Study on Engineered Cementitious Composites with Different Fibres: A Critical Review

B. D. Gohil
PG Student,
Government Engineering Collage,
Government Engineering Collage, Dahod-389151, India

Dr. K.B.Parikh
Assistant Professor,
Department of Applied Mechanics,
Government Engineering Collage, Dahod-389151, India

Abstract – Bendable concrete also known as Engineered Cementitious Composites abbreviated as ECC is class of ultra-ductile fiber reinforced cementitious composites, characterized by high ductility and tight crack width control. Conventional concretes are almost un-bendable and have a strain capacity of only 0.1 percent making them highly brittle and rigid. This paper presents review of ECC composites with different fibres i.e. PVA and Steel fibres, influence of different percentage of fibres, tensile behaviour and durability under varying percentage of fibres.

Keywords- Bendable concrete, ECC-Engineered Cementitious composite, Compressive strength, Tensile strength, Durability

I. INTRODUCTION

Bendable Concrete also known as Engineered Cementitious Composite (ECC) is an easily moulded mortar based composite reinforced with specially selected short random fibres, usually polymer fibres. The past study on ECC concluded that Conventional concrete is of low strain capacity i.e. about 0.1 percent. Due to that conventional concrete is highly brittle and rigid. This lack of bendability is a major cause of failure under strain and has been a pushing factor in the development of an elegant material known as Bendable concrete. Bendable concrete (ECC) is a new class of HPFRCC micro-mechanically designed to achieve high damage tolerance under severe loading and high durability under normal service conditions.

Bendable concrete(ECC) is made from the same basic ingredients as conventional concrete but with the addition of high- range water reducing (HRWR) agent is required to impart good workability. The main ingredients in an ECC are fine aggregate, cement and fibre. Cementitious materials, such as fly ash, silica fume, blast furnace slag, silica fume etc. may be used in addition to cement to increase the paste content. The powder content of ECC is relatively high. Additionally, ECC uses low amounts, typically 2% by volume, of short, discontinuous fibres. ECC incorporates super fine silica sand and tiny Polyvinyl Alcohol-fibres covered with a very thin (nanometre thick), slick coating. This surface coating allows the fibre to begin slipping when they are over loaded so they are not fracturing. Different ingredients of ECC work together to share the applied load. ECC has proved to be 50 times more flexible than traditional concrete, and 40 times lighter, which could even influence design choices in skyscrapers. Additionally, the excellent energy absorbing properties of ECC make it especially suitable for critical elements in seismic zones.

II. LITERATURE REVIEW

S.M. Gadhiya (2013) has carried out parametric study on bendable concrete to find out compressive strength, flexural strength and deflection characteristic for different types of fibres for varying depth of beams. Comparison study for fresh and hardened properties of concrete has been carried out for different fibers and deflection of specimen with respect to the depth of specimen found out. The results shows that the compressive strength of ECC with steel fibers is 5% more than Conventional concrete were as for PVA and Hybrid fibers it is 15% and 20% less than Conventional concrete. Density of ECC is 20 % lower than Conventional Concrete. Flexural strength and deflection is inversely related with the cross section area of the specimen. ECC with increasing % of Fibers increases about 20% of Energy Absorption whereas by increasing cross section of the specimen, 10% of increment in Energy absorption is evaluated.

Jian Zhou et al. (2012) experimented on improved 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.

Mustafa Sahmaran et al. (2012) experimentally studied to find out the influence of the high volumes of fly ash (FA) and micro poly-vinyl-alcohol (PVA) fibers on the cyclic freeze–thaw resistance and microstructure of the Engineered Cementitious Composites (ECC). They prepared ECC mixtures with two different FA–cement (FA/C) ratios (1.2 and 2.2 by weight), and at constant water-cementitious materials (fly ash and cement) ratio of 0.27. Experimental tests consist of measuring the residual mechanical properties (flexural strength, mid-span beam deflection and flexural stress-deflection curve), ultrasonic pulse velocity and mass loss were conducted. The results confirm that both ECC mixtures with high volumes of FA remain durable, and show a tensile strain capacity of more than 2% even after 300 freezing and thawing cycles. The results indicate that the addition of micro PVA fiber to the ECC matrix improved the frost resistance. The results of freeze–thaw tests indicated that the reduction of residual physical and mechanical properties with increasing number of freeze–thaw cycles is relatively more for ECC mixture with FA/C ratio of 2.2 than for ECC mixture with FA/C ratio of 1.2.

Salahuddin Qudah et al. (2014) carried out experimental study to evaluate the feasibility of using ultra-ductile Engineered Cementitious Composites (ECC) as a means to enhance the performance of Type-2 interior beam–column connections. They have tested interior connections at a zone 3 as per uniform building code (UBC) of high seismicity under reverse cyclic loading for simulating seismic excitation. The test results indicated that the use of ECC material in the connection plastic zone as a replacement of concrete and partial replacement of transverse reinforcement can significantly enhance the joint shear resistance, energy absorption capacity, and cracking response which enhancing the joint seismic resistance and reducing reinforcement congestion and construction complexity. They found that all ECC-enhanced specimens had exhibited a higher capacity compared to the control specimen. The amount of increase in the energy dissipation capacity obtained from the use of ECC ranged from 11% to 20%.The results shows a reasonable safety factor against shear stress-induced joint failure under cyclic loading.

Yu Zhu et al. (2014) experimental studied on mechanical properties of engineered cementitious composites (ECC) produced by high volume mineral admixtures which are fly ash, slag and silica fume. The water–binder materials ratio (W/B) is kept at 0.25 for various ECC mixtures. 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. 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.

Mustafa Sahmaran et al. (2013) experimented on 36 different ECC mixtures to evaluate the combined effects of the following factors on workability and rheological properties: water-binder (w/b), sand-binder (s/b), super plasticizer-binder (SP/b) ratios and maximum aggregate size (D_{max}). A mini-slump cone, a Marsh cone and a rotational viscometer was used to evaluate the workability and rheological properties of ECC mixtures. Experimental results indicate that w/b, s/b and SP/b parameters affect the rheological and workability properties. On the other hand, for the range of studied aggregate sizes, Dmax is found to be statistically insignificant on the rheological and workability properties of ECC, also in addition to that the mid-span beam deflection capacities, which reflect material ductility, of ECC mixtures varied noticeably with the change of s/b and Dmax design parameters. Both of these two parameters negatively affect the deflection capacity of the ECC mixtures. The other parameters have almost no effect on the mid-span beam deflection capacities of ECC mixtures.

Suleyman Bahadir Keskin et al. (2014) published a correlation between the viscoelastic properties and cracking potential of engineered cementitious composites. Along with the mechanical properties of ECC, viscoelastic properties like autogenous shrinkage, drying shrinkage and tensile creep which were used to calculate ECC's cracking potential were studied. The tendency of ECC mixtures to crack under restrained shrinkage conditions was also investigated by him using restrained shrinkage rings. The results shows that The compressive strength of the mixtures containing GGBFS was higher than that of the mixtures containing FA due to the earlier reaction, self-cementing property and high specific surface area of the GGBFS compared to FA. When the amount of the mineral admixture was increased, the drying shrinkage of the mixtures decreased significantly. Low compatibility of GGBFS is attributed to lower ductility, lower tensile creep and higher shrinkage, which in turn resulted in higher induced tensile stresses. Mixtures containing FA had higher tensile creep compared to the mixtures with GGBFS.

Mustafa Sahmaran et al. (2012) carried out experimental study to find out the influence of the high volumes of fly ash (FA) and micro poly-vinyl-alcohol (PVA) fibers on the cyclic freeze–thaw resistance and microstructure of the Engineered Cementitious Composites (ECC). They prepared ECC mixtures with two different FA–cement (FA/C) ratios (1.2 and 2.2 by weight), and at constant water-cementitious materials (fly ash and cement) ratio of 0.27. Experimental tests consist of measuring the residual mechanical properties (flexural strength, mid-span beam deflection and flexural stress-deflection curve), ultrasonic pulse velocity and mass loss were conducted. The results confirm that both ECC mixtures with high volumes of FA remain durable, and show a tensile strain capacity of more than 2% even after 300 freezing and thawing cycles. The results indicate that the addition of micro PVA fiber to the ECC matrix improved the frost resistance. The results of freeze–thaw tests indicated that the reduction of residual physical and mechanical properties with increasing number of freeze–thaw cycles is relatively more for ECC mixture with FA/C ratio of 2.2 than for ECC mixture with FA/C ratio of 1.2.

Li-li Kan et.al. (2012) investigated self-healing behaviour of Engineered Cementitious Composites (ECC) materials. Crack characteristics of M45-ECC and HFA-ECC specimens pre-loaded to strain levels of 0.3%, 0.5%, 1.0% and 2.0% were investigated. This was done at different ages, resonant frequency and mechanical recovery behaviour of re-healed ECC materials, new crack paths after reloading and the chemical analysis of healing products. Based on the experimental results, ECC with multiple micro-cracks benefits self-healing behaviour. Longer aged samples and high fly ash contribute to create more cracks of smaller width. Ultimate tensile strength and tensile strain capacity of the majority ECC specimens at reloading are higher than the control specimens without cracks.

M. G. Albert et al. (2014) experimented on Polyolefin fibre-reinforced concrete enhanced with steel-hooked fibres in low proportions. Four types of conventional fibre-reinforced concrete with steel and polyolefin fibres were produced on the basis of the same self-compacting concrete also manufactured as reference. These concrete mixtures were manufactured separately with the same fibre contents being subsequently used for two more hybrid mixtures. Fracture properties, in addition to fresh and mechanical properties, were assessed. The result revealed that it is possible to produce a hybrid fibre reinforced self-compacting concrete with a combination of hooked steel fibres and macro polyolefin fibres, preserving the high performance fresh properties within the most common self-compacting requirements. It should also be noted that the addition of Fibres did not noticeably change the compressive strength, indirect tensile strength or modulus of elasticity of the reference SCC for any of the amounts, types or combination of fibres used.

Jun Zhang et al. (2013) published a 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. 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.

Bensaid Boulekbache et.al. (2012) experimentally studied influence of the paste yield stress and compressive strength on the behaviour of fibre-reinforced concrete (FRC) versus direct shear. The parameters studied are the steel fibre contents, the aspect ratio of fibres and the concrete strength. Three types of concretes with various compressive strength and yield stress were tested, an ordinary concrete (OC), a self-compacting concrete (SCC) and a high strength concrete (HSC). The results show that the shear strength and ductility are affected and have been improved very significantly by the fibre contents, fibre aspect ratio and concrete strength. As the compressive strength and the volume fraction of fibres increase, the shear strength increases. The ductility was much higher for ordinary and self-compacting.

S.Z. Qian et al. (2010) investigated the self-healing behaviour of Engineered Cementitious Composites (ECC) with focus on the influence of curing condition and pre-cracking time. Four-point bending tests was used to pre crack ECC beams at different age, followed by different curing conditions, including air curing, 3% CO2 concentration curing, cyclic wet/dry (dry under 3% CO2 concentration) curing and water curing. After self-healing, flexural stiffness was also retained significantly compared with that from virgin samples, even though the level of retaining decreases with the increase of pre-cracking time. The flexural strength increases for samples pre-cracked at the age of 14 days and 28 days, presumably due to continuous hydration of cementitious materials afterwards. Furthermore, it was promising to utilize Nano clay as distributed internal water reservoirs to promote self-healing behaviour within ECC without relying on external water supply.

Jin-Keun Kim et al. (2007) has evaluated tensile and dispersion performance of ECC produced with ground granulated blast furnace slag. They used water–binder ratios (W/B) of 60%, 48%, 38%, 35%, and 28% to measure the fiber/matrix interfacial properties and the fracture toughness of the mortar matrix. The results show that both ductility and tensile strength of the Slag-ECC were measured to be significantly higher than these values for the ECC without slag. The use of slag particles should be helpful for achieving strain-hardening behaviour. Although the toughness ratio decreases with the addition of slag particles at an identical W/C (60%), the tensile strain capacity of Slag-ECC is approximately 50% higher than that of ECC without slag. The contribution of slag particles in ECC improves workability.

Gabriel Jen et.al. (2015) carried out experimental study for observations of self-consolidated hybrid fiber reinforced concrete on corrosion damage reduction. Correlations between the rate of corrosion damage in reinforced concrete and observable cracking have been established by a multitude of design codes. A self-consolidated hybrid fiber reinforced concrete mixture is tested under a chloride-induced corrosive environment to determine the role of crack suppression in both the initiation and the propagation phases of corrosion damage. It is observed that in the presence of the hybrid fiber reinforcement, chloride migration rates are not significantly altered by the introduction of moderate cyclical mechanical loading in contrast to conventional concrete samples. Hybrid fiber reinforcement is providing an increased measure of durability.

III. CRITICAL REMARKS

Following remarks are carried out from above literature review;

1. The compressive strength of ECC with steel fibres is 5% more than Conventional concrete were as for PVA and Hybrid fibres it is 15% and 20% less than Conventional concrete.[1]
2. ECC with increasing percentage of Fibres increases about 20% of Energy Absorption.[1]
3. Compared with the standard mixing sequence, by adjusting mixing sequence increases the tensile strain capacity and ultimate tensile strength of ECC and improves the fibre distribution. [2]
4. The water to cementitious material (w/c) ratio 0.22-0.27 gives the best result. [2,3]
5. High volume fly-ash ECC maintained its unique characteristics of multiple-cracking, strain hardening and tight crack width control in extreme temperature condition. [3,11]
6. ECC-enhanced specimen exhibits a higher capacity compared to the conventional concrete. [4]
7. The tensile strain capacity of strain-hardening cement based composites is affected by freezing and thawing cycles. [14]
8. FA/C ratio of 4.4 gives good residual tensile ductility after the sub-elevated temperature exposures. [5]
9. The Polycarboxylate based super plasticizer mortar mixes give more workability and higher compressive and tensile strength at all ages compare with sulphonated melamine formaldehyde based SP. [6,7]
10. Water-binder (w/b), sand-binder (s/b), super plasticizer-binder (SP/b) ratios affect the rheological and workability properties. [6]

11. ECC mixtures with high volumes of FA remain durable, and show a tensile strain capacity of more than 2% even after 300 freezing and thawing cycles. [8]

12. Ultimate tensile strength and tensile strain capacity of ECC is higher than conventional concrete without cracks. The maximum crack width is below 80µm for M45-ECC, 40µm for HFA-ECC at 2.0% tensile strain damage. [9]

13. Addition of Fibres did not noticeably change the compressive strength, indirect tensile strength or modulus of elasticity of the reference SCC for any of the amounts, types or combination of fibres used. [10]

14. As the compressive strength and the volume fraction of fibres increase, the shear strength also increases. The ductility was much higher for ordinary and self-compacting. [12,10]

15. It was promising to utilize Nano clay as distributed internal water reservoirs to promote self-healing behaviour within ECC without relying on external water supply. [13]

16. Hybrid fiber reinforcement is providing an increased measure of durability. [15]

REFERENCES

[1] S.M.Gadhiya, "Parametric study on Bendable concrete", Journal of international journal for scientific research and development vol.3 (2015) pp.1494-1497.

[2] Jian Zhou, Shunzhi Qian, Guang Ye, Oguzhan Copuroglu, Klaas van Breugel , Victor C. Li, "Improved fibre distribution and mechanical properties of engineered cementitious composites by adjusting the mixing sequence", Journal of Cement & Concrete Composites 34 (2012) pp. 342–348.

[3] Mustafa Şahmaran a, Victor C. L," Durability properties of micro-cracked ECC containing high volumes fly ash", journal of Cement and Concrete Research 39 (2009) pp.1033–1043

[4] Salahuddin Qudah, Mohamed Maalej," Application of Engineered Cementitious Composites (ECC) in interior beam–column connections for enhanced seismic resistance", journal of Engineering Structures 69 (2014) pp.235–245.

[5] Yu Zhu, Yingzi Yang, Yan Yao, "Use of slag to improve mechanical properties of engineered cementitious composites (ECCs) with high volumes of fly ash", Construction and Building Materials 36 (2012) pp.1076–1081

[6] Mustafa Sahmaran, Zafer Bilici, Erdogan Ozbay, Tahir K. Erdem, Hasan E. Yucel, Mohamed Lachemi, "Improving the workability and rheological properties of Engineered Cementitious Composites using factorial experimental design", Journal of Composites: Part B 45 (2013) pp. 356-368.

[7] Suleyman Bahadir Keskin, Mustafa Sahmaran, Ismail Ozgur Yaman , Mohamed Lachemi," Correlation between the viscoelastic properties and cracking potential of engineered cementitious composites", journal of Construction and Building Materials 71 (2014) 375–383.

[8] Mustafa Sahmaran , Erdog˘an Özbay , Hasan E. Yücel , Mohamed Lachemi , Victor C. Li," Frost resistance and microstructure of Engineered Cementitious Composites: Influence of fly ash and micro poly-vinyl-alcohol fiber", journal of Cement & Concrete Composites 34 (2012) pp.156–165.

[9] Li-li Kan , Hui-sheng Shi," Investigation of self-healing behaviour of Engineered Cementitious Composites (ECC) materials", journal of Construction and Building Materials 29 (2012) pp.348–356.

[10] M.G. Alberti, A. Enfedaque, J.C. Galvez, M.F. Canovas, I.R. Osorio, " Polyolefin fibre-reinforced concrete enhanced with steel-hooked fibres in low proportions" , Journal of Materials and Design 60 (2014) pp. 57–65.

[11] Jun Zhang, Zhenbo Wang, Xiancun Ju, "Application of ductile fibre reinforced cementitious composite in joint less concrete pavements", Journal of Composites: Part B 50 (2013) pp. 224–231

[12] Bensaid Boulekbache, Mostefa Hamrat, Mohamed Chemrouk, Sofiane Amziane, "Influence of yield stress and compressive strength on direct shear behavior of steel fibre-reinforced concrete", Journal of Construction and Building Materials 27 (2012) pp. 6–14.

[13] S.Z. Qian, J. Zhou, E. Schlangen, "Influence of curing condition and precracking time on the self-healing behaviour of Engineered Cementitious Composites", Journal of Cement & Concrete Composites 32 (2010) pp. 686–693.

[14] Jin-Keun Kim , Jeong-Su Kim , Gee Joo Ha , Yun Yong Kim," Tensile and fiber dispersion performance of ECC (engineered cementitious composites) produced with ground granulated blast furnace slag", journal of Cement and Concrete Research 37 (2007) pp.1096–1105.

[15] Gabriel Jen, Claudia P. Ostertag," Experimental observations of self-consolidated hybrid fiber reinforced concrete (SC-HyFRC) on corrosion damage reduction", journal of Construction and Building Materials 105 (2016) pp.262–268.