curve-RC-ECC 75 beam-1

To check the load-deflection behaviour of RC-ECC 100 beams, two beams were casted. It was found that first crack appeared on 94.32 kN for RC-ECC 100 beam-1 and 94.56 kN for RC-ECC 100 beam-2. The corresponding deflection was found 8.92 mm and 9.20 mm for the two composite beams respectively. Similarly, the yield load was noted as 125.73 kN for RC-ECC 100 beam-1 and 115.89 kN for RC-ECC 100 beam-2. The corresponding deflections found 12.24 mm and 12.29 mm for the respective two Beams. Similarly, the ultimate load was noted as 130.65 kN for RC-ECC 100 beam-1 and 120.57 kN for RC-ECC 100 beam-2. The corresponding deflections were found 28.48 mm and 22.02 mm for the two Beams respectively. The results showed that as compared to RC-ECC 75 beams the cracked loads, yield loads and ultimate loads were improved. These results are tabulated in Table-4 and Table-5. The load deflection curves for the two beams are illustrated in Fig.12. and Fig.13.

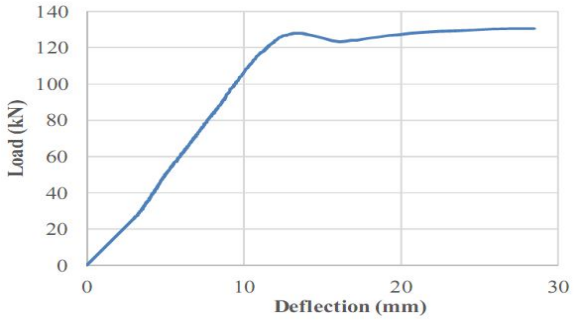


Fig.12. Experimentally obtained load-deflection curve RC-ECC 100 beam-1

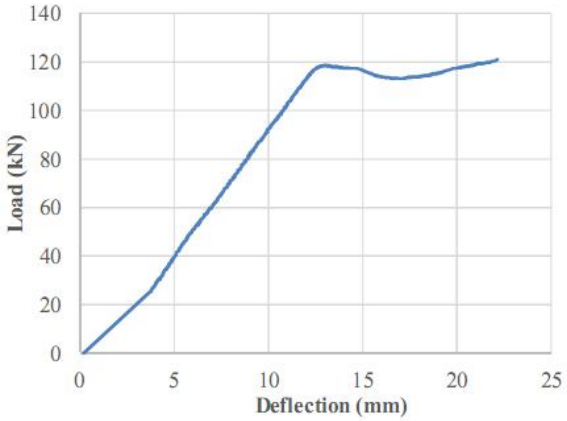


Fig.13. Experimentally obtained load-deflection curve-RC-ECC 100 beam-2

Table 4. Data comparison of cracked, yield and ultimate loads of full scale beams

Beam type	P_{cr} (kN)	P_y (kN)	P_u (kN)
RC Control Beam-1	55.19	107.21	137.57
RC Control Beam-2	56.12	96.20	116.71
RC ECC 75 Beam-1	74.06	118.35	127.61
RC ECC75 Beam-2	72.65	108.04	114.25
RC ECC100 Beam-1	94.32	125.73	130.65
RC ECC100 Beam-2	94.56	115.89	120.57

Table 5. Data comparison of cracked, yield and ultimate deflections of full scale beams

Beam type	Δ_{cr} (mm)	Δ_y (mm)	Δ_u (mm)
RC Control Beam-1	5.00	10.10	49.79
RC Control Beam-2	4.68	8.50	30.07
RC ECC 75 Beam-1	6.42	10.46	22.32
RC ECC75 Beam-2	8.08	12.00	23.75
RC ECC100 Beam-1	8.92	12.24	28.48
RC ECC100 Beam-2	9.20	12.29	22.02

CONCLUSIONS

A variety of conclusions were drawn from the current study after carefully analyzing test results. The average cracked load was found to increase with increasing thickness of ECC layer at the bottom face. As compared to control RC beams, an average increase of 32% and 70% was observed in first cracked load for layer thickness of 75 mm and 100 mm layer respectively. Similarly, the yield load was also found to increase by 11% and 19% for RC-ECC 75 and RC-ECC 100 respectively. Further, the ultimate load of RC composite beams was decreased 5% & 1% for 75 mm and 100 mm ECC layer respectively. However, the individual values of ultimate load for RC-ECC 75 beam-1 and RC-ECC 100 beam-1 was increased 9% and 12% with reference to RC control beam-2. Thus the load

carrying capacity of the beams was observed to increase with the addition of ECC layer at the bottom. LDTs were mounted to find mid span deflection at yield point. It was found that average value of mid span deflection for RC-ECC 75 beam and RC-ECC 100 beam increased up to 21% and 32% as compared to RC Control beams.

Similarly, the average value of mid span deflection was determined for ultimate point and the average value of mid span deflection for RC-ECC 75 beam and RC-ECC 100 beam was found to decrease up to 42% and 37% as compared to RC control beams.

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