A Review Paper on an analytical study on ECC composite beam

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Abstract - *Engineered cementitious composite (ECC) exhibits tensile strain hardening behavior, excellent crack dispersion capacity and good workability. As the main problem of reinforced concrete is that it possess inherent brittleness in tension and low strength in shear under seismic conditions. The application of ECC material may be a feasible way to improve the seismic behavior of engineering structures. This paper presents a comprehensive review of experimental and analytical studies on the use of reinforced ECC members and reinforced concrete/ECC composite members. The review is mainly focused on design programs for structural members and their seismic response behavior. The effectiveness of the application of ECC for seismic improvement is discussed. In this study, aim of this project is to analytically presents the results by analyzing various efficacy of using ECC in the joint area along with beam or column with varying positions on ANSYS 14.0 workbench and comparing it with control conventional RC beam to study the effect of deflection, shear stress, stress-strain and temperature and comparing result with experimental data.*

Key Words: ECC, Beam, Beam-column joint, ANSYS, Deflection, Shear stress, Ramp Load, Stress-Strain, elevated Temperature

1.0 INTRODUCTION

The most common types of structures constructed nowadays are Reinforced Concrete (RC) structures. Although, new methods are suggested every day to improve the performance of these structures and eliminate their defects. The intrinsic brittleness of concrete is one of the main problems which still challenge these buildings. Compared to conventional concrete, Engineered Cementitious Composites (ECC) shows higher composite ductility in both tension and compression. This property of ECC makes it a promising material for structures under extreme loadings, such as earthquakes and its application can be a feasible way to improve the seismic behavior of engineering structures. The use of ECC in RC beam–column joints and beam ends can greatly improve the seismic behavior and allow reducing stirrup use in these regions, which is helpful for solving reinforcement congestion and construction defect problems. Thus, the discussed literature review further mainly focuses on design programs for structural members and their seismic response behavior, effectiveness of the application of ECC for seismic improvement is also discussed.

2.0 Literature review

After studying various research papers related to application of Engineered Cementitious Composites, the short explanation about its approach, methodology and conclusion is been discussed results are as follows:-

[2.1] **Jun Zhang, et.al (2006):-** In this paper, 3-point bending test to obtain stress-crack relationship and 4-point bending test on 3 specimens (100x100x500mm) layered ECC concrete beams with (25mm,50mm) layered ECC thickness at its tensile side was studied to find its flexural performance. Theoretical and experimental study was performed and found that ECC thickness beyond critical value results in increase in flexural strength and ductility reflected by crack mouth opening and crack length at ultimate load.

[2.2] **Nurdeen M. Altwair, et.al (2012):-** In this paper, the flexural performance of green engineered cementitious composites (ECCs) containing treated high volume of palm oil fuel ash (POFA) content 0, 0.4, 0.8, 1.2 from mass of cement with water-binder ratios 0.33, 0.36, and 0.38 was studied for flexural test after 3, 28 and 90 days of curing, to investigate the effect of w/b ratios on the first cracking strength, flexural deflection capacity and tensile strain capacity, MOR, crack widths and its flexural performance. It concluded that increase in Palm oil fly ash (POFA) content and water–binder ratio in result increases number of cracks, improves the flexural deflection capacity but the first cracking strength, crack width and flexural strength of the ECC beams gets reduced. Furthermore, at 28 days curing time, good correlations was found between the flexural deflection capacity from the four-point bending test and tensile strain capacity from the uniaxial tensile test.

[2.3] **Yuan Fang, et.al (2014):-** In this paper, numerical study was performed on the flexural behaviors of the steel reinforced ECC and ECC/concrete composite beams with finite element method. Parametric studies were performed to analyze the effect of the ECC modulus reduction on the initial stiffness and strengths of both beams. Accordingly, in terms of ultimate moment, deflection and the maximum crack width of ECC/concrete composite beam the effect of ECC's tensile ductility, thickness and position of flexural behavior were evaluated. Result shows increase in the moment capacity and ultimate moment when ECC layer was provided at both the sides of the beam.

[2.4] **Ozgur Anil, et.al (2016):-** This paper aimed to study the impact behaviors of reinforced concrete beams with the effect of material properties from several concrete types and were experimentally and numerically investigated under dynamic impact loading. Experimentally, twelve beams manufactured using low strength concrete, normal strength concrete and engineered cementitious composites (ECC) containing polyvinyl alcohol (PVA) fibers were tested under dynamic impact loading. Further, finite element analyses on ABAQUS of the tested beams were conducted to observe the stress distribution under the impact loading. The results derived from the test specimen illustrated that the smallest cracks formed on the specimen was by using ECC and the largest crack were formed using low strength concrete. Finite element study showed that ECC prevent formation of the cracks under high free dropping heights.

[2.5] **Xinchen Zhang et.al (2020):-** This paper investigates experimentally and analytically the seismic performance of interior and exterior beam–column joints using ECC material in the joint core with different reinforcing detailing. A parametric study shows the effect of column axial load ratio with various ECC strengths applied and the effect of transverse reinforcements in the joint core with lateral cyclic loadings. Three interior joints and as well as exterior joints with different transverse reinforcement in the joint core and a constant column axial loading were tested for energy dissipation capacity, crack patterns, joint shear stress, hysteresis behavior and strain profiles. Result shows that high strength of ECC in the joint shear was dangerous but without increase of peak capacity. Axial load ratio above 0.3 results in decrease of ductility.

[2.6] **P. Bhuvaneshwari et.al (2016):-** This paper concludes flexural study on (100 mm x 150 mm x1500 mm) un-strengthened fire-affected (FD i.e., B1, B3, B5) beams and strengthened fire-affected (FDS i.e., B2, B4, B6) beams. The parameters considered were different intensities of fire, load deflection behavior, spalling, crack pattern, stiffness, ductility and energy absorption. The three phases (300, 500 and 900C) by ISO834 effect of strengthening of fire-damaged beams using glass fiber sheet and polypropylene-based ECC as binders was carried out. The residual strength of stirrup reinforcements lost due to thermal load at 300°C was 10%, at 500°C was 50% and at 900°C only 10%of its strength retained and therefore, the shear capacity of concrete was utilized. Flexure loading of un-strengthened beam showed brittle shear failure with the formation of inclined shear cracks in support region.

[2.7] **Shwan H. Said, Hashim Abdul Razak (2016):-** In this paper, experimental study was conducted on 2 specimen of full scale one cast with normal concrete and other with ECC using PVA fiber in joint zone to observe the effect it on reinforced concrete exterior beam–column joint specimens under cyclic hysteretic loading. Further, comparison between the behaviors of both the specimen was done in terms of flexural capacity, shear capacity, joint rotation, and energy dissipation capacity of the joint. Result shows that the ultimate moment value of ECC specimen was more than 23.4% corresponding to NC specimen. The joint in the NC was damaged at 4.5% drift ratio but ECC specimen was still intact. At post cracking stages, the ECC joint showed significant improvement in the ultimate shear and moment capacities, as well as in the deformation behavior and damage tolerance, compared with the NC specimen at ultimate and failure stages.

[2.8**] Siong Wee Lee et.al (2016):-** In this paper, bond-slip behavior of steel reinforcement embedded in engineered cementitious composites (ECC), showing tensile strain hardening performance was investigated. Pull-out tests were conducted on short and long embedded reinforcement experimentally, that shows ECC significantly increase the maximum bond stress of steel reinforcement while long reinforcement needed care after post-yield stage. Short reinforcement with embedment length of five times rebar diameter exhibited pull- out failure at elastic stage which indicates that ECC could increase the maximum local bond stress of short reinforcement by 14%. Thereafter, an analytical model was proposed based on experimental results to predict the force-slip relationship of long reinforcement either anchored in concrete or in ECC. Reasonably good agreement was achieved between experimental and analytical force-slip curves.

[2.9] **Dan Meng, C.K. Lee, Y.X. Zhang (2017):-** This paper investigates the effect of PVA-ECC matrix, transverse reinforcement (stirrups) and longitudinal reinforcement bars on the flexural and shear structural performances of reinforced PVA-ECC beams. 4-point bending tests were conducted and normal steel reinforced concrete beams were tested for comparison. Digital Image Correlation technique was used to monitor single crack development and was validated by LVDT measurements. Experimental results show that PVA-ECC beams present significantly improved flexural behavior compared with normal concrete beams. Furthermore, PVA-ECC beams without stirrups eventually fail in flexure rather than in shear, and exhibit similar load-deflection, moment-curvature relationships and crack development history when compared with PVA-ECC beams with stirrups Flexural behavior and ductility of RECC beam was 14.8% and 103.6%, respectively more than RC beam. Shear resistance RECC-NS beam was 1.5 times more than RC-NS beam. No. of stirrups could be reduced when concrete was replaced by PVA-ECC. Flexural behavior of RECC-NS was improved by longitudinal reinforcement bars compared to PECC beams with increase in load carrying capacity 5.5 times and mid span deflection 4.0 times.

[2.10] **Jingming Cai et.al (2017):-** This paper investigate about the flexural behavior of ECC and concrete beams reinforced with BFRP bars with nonlinear finite element method. The flexural behaviors of the BFRP reinforced ECC and concrete beams were numerically modeled with the finite element software ATENA. 18 BFRP reinforced ECC beams were modeled to investigate the effects of compression strength, tension strain, tension strength of ECC, longitudinal BFRP reinforcement ratio. Result showed that BFRP reinforced ECC beams improved the flexural properties in terms of load-carrying capacity, crack controlling ability and deformability compared with the BFRP reinforced concrete beams. Tension strain of ECC exceeded 1.5%, rest all parameters increases with the increase of ultimate strength while ultimate deflection increased with increase of tension strain of ECC and compression strength of ECC. The increase of longitudinal reinforcement ratio in result changed the failure mode of ECC beams.

[2.11] **Mohan Zhou et.al (2017):-** This paper studies 10 different ratio of high ductility fiber reinforced concrete beam bending resistance to analyze the initial cracking, bending moment and yield strength of the beam under yielding of ECC beams on ANSYS with the variables such as content of fly-ash (1040,1300,1560)kg/m^3, water binder ratio(0.26,0.29,0.32), fiber content(0,13,19.5,26)kg/m^3. The results showed that the beam performance increased with decrease in W/B ratio. At 13kg/m3 fiber content, the mechanical properties of the ECC beams were the lowest, and then strengthen. As content of fly ash increases deflection increases while bending moment of the beam decreases. But during initial cracking stage, deflection decreases when fly ash is higher than 50%.

[2.12] **Qiang Du et.al (2017):-**This paper investigates the effects of elevated temperature (20, 100,200,200, 400°C) for 6hrs on the mechanical behavior of Polyvinyl Alcohol Engineered Cementitious Composites (PVA-ECC). The fire resistance of PVA fiber was determined based on thermal analysis. Result showed that as the temperature increases compressive strain capacity increases while the compressive strength, flexural strength, modulus of elasticity decreases. Change in compressive strength in PVA-ECC is seen when exposed to long-term high temperatures especially above 200 C. At 400 C, the average reduction in flexural strength reached 60%.

[2.13] **Ali S. Shanour et.al (2018):-** In this study, the performance of ECC concrete beams reinforced with conventional reinforcement bars were investigated regarding the cracking load, ultimate load, the ductility and the load-to deflection response using Polyvinyl Alcohol Engineered Cementitious Composite (PVA-ECC) fibers. 12 RC beams were poured and tested to study flexure behavior under four-point loading test with two different longitudinal reinforcement percentages, variable volume ratios of (PVA) and polypropylene fibers (PP) experimentally. With low longitudinal reinforcements ratio, ECC improves the percentage of increasing in the load up to 19% and 39% when using a mixer of both PVA and PP fiber with the ratios of 0.5% and 1.0%. It was found that ECC fibers in form of PVA has more maximum capacity rather than discrete fiber PP. Simultaneously, a numerical model was also performed to study the behavior of tested beams, for crack behavior and load-deflection response using ANSYS software. Result showed that the maximum load capacity increases from 20% to 25% when using a limited layer thickness of PVA concrete (100 mm or 200 mm). The relative ductility factor increases by 30% and 45% for 1.0% and 2.0% of PVA content.

[2.14] **Jingming Cai et.al (2018):-** In this paper, mechanical behavior of ECC-encased CFST columns subjected to eccentric loading was studied for parameters like eccentricity ratio, stirrup reinforcement ratio, longitudinal reinforcement ratio and thickness of inner steel tube for which with different eccentricity ratios and components seven ECC-encased CFST columns were tested. Result showed that all ECC-encased CFST columns failed in a ductile mode under different eccentricity ratios from compression-controlled failure to balanced failure mode, and then tension-controlled failure. With increase of longitudinal reinforcement ratio load carrying capacity increases, while the stirrup ratio has little influence on it but improves the ductility of the composite column. The load carrying capacity increased by 11% and the columns become more ductile by increasing thickness of steel tube.

[2.15] **Mohammad M. Rana et.al (2018):-** In this paper, flexural behavior of steel composite beams encased by engineered cementitious composites are studied to investigate the effects of ECC cover thickness on the ultimate load carrying capacities and failure modes. Four-point bending loading of 4 composite beams were tested under simply-supported conditions. Further, (3D) nonlinear finite element (FE) modeling procedure was developed to predict the ultimate load carrying capacities and failure modes of the beam. Result shows that, with different cover thickness (50, 75, 100) indicated, a minimum ECC encasement thickness (50% of depth of the beam in this test) encasing the steel flanges was sufficient to produce significant performance improvements in terms of stiffness, ultimate load carrying capacity and ductility even the compressive strength of the ECC used is only 63% that of NC. In addition, a 13% weight reduction was also achieved.

[2.16] **Xuan Zheng, Jun Zhang et. al (2018):-** Flexural performance of effect of internal curing of high strength engineered cementitious composite (HSECC)-steel composite beam on cracking load, ultimate load, deflection and crack opening under load, is studied by experimentally by taking 5 mixtures of HSECC, 4 mixtures internally cured (IC) with pre-wetted calcined particles and 1mixture with ordinary curing (OC).The test results shows that cracking, deflection at cracking and ultimate bending load of internally cured HSECC-steel composite beam is greater than that of ordinarily cured composite beam thus internal curing can also improve the ability of crack opening control after cracking. Result concludes that Deflection at cracking and peak load of internally cured composite beam is larger than beam with ordinarily cured HSECC. Cracking and ultimate bending load of internally cured HSECC-steel composite beam is greater than that of ordinarily cured composite beam. Average crack-width of internally cured HSECC at peak bending load (0.025 to 0.018) rather than ordinary cured HSECC which is 0.38.

[2.17] **Yao Ding, Ke-Quan Yu et.al (2018):-** In this paper, two series of beams reinforced or unreinforced with stirrups, were prepared and tested for the flexural and shear performance of steel reinforced UHP-ECC (RU) beams with controlled RC beam. The longitudinal steel reinforcement ratios were (0.69, 1.86, 2.94) % for both RU and RC beams. Research was done on the structural behaviors of UHP-ECC beams under bending and compared with the traditional RC beams with the same longitudinal reinforcement. It concluded that more cracks were generated in UHP-ECC beams than RC beam. RU-NS (UHP-ECC with no stirrups) beam show ductility rather than brittle mode as RC-NS (RC with no stirrups).Ductility index of RU-NS and RC beam decreased with increase in reinforcement while compressive strain of UHP-ECC was much larger than RC beams which in result shows better ductility in RU beams. Non-steel reinforced UHP-ECC beam was an alternative to RC beam with comparable load bearing capacity and higher ductility.

[2.18**] Joan Mary Jojo, Nayana A (2019):-** This paper analyze deep beams in reinforced concrete and fiber-reinforced flexible concrete (ECC) subject to cracking under flexural two point loading by performing finite element analysis in ANSYS which is compared to RC beam. It was found that the cracks simulated in ECC at the same fracture load for RC deep beam was quite insignificant, while it became a major mode of failure in RC beam. Result concludes that ECC material attain 500 times the strain capacity of normal types of concrete and is 30-40% lighter than conventional concrete, which results increase in service life of the structure and is cost effective.

[2.19] **Qing Wanga, et.al (2019):-** This paper studies, the shrinkage and internal relative humidity (IRH) of OPC-HSECC containing zeolite as internal curing agent were investigated experimentally. 15% (18%), 20% (24%) and 30% (36%) were the replacement ratios by weight (and by volume) of quartz sand by natural or calcined zeolite powder were selected. Results showed that use of zeolite at the selected replacement ratios can successfully decrease the 28-day shrinkage of OPC-HSECC while maintaining similar level of compressive strength. Thus, it increases the strength-and-shrinkage performance of OPC-HSECC, and is more cost effective. It was found that the optimal ratio of calcined zeolite replacement of sand was 30% (36%) to give the best simultaneous strength-and shrinkage performance of OPC-HSECC. The optimal ratio of calcined zeolite was 20% (24%) for minimum 100MPa strength.

[2.20] **Jiansheng Fana et.al (2020):-** This paper studies experimentally and analytically the flexural performance of steel-ECC composite beam under hogging moments and also the behavior of tension stiffening effect of one steel concrete and two steel –ECC composite beams with different slab and reinforcement ratios. Result shows that under hogging moment, using ECC significantly improved the cracking load and reduced the crack width in flange slabs of composite beams. With increase in reinforcement ratio the crack resistance improved. The model was further use to predict the flexural behaviour of steel–ECC composite beams in finite element analysis and was observed in terms of the stiffness and crack propagation. It concluded that increase of fibre volume fraction and fibre hardening results in higher stiffness, crack resistance and higher strength, ductility of steel–ECC composite beams, respectively and by increasing ECC slab area, reinforcement ratio, steel plate thickness, and decreasing crack spacing could reduce initial crack width.

[2.21] Liang Baia, Yilin Lia et.al (2020):- in this study, the longitudinal shear behaviour and failure modes of 11 composite slab specimens consisting of profiled steel sheeting and ECC are studied under four-point flexural loading. With a set of critical factors varied including the shear span, the thickness of steel sheeting, the depth of composite slab, as well as the arrangement of shear studs and shear reinforcement. The longitudinal shear resistance of ECC composite slab can be improved by arranging shear studs as end anchorage and by setting up shear reinforcement in the shear span. Increase in the thickness of profiled steel sheeting or the depth of slab also affect the longitudinal shear resistance of an ECC composite slab.

[2.22] Md. Imran Kabira et.al (2020):- In this study, to enhance the flexural strength of welded High Strength Steel (HSS) beam ECC encasement was investigated experimentally and numerically investigated 3D finite element model was proposed to simulate the flexural responses and interfacial slip of the encased beams. a similar approach was applied to enhance the flexural resistance of HSS beams by using ECC and LWC to provide continuous lateral restraint to the compressive flange of the HSS section. Result showed that ECC encased HSS beam enhance the flexural resistance by preventing the onset of lateral torsional buckling (LTB) and prevented the brittle crushing of the beam's top layer at peak load. Very small amount of slip between the ECC encasement and HSS flanges occurred even after the whole HSS section was yielded.

[2.23] **Muppalla Venkata Sai Surya Pratap Chowdary et.al (2020)**:- On the basis of past research done by the researchers they conclude the steps for mechanics of preparation of eco-friendly natural fiber reinforced ECC beams and its analysis by considering characteristics of material(treatment of fibers 100nm and gradation of silica sand of size 1.18mm, used for base mix, type of mixer and its speed, 2% of total volume of PVA and natural fiber to be add in ECC composites while casting of full ecc layer beam for its better performance than conventional beam.

[2.24] **Selvamole A , Binu P (2020):-** - This paper experimentally investigates the static analysis with full ECC beam and NC is conducted to evaluate its performance. Result concludes that ECC can be alternative to normal concrete as it can withstand more load carrying capacity. And it can be used as a flexible material which can be utilized in various purpose where fiber reinforced concrete can't be used.

[2.25] **Yu-Zhou Zhenga et.al (2020):-** In this study, experimentally, 5 RC beam strengthened with BFRP-ECC were tested along with one conventional RC beam to study their strengthening performance improvement, particularly in shear capacity and it was found that bonding between the BFRP-ECC effectively suppress the propagation of diagonal cracks in the shear/ bending moment regions. mechanical behavior of the strengthened beam through finite element method (FEM) analysis was also studied. Result concludes that failure modes of the tested beams were dominated with shear-compression failure in the shear/bending moment regions and concrete crushing in the compression part of the pure bending zone. 30mm Composite reinforced layer of BFRP-ECC with grid reinforcement ratio(0.03 to 0.2)% increases the shear capacity of RC beam from (27 to 59%) as compared to reference beam without CRL and shear span ratio(2.40 to

4.37%) improved shear capacity from (52 to61%). Debonding was seen after shear compression failure due to the diagonal crack propagation of RC beam.

3.0 CONCLUSIONS

After reviewing a lot of research papers that are based on Engineered Cementitious Composites. It can be concluded that intrinsic brittleness of concrete in tension and shear is one of the main problems which still challenge RC buildings under seismic conditions. For further work in direction of the beam-column joint, seismic design requirement of strong joints-weak components aims to ensure adequate shear resistance to avoid joint shear failure. As, ECC characterizes tensile strain hardening and multiple cracking properties, as well as strong interfacial bonding performance with substrate concrete and makes it a promising retrofitting material to use.

The conclusion is further work on the efficiency of using engineered cementitious composites in the joint area and the end part of the beam or column could be investigated.

- Use of ECC significantly increases the load capacity, stiffness, deformation capacity, and energy dissipation.
- ECC combined with FRP textiles or steel bars have been used to strengthen RC structures.
- Normal concrete show brittle shear failure while ECC showed a ductile shear failure.
- Maximum load carrying capacity increases from 20 to 25% using a limited thickness of PVA-ECC concrete.
- The flexural strength of the beam increases non-linearly with increase in ECC layer while ductility factor increase by 30% and 40% for 1.0% and 2.0% of PVA content.
- With Increase in longitudinal reinforcement ratio load carrying capacity increases, as stirrup ratio has little influence on it.
- Increase in additional reinforcement in core zone increases the compressive strength and stiffness of the joint.
- Internally curing of HSECC performs better and improves cracks opening at ultimate load.
- In composite beam, increase of ECC layer improve its moment capacity and decrease crack width.
- BFRP-ECC composite reinforced layer increases the shear capacity of composite beam with 59%.
- ECC increase the local bond stress of short reinforcement by 14% and use of ECC with 30% zeolite yields the lowest shrinkage per compressive strength.
- Rise in temperature above 400C reduces the flexural strength up to 60% and at 900C sudden shear failure occurs.

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