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Bendable Concrete – State of the art

Vennam Swathi[1], Syed Khaja Mohiddin [2],

[1]*Department of civil Engineering &VFSTR University, vennam.swathichowdary@gmail.com*
[2]*Department of Civil Engineering& VFSTR university, khaja3046@gmail.com*

Abstract— Bendable concrete also known as Engineered Cementitious Composites abbreviated as ECC is class of ultra-ductile fibres reinforced Cementitious composites, characterized by high ductility and tight crack width control. This material is capable to exhibit considerably enhanced flexibility. An ECC has a strain capacity of more than 3% and thus acts more like a ductile metal rather than like a brittle glass. A bendable concrete is reinforced with micromechanically designed polymer fibres. Conventional concretes are almost un-bendable and have a strain capacity of only 0.1 percent making them 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 namely, bendable concrete. Bendable concrete is an easily moulded mortar-based composite reinforced with specially selected short random fibres, usually polymer fibres. Unlike regular concrete, bendable concrete has a strain capacity in the range of 3–7%, compared to 0.01% for ordinary Portland cement (OPC). Bendable concrete therefore acts more like a ductile metal than a brittle glass (as does OPC concrete), leading to a wide variety of applications.

Keywords— Bendable concrete, ductility, polymer fibers, strain capacity, OPC.

I. INTRODUCTION

However, coarse aggregates are not used in bendable concrete (hence it is a mortar rather than concrete). Additionally, bendable concrete uses low amounts, typically 2% by volume, of short, discontinuous fibers. Bendable concrete incorporates super fine (100 microns in diameter) 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. It prevents the fibre from rupturing which would lead to large cracking. Thus an bendable concrete deforms much more than a normal concrete but without fracturing. The different ingredients of bendable concrete work together to share the applied load. Bendable concrete looks similar to ordinary portland cement-based concrete except that it can deform (or bend) under strain. The new concrete looks like regular concrete, but is 500 times more resistant to cracking and 40 percent lighter in weight. Also, the materials in the concrete itself are designed for maximum flexibility. Because of its long life, the bendable concrete is expected to cost less in the long run, as well.

Bends Without Breaking ECC flexes without fracturing, due to the interaction between fibers, sand, and cement working in a matrix that binds everything together within the material. “In addition to reinforcing the concrete with fibers that act as ligaments to bond it more tightly,” Li explains, “we design the cement matrix with special ingredients to make it more compatible with the fibers and to increase flexibility.” Where ordinary concrete and fiber-reinforced concrete (FRC) are designed to resist cracking, ECC is designed to crack only in a carefully controlled manner. The cracks that appear in ordinary concrete and FRC are Griffith-type cracks; they increase in width as they grow longer. The cracks that are designed into ECC are steady state (or flat) cracks; the width of these cracks remains constant regardless of the length. “Through microstructure tailoring, we’re able to design ECC with a combination of materials such that the capacity of the fibers that bridge the cracks is greater than the capacity of the matrix to resist cracking,” Li explains. U-M holds several patents on ECC technologies.

II. LITERATURE

Jun Zhang et al. (2013) carried out an experimental study on the 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. The crucial problem that interfacial failure in composite slab was prevented by using reinforcing bars across the interfaces. 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.

Yu Zhu et al. (2014) carried out experimental study to investigate the mechanical properties of ECC produced by high volume mineral admixtures which are fly ash, slag and silica fume. Emphasis of this study is placed on building the correlation between compressive strength and the parameters obtained in load–deflection curves of 12 different ECC mixtures in binary and ternary system of binder materials with different mineral admixtures (FA, SL and silica fume) and to build the correlation between compressive strength and durability of ECC. The water-binder materials ratio (W/B) is kept at 0.25 for various ECC mixtures. The replacement levels of different mineral admixtures in all ECCs in binary systems of binder materials are 50%, 60%, 70% and 80%, respectively (FA + cement and SL + cement). In ternary system (FA + SL + cement and FA + SF + cement), the total replacement of mineral admixtures is 70%, the ratios of FA/SL and FA/SF are different in ECC mixture proportions. The toughness behaviour and compressive strength of 12 different ECC mixtures are firstly measured by four point bending test and compressive strength test, respectively.

Tahir Kemal Erdem (2014) carried out experimental work to study size effect on the residual properties of ECC was investigated on the specimens exposed to high temperatures up to 800°C. Cylindrical specimens having different sizes were produced with a standard ECC mixture. Changes in pore structure, residual compressive strength and stress–strain curves due to high temperatures were determined after air cooling. Standard ECC mixture (M45) with a fly ash-cement ratio (FA/C) of 1.2 by mass was used in this investigation which was prepared in a standard mortar mixer at water to cementitious material ratio of 0.27.

Bensaid Boulekbacheet al. (2012) carried out experimental study to examining the 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. Prismatic specimens of dimensions 10 * 10 * 35 cm made of concrete of various yield stress reinforced with steel fibres hooked at the ends with three fibre volume fractions (i.e., 0%, 0.5% and 1%) and two aspects ratio (65 and 80) were tested to direct shear. 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 concrete strengths investigated include 30 MPa for OC, 60 MPa for SCC and 80 MPa for HSC.

Soutsos et al. (2012) carried out experimental study on commercially available steel and synthetic fibres. Flexural stress – deflection relationships have been used to determine: flexural strength, flexural toughness, equivalent flexural strength, and equivalent flexural strength ratio.

The flexural toughness of concrete was found to increase considerably when steel and synthetic fibres were used. However, equal dosages of different fibres did not result in specimens with the same flexural toughness.

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III.INGREDIENTS OF BENDABLE CONCRETE

Engineered Cementitious composite or bendable concrete is composed of cement, sand, fly ash, water, small amount of admixtures and an optimal amount of fibers. In the mix coarse aggregates are deliberately not used because property of ECC Concrete is formation of micro cracks with large deflection. Coarse aggregates increases crack width which is contradictory to the property of ECC Concrete.

A. *CEMENT*

Cement used is Ordinary Portland cement. Numerous organic compounds used for adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. Blast furnace slag may also be used in some cements and the cement is called Portland slag cement (PSC). The colour of the cement is due chiefly to iron oxide. In the absence of impurities, the color would be white, but neither the colour nor the specific gravity is a test of quality. Ordinary Portland cement (OPC) – 53 grade (Ultratech Cement) was use.

B. *SAND(FINE AGGREGATE)*

Usually commercial sand is obtained from river beds or from sand dunes originally formed by the action of winds. The most useful commercially are silica sands, often above 98% pure. The fine aggregate obtained from river bed of Koel, clear from all sorts of organic impurities was used in this experimental program. The fine aggregate was passing through 4.75 mm sieve and had a specific gravity of 2.68. The grading zone of fine aggregate was zone III as per Indian Standard specification 4.3.

C. FLYASH

Fly ash used was pozzocrete dirk 60.And specifications provided by suppliers are given in Table 1.below. In RCC construction use of fly ash has been successful in reducing heat generation without loss of strength, increasing ultimate strength beyond 180 days, and providing additional fines for compaction. Replacement levels of primary class fly ash have ranged from 30-75% by solid volume of Cementitious material. In proportioning mixes for minimum paste volumes one principal function of a fly ash is to occupy void space which would otherwise be occupied by cement or water. To occupy void space with water would obviously result in reduction in concrete strength. The fact is that even a small amount of free lime liberated from cement is sufficient to react with large volume of fly ash.

TABLE I

Specifications of Fly ash:

1	Fineness-specific surface by Blaine’s permeability Method	320
2	ROS 45 micron sieve (max)	18
3	Loss on ignition	2.5
4	Water requirement	95%
5	Moisture content (max)	0.5
6	Soundness by autoclave(max)	0.1%
7	Compressive strength at 28 days of plain cement mortar(min)	85%
8	Lime reactivity (min)	5
	Chemical Analysis	
1	Sio2+Al2O3+Fe2O3	90min
2	2 Sio2	50min
3	3 Cao	5max
4	4 Mgo	4max
5	SO3	2max
6	6 Na2O	1.5max

D. **PVA FIBERS**

It has suitable characteristics as reinforcing materials for Cementitious composites. High modulus of elasticity, durability, tensile strength and bonding strength with concrete matrix are some of its desirable properties. PVA fiber has high strength and modulus of elasticity (25 to 40GPa) compared to other general organic fiber which widely used for cement reinforcing. Fiber elongation is about 6-10%. The tensile strength of fiber is 880-1600MPa.One of the remarkable characteristics of PVA fiber is strong bonding with cement matrix. The layer of Ca(OH)2 called ITZ(Interfacial transition zone) round PVA fiber is formed as white part, and in case of PP, this layer is not observed. It is known that PVA is easy to make complex cluster with metal hydroxide. It is assumed that Ca+ and OH- ions in cement slurry are attracted by PVA and makes Ca(OH)2layer. It seems reasonable to think that Ca(OH)2 layer plays important role for bonding strength. Figure 2.shows images of surface for coarse PVA fiber after single fiber pull-out test. This image implies that surface of PVA fiber is peeled by Ca(OH)2 layer and this phenomena is related to strong bonding between PVA fiber and cement matrix.

Fig.1. PVA Fibers

IV. **METHODOLGY**

A. BENDABLE CONCRETE MIX DESIGN

The mix design for ECC Concrete is basically based on Micromechanics design basis. Micromechanics are a branch of mechanics applied at the material constituent level that captures the mechanical interactions among the fiber, mortar matrix, and fiber–matrix interface. Typically, fibers are of the order of millimetres in length and tens of microns in diameter, and they may have a surface coating on the nanometre scale. Matrix heterogeneities in ECC, including defects, sand particles, cement grains, and mineral admixture particles, have size ranges from nano to millimimeter scale. However the micromechanics based mix design requires pull test to be carried on the PVA fibers, which is not possible in the laboratory. Hence the ideal mix proportion given in the literature of ECC-ECC Concrete was used as the guidelines to determine the proportion of various constituents in the concrete. The ideal Mix proportion which was taken as reference is given below:

B. **PROPORTIONING OF CONCRETE:**

The initial mix proportion was 1:0.8004:1.1996, PVA fiber 1% and super plasticizer dose was 1040.47 ml/bag and water to Cementitious material ratio was 0.274. But by using this proportion workability was not achieved. Hence for second trial, the mix proportion was changed to 1 : 0.9 : 1.1 and PVA fiber percentage increased to 1.2% by keeping same dose of super plasticizer and increasing water to Cementitious material ratio to 0.3048. Third trial mix proportion was 1:1:1 and PVA fiber 1.2%, super plasticizer dosage was reduced to 600ml/bag and water to cementitious material ratio was 0.33. Forth trial mix proportion was 1:0.9:1.1, PVA fiber percentage 1.2%, super plasticizer dosage 600ml/bag along with water to cementitious material ratio was 0.3118. To achieve workability various trials were taken. In fourth proportion super plasticizer dose was reduced to obtain workability. For each trial mix, 3 cubes were casted and cured using the accelerated curing tank & were tested to obtain desired strength requirement. After testing cubes for each trial, the trail mix no. 3 was considered as most suitable & hence the final mix proportion. However in order to increase the workability of concrete the water to cementitious ratio was increased to 0.35.

C. CASTING PROCEDURE OF ECC- CONCRETE:

The performance of the ECC Concrete was influenced by the mixing. This means that a proper & good practice of mixing can lead to better performance & quality of the ECC Concrete. The quality of the concrete is also influenced by the homogeneity of the mix material Flexural Test on Slab during the mixing & after the placement of fresh concrete. A proper mix of concrete is encouraged to the strength of concrete & better bonding of cement with the PVA fibers. Once the concrete mix design was finalized, the mixing was carried out. The mixing of ECC Concrete was carried out by using hand mixing. The procedure of hand mixing was as follows:- Add sand, cement, 50% of fly ash & 50% water &super plasticizer. Add slowly remaining quantity of fly ash, water &super plasticizer. Once the homogenous mixture is formed, add the PVA fibers slowly. Mix all the constituents till the fibers are homogenously mixed in the matrix.

D. CURING OF CONCRETE SPECIMEN:

After leaving the fresh concrete in the moulds to set overnight, the concrete specimens in the moulds were stripping. The identification of concrete specimens was done. After 24 hours, all the concrete specimens were placed into the curing tank with a controlled temperature of 25 0C in further for 28 days for the hardened properties test of concrete. Some of the cubes were cured in the Accelerated Curing Tank due to time limit. Curing is an important process to prevent the concrete specimens from losing of moisture while it is gaining its required strength. Lack of curing will lead to improper gain in the strength. After 28 days of curing, the concrete specimens were removed from the curing tank to conduct hardened properties test of ECC Concrete.

E. BENDS WITHOUT BREAKING:

ECC flexes without fracturing, due to the interaction between fibers, sand, and cement working in a matrix that binds everything together within the material. “In addition to reinforcing the concrete with fibers that act as ligaments to bond it more tightly,” Li explains, “we design the cement matrix with special ingredients to make it more compatible with the fibers and to increase flexibility.” Where ordinary concrete and fiber-reinforced concrete (FRC) are designed to resist cracking, ECC is designed to crack only in a carefully controlled manner. The cracks that appear in ordinary concrete and FRC are Griffith-type cracks; they increase in width as they grow longer. The cracks that are designed into ECC are steady state (or flat) cracks; the width of these cracks remains constant regardless of the length. “Through microstructure tailoring, we’re able to design ECC with a combination of materials such that the capacity of the fibers that bridge the cracks is greater than the capacity of the matrix to resist cracking,” Li explains. U-M holds several patents on ECC technologies.

V.APPLICATION

FIRST APPLICATION IN THE U.S:

MDOT initiated the first use of ECC in a U.S. transportation infrastructure project in 2005. The Grove Street Bridge over I94 in Ypsilanti was originally built using steel girders supported at concrete piers. The girders supported cast-in-place concrete decks. A mechanical expansion joint was used between these simple decks to allow for deck deformations imposed by deflection, concrete shrinkage, and temperature variations. Over time, deterioration of joint performance allowed water and deicing chemicals to leak through the joint and over the sub structure and ultimately resulted in severe damage to the bridge deck and substructure (see Figure 2)

VI.ADAVANTAGES

A. Lower Environmental Impact, Less Expensive :

Over Time The results of a study conducted by Keoleian, Kendall, Lepech, and Li (2006) provide another indication that ECC could play a key role as a material in sustainable transportation infrastructure applications. This study used life cycle modelling techniques to compare the sustainability performance of a bridge that uses traditional steel expansion joints to that of a bridge that uses ECC link slabs. Life cycle modeling is completed in two parts. The first involves performing a life cycle assessment, which provides a measure of environmental and social impacts of using a product, system or technology. The second part is a life cycle cost analysis, which uses life cycle assessment data to calculate costs from various perspectives.

B. Exciting Possibilities for Sustainable Applications:

Dr. Michael Lepech, research fellow at the University of Michigan’s Center for Sustainable Systems, and a co-author of the ECC link slab project, is keenly interested in this process of experimentation that requires a holistic approach to development. “It comes down to sustainability,” Lepech explains. “A sustainable system is one that takes all components into consideration and creates cooperation and synergy among them.” ECC is an exciting material for those interested in sustainability. The very process of designing ECC, for example, lends itself to experimentation with recycled, reclaimed, and waste materials. “Our growing understanding of the interaction between fibers, sand, and cement within ECC enables us to precisely adjust anyof the elements to accommodate variations in the others.” Lepech explains. An experimental version of ECC that uses a combination of cement kiln dust and green foundry sand to replace some or all of the ordinary cement and sand actually performed better than a version that used the ordinary materials. Cement kiln dust is a byproduct of the portland cement production process. Green foundry sand is a by-product of the metal casting process. Both materials are produced in large quantities in Michigan, and both have historically been disposed of in landfills. “It’s great to be able to put these otherwise useless and even environmentally damaging materials to use like this”.

VI.CONCLUSIONS

This research work 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 principles. The result is a moderately low fiber volume fraction (<2%) composite which shows extensive strain-hardening, with strain capacity of about 3 to 5% compared to 0.01% of normal concrete. According to test results, the beam is withstanding high load and a large deformation without succumbing to the brittle fracture typical of normal concrete, even without the use of steel reinforcement. The significant properties of ECC- Concrete are ductility, durability, compressive strength, and self-consolidation. The cost of ECC is currently about three times that of normal concrete per cubic yard. However initial construction cost saving can be achieved through smaller structural member size, reduced or eliminated reinforcement elimination of other structural protective systems, and/or faster construction offered by the unique fresh and hardened properties of ECC. When long term cost and environmental impacts are accounted for, as suggested by the life cycle cost/impact analyses for the ECC bridge deck highlighted above, the advantages offered by ECC over conventional concrete become even more compelling.

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