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Experimental Investigation of Failure behavior of Reinforced ECC Beams in Flexure

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Abstract — *this paper is based on the experimental investigation of failure behavior of larger size steel reinforced Engineered Cementitious Composite (R/ECC) beams in flexure. A typical mix of ECC known as M45 with Polyvinyl Alcohol fiber content of 2% has been modified by reducing fiber content to 1.5% by volume and water to binder ratio was increased from 0.25 to 0.33, in order to lower the compressive strength of PVA-ECC up to 33MPa. Failure behavior of R/ECC beams in flexure is compared with normal RC beams having same dimensions, steel reinforcement and compressive strength of concrete. R/ECC beams showed an improved performance in flexure under similar loading conditions as compared to RC beams and maintained greater load carrying capacity even after cracking thus absorbing greater energy after yield point. This might be due to the bridging effect of fibers in ECC at micro-structure level where PVA fibers played role in transmitting stresses across the cracks and resisted the applied load. Cracking pattern of R/ECC observed was different than RC beams as cracks in R/ECC were more in number and closely spaced while maintained smaller opening size. While in RC beams a typical Griffith crack pattern was observed. R/ECC beams performed better than RC beams in terms of energy dissipation under the given conditions and proved to be capable of being used in critical elements with higher energy dissipation requirements.*

Keywords*- engineered cementitious composites, strain-softening, ductility, energy dissipation*

I. INTRODUCTION

Brittleness is one of the major problems with high strength concrete as it increases with increase in strength, thus showing little warning before failure. As concrete is weak in tension, steel reinforcement is provided in tension zone of concrete member to resist flexural stresses when subjected to bending, while compression is resisted by concrete in compression region [1]. In Reinforced Concrete (RC) beam, when load exceeds the tensile strength of concrete, tensile cracks are being developed and propagated towards the neutral axis. Due the brittleness of concrete, Griffith crack pattern is observed at failure where less number of cracks are developed having wide opening size [1]. After first cracking, a sudden drop in load carrying capacity is typical in ordinary concrete, especially for lightly reinforced concrete sections [2].

Efforts have been made to reduce the brittleness of concrete by adding different types of fibers during the course of history. Short steel fibers were used in 1960's and various fibers have been used in the following years from steel fibers to glass, carbon, synthetics and natural fibers [3]-[4]. These efforts of using fibers resulted an increase in material toughness but the ductility was not achieved which is the measure of strain (deformation) capacity associated with steel but not concrete [5]. Attempts have been made to achieve high tensile ductility by using continuous aligned fibers with high dosage (4-20%) in concrete. Such material was classified as High Performance Fiber Reinforced Cementitious Composites (HPFRCC) which differs in possessing strain hardening behavior as compared to tension softening behavior of FRC. During the development process, two new classes of HPFRC were introduced [6]. One is Ductal with high tensile strength (up to 12MPa) and ductility of 0.02-0.06% and other is Engineered Cementitious Composites (ECC) which has moderate tensile strength of 4-6 MPa while higher ductility of 3-5%[7] -[8]-[9].

ECC was originally developed and given the name at the University of Michigan by Professor Victor C. Li and Co-workers. Its ingredients are similar as Fiber Reinforced Concrete and contain water, cement, sand and discontinuous short fiber where volume of fiber is kept as lower as 2% [10]. Different fibers are used in ECC but most commonly Polyethylene (PE) and Polyvinyl Alcohol (PVA) are used. The fundamental property of PVA-ECC is strain hardening where the strength rises after first crack loading and is more or less maintained until failure occurs. While, FRC loses its strength slowly after encountering first crack which is called as tension softening property [10]. The most common mix design of Engineered Cementitious Composites (ECC) is referred as M45 with fiber content of 2% by volume which has been extensively used in experiments to investigate the properties of PVA-ECC [10]-[11]. Other constituents include cement, sand, fly-ash and superplasticizers along with PVA fibers. PVA fiber has diameter of 39 micrometer, length of 12mm and overall Young's Modulus of 25.8MPa. The sand size is 250 micrometer and an average of 210 micrometer.

This research paper is based on the investigation of failure behavior of steel reinforced PVA-ECC beams, in flexure with reduced compressive strength of ECC. This has been achieved by modifying M45 mix of PVA-ECC where fiber content is reduced to 1.5% by volume and water to binder ratio was increased from 0.25 to 0.33 as in the original M45. Mechanical properties like compressive strength, split tensile strength and Modulus of Rupture have been investigated before casting of full scale specimen for testing under point loading at L/3 from both supports. Results were compared with the normal concrete beams having same dimensions, reinforcement and compressive strength.

II. RESEARCH SIGNIFICANCE

To overcome the sustainability of normal concrete infrastructure due to its brittleness and deteriorating nature, materials like ECC are considered as an alternate material for construction of infrastructure in the developed world. In Pakistan, ECC and especially with PVA fibers is yet to be introduced in construction industry which requires extensive research in order to highlight its significance and to fully recognize it as replacement of normal concrete with better results in different circumstances where normal concrete cannot give the desired results which are characteristics of ECC.

III. EXPERIMENTAL PROGRAMME

2.1 Material and Mix Design

In this research, two types of mix designs have been used for normal concrete and ECC. Normal concrete contained Ordinary Portland cement, local sand with Fineness Modulus of 2.31 and coarse aggregate. Mix proportion of 1:1.5:3 (cement: sand: coarse aggregates) by weight has been used in specimens after trial mixes for normal concrete with required compressive strength of 31 MPa. Mix design of normal concrete is give in Table – I. After making trial mixes of ECC by varying fibers content and water to binder ratio for lowering the compressive strength of PVA-ECC up to 33 MPa in order to bring it closer to normal concrete, a design mix was achieved which is given in Table – II.

Table – I Mix design of normal concrete (Kg/m^3)

Cement	Fine Aggregate	Coarse Aggregate	Water
422	738	1160	200

Table – II Modified M45 Mix for ECC with 1.5% PVA fiber by volume (Kg/m^3)

Cement	Fly Ash	Sand	Water	HRWR	PVA-Fibers
583	646	467	390	10.2	19.5

2.2 Preparation of Test Specimens

To investigate the mechanical properties of both mix designs, trials were made for adjustment of proportions while standard cylinders and prisms (beams) were prepared for testing of hardened concrete and ECC. ASTM (C-31/31M) standard cylinders [150 mm x 300 mm] for nominal size were prepared for compressive and split cylinder tests. Similarly concrete and ECC prisms were prepared for testing to find out Modulus of Rupture (MOR) of both mix designs. Two number of large size beams each for RC and R/ECC with dimensions of 2440 mm x 305 mm x 230 mm were prepared in Concrete Laboratory of Civil Engineering Department at University of Engineering and Technology Peshawar. All beams were of the same dimensions and were provided with minimum longitudinal reinforcement as per ACI code. Detail of both types of samples is given in Table – II and figure – I.

Table – II Samples Detail

S.N	Beam Dimensions (mm)	Longitudinal Reinforcement (%)	Shear Reinforcement (mm)	Test Performed
1	2440 x305 x 230	0.55 (3, ϕ14)	ϕ10 @ 100	Third point bending Test

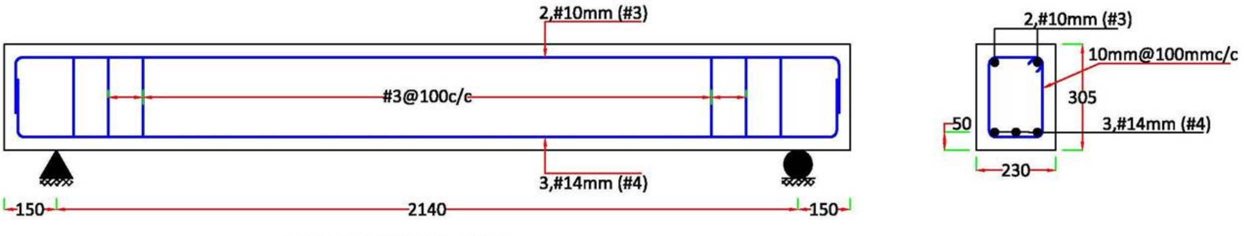

Figure – I RC and R/ECC Beam Specimens

2.3 Properties of Fresh and Hardened Concrete and ECC

Density of fresh concrete was found 2307 Kg/m^3 while that of ECC was 1842 Kg/m^3. Mechanical properties of material like compressive strength, split tensile strength and Modulus of Rupture (MOR) were obtained by testing 4 numbers of standard size cylinders and prism beams (150mm x 150mm x 750mm) for each type of test and material. The average cylindrical compressive strength of normal concrete of 4 cylinders was found as 32.0 MPa whereas that of ECC was 33.0 MPa. Split Cylinder test result for was 3.3 MPa for normal concrete and 4.4 MPa for ECC. Similarly Modulus of Rupture (MOR) of normal concrete was 4.8 MPa and 6.8 MPa for ECC specimens. All these tests were performed in material Testing Laboratory of UET Peshawar, using UTM of 300 Ton capacity.

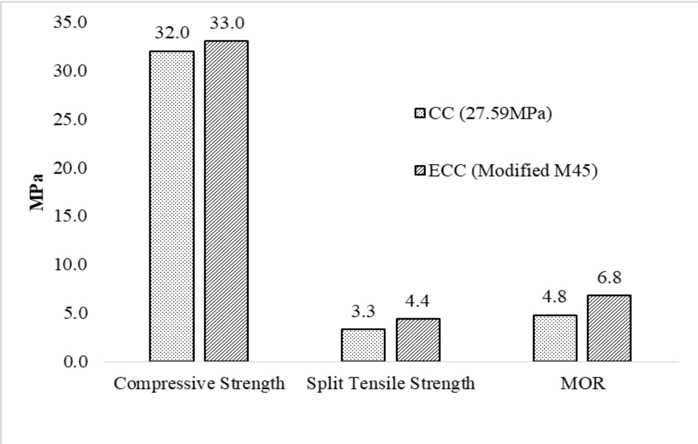

Figure – II Mechanical Properties of hardened concrete and ECC

IV. LOADING AND TEST SET UP

Test setup was arranged for flexural testing at Structural Engineering Lab of Civil Engineering Department at UET Peshawar by using a Load Cell of 50 Ton capacity. Two numbers of beams each from normal RC and R/ECC were tested using Third Point bending test method where point load was applied at L/3 from end supports of beams. A Strain gauge was installed on longitudinal reinforcement at the bottom of beam in mid span and another one on top surface of beam in order to record strain at both chords simultaneously. LVDT was installed at mid depth to record vertical displacement at the center of beam during loading. All gauges and LVDT were connected to a data logger UCAM70 for data recording. Experimental setup is shown in Fig. – III.

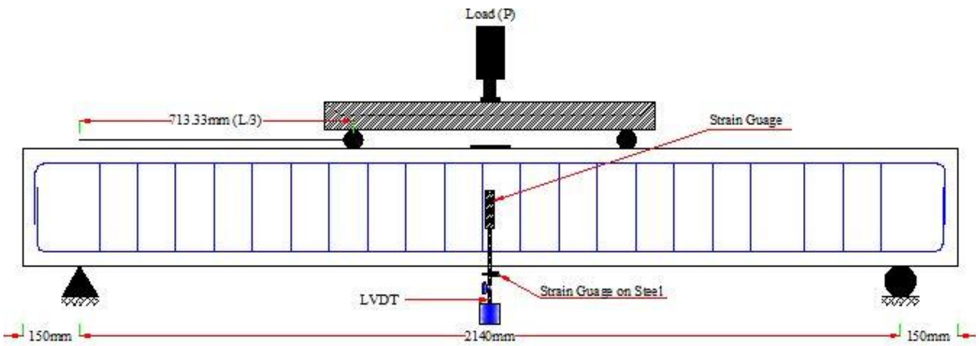

Figure – III Test setup for testing of beams under flexure

V. RESULTS AND DISCUSSION

Objective of testing was to observe the behavior of failure in flexure under given loading conditions. Results obtained from testing arrangement have been plotted for both types of samples. Mid-span deflection of beam is plotted against loading by installing LVDT (50 mm) at mid depth and center of span length of beam. Cracking of beams was closely observed right from first crack witnessed with naked eye till the failure of beams.

5.1 Load vs Mid Span Deflection

LVDTs were installed at the middle of the beam to measure mid-span deflection during loading until ultimate load carrying capacity is reached. Curve for mid span deflection of both RC and R/ECC beams are given on the average of two samples for each type of material.

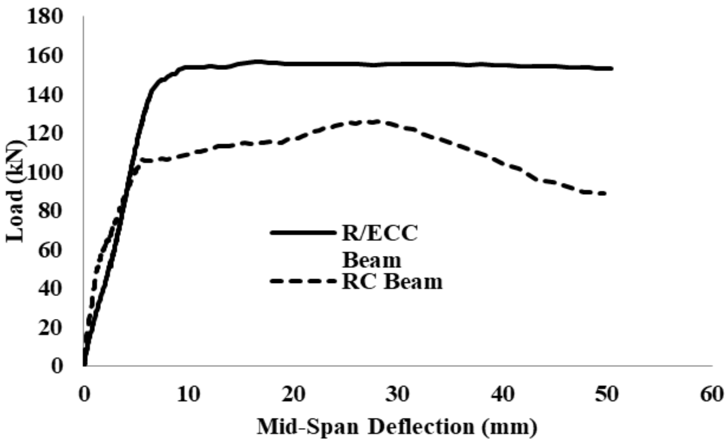

Figure – V Mid-Span deflection of RC and R/ECC Beams

5.2 Crack Pattern in Flexural Failure

Crack pattern of the both types of specimen were closely observed with naked eye and marked at first sight during loading and with propagation of cracks load has been recorded accordingly. Cracks observed in R/ECC beams were closely spaced and have less opening size. Whereas in RC beams the cracks were initiated on little higher load but leaded to failure earlier than R/ECC. Also cracks observed in RC were lesser in number with wide opening size which shows the brittle nature of normal concrete.

Figure – VI (a) Crack pattern of RC beams in failure at 12.8 Ton

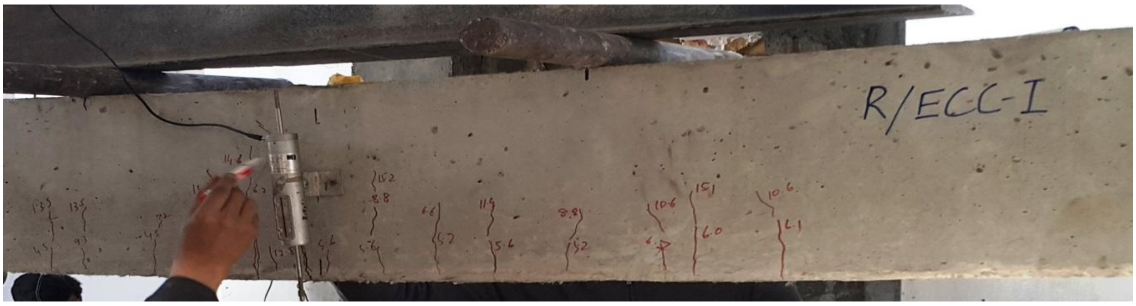

Figure – VI (b) Crack pattern of R/ECC beams in failure at 15.8 Ton

VI. SUMMARY AND CONCLUSION

Test results obtained from experimental work are formulated as below;

- ECC in fresh state was 20% lighter than normal concrete.
- The split tensile strength of ECC was 18% higher than normal concrete specimen.
- MOR for ECC was recorded 30% higher than normal concrete specimen.
- First visible crack in R/ECC beam under flexure was appeared earlier than RC beams but the ultimate load of R/ECC was higher than the ultimate load of RC beams.
- R/ECC beams took higher load and deflection occurred as smooth curve after yield point by maintaining the load carrying capacity after cracking until yielding of steel reinforcement occurred, whereas RC beams showed typical behavior of three distinct stages i.e. elastic, yield and ultimate loading stage before complete failure.
- Both types of beams were designed and loaded to make them fail in flexure to avoid any shear failure in order to fully examine the flexural behavior of both beams and were failed in flexure accordingly.

- Cracks observed in R/ECC were closely spaced and more in number as compared to normal concrete or RC beams until steel yielded at a point of ultimate bending stress.
- It was observed that in case of normal concrete beams, the concrete in compression region which in this case was the top of beam was crushed along during failure stage due to tensile cracks in tension region whereas R/ECC performed better in compression where no such crushing of ECC was observed.

It can be concluded from the above results and discussion that R/ECC beams had absorbed more energy than normal RC beams and can be used in selective structural elements, like beam-column connection, coupling beams etc. Due to its typical smaller crack width and pattern, it can also be used in water retaining structures like underground and elevated water tanks, water treatment plants and sewage tanks etc. R/ECC may also be used in slabs and other thin members in areas where plastic shrinkage cracks are likely to occur due to continuous wind or other surface drying agents.

REFERENCES

[1] Arthur H. Nilson, David Darwin and Charles W. Dolan, "Design of Concrete Structures, 14th Ed", McGraw Hill Higher Education
[2] Maria M. Szersen, Aleksander Szwed and Victor C. Li, (2006), "Flexural Response of Reinforced Beam with High Ductility Concrete Materials".
[3] Romualdi, N.P. and Batson, G.B. 1963. Mechanics of crack arrest in concrete. Proc. ASCE Eng. Mech. J. 89(EM3):147-168.
[4] Romualdi, J.P. and Mandel, J.A. 1964. Tensile strength of concrete affected by uniformly distributed closely spaced short lengths of wire reinforcement. Proc. ACI J. 61(6):657-671.
[5] Li, V.C., "Engineered Cementitious Composites (ECC) – Material, Structural, and Durability Performance," in Concrete Construction Engineering Handbook, Chapter 24, Ed. E. Nawy, published by CRC Press, 2008.
[6] Naaman, A.E. and Reinhardt, H.W. 2003. "Setting the stage: toward performance-based classification of FRC composites. In High Performance Fiber Reinforced Cement Composites (HPFRCC-4)", Proc. Of the 4th Int'l RILEM Workshop, A.E. Naaman and H.W. Reinhardt, eds. Published by RILEM S.A.R.L.
[7] Chanvillard, G. and Rigaud, S. 2003. "Complete characterization of tensile properties of ductal UHPFRC according to the French recommendations. In Proc. of High Performance Fiber Reinforced Cement Composites (HPFRCC4)", A.E. Naaman and H.W. Reinhardt, eds, pp. 21-34. RILEM Publications, S.A.R.L.
[8] Li, V.C. 1993. "From Micromechanics to Structural Engineering – the design of cementitious composites for Civil Engineering applications". JSCE J. of Struc. Mechanics and Earthquake Engineering 10(2):37-48.
[9] Fischer, G., Wang, S. and Li, V.C. 2003. "Design of engineered cementitious composites for processing and workability requirements". Seventh International Symposium on Brittle Matrix Composites, pp. 29-36. Warsaw, Poland.
[10] Li, V.C. 1998. "Engineered Cementitious Composites for Structural Applications". ASCE J. Materials in Civil Engineering, Vol. 10, No. 2, pp. 66-69, 1998.
[11] Shuxin Wang and Li. Victor C, University of Michigan, USA, "Polyvinyl Alcohol Fiber Reinforced Engineered Cementitious Composites: Material Design and Performances".
[12] Advanced Civil Engineering - Materials Research Laboratory http://www.umich.edu/~acemrl/

