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Engineered Cementitious Composite(ECC): Bendable Concrete

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ABSTRACT

Bendable concrete also called as "Engineered Cementations Composites (ECC)" is an ultra-ductile fiber reinforced composites with extreme tensile ductility which has the ability to control the hard crack width. Generally in construction sector normal concrete is used but normal concrete can't take much tensile stresses. In that case, Bendable Concrete can be used in place of normal concrete. There has been a lot of progress in the production of Bendable Concrete with extreme tensile ductility over the last decade. Coarse aggregates are not used in this concrete. Instead of that some fibers are used to provide the flexibility of concrete like Jute fiber, Coir fiber, Steel fiber, Asbestos fiber, Recron fiber, Polyvinyl alcohol fiber etc. It is 500 times more capable of cracking resistance and 40% lighter in weight. Tensile strain capacity of Bendable Concrete can be 3-5% compared to 0.1% for Normal Concrete. In the future it is going to be in special demand in construction field because it has some special qualities such as flexibility, self-healing, lighter weight, etc. A review on Bendable Concrete has been put in this paper.

KEYWORDS: ***Bendable Concrete, Engineered Cementitious Composite(ECC), Self healing, Ductility, Flexibility, Conventional Concrete***

1. INTRODUCTION

Bendable concrete is an Engineered Cementitious Composite (ECC) that exhibits the properties of ductile material as opposed to the fragile nature of conventional concrete. Professor Victor Li at University of Michigan first introduced this Bendable Concrete. Victor C Li et al.(2006)[1] carried out an experimental study to develop bendable concrete. It is a special type of concrete that are capable of carrying tensile stress more than the conventional concrete by incorporating special type of materials. Conventional concrete is not flexible and has a strain capacity of only 0.1% which makes them extremely brittle and rigid. The material composition of conventional concrete is modified to provide a flexible nature to the concrete. Natural and artificial fibers are used instead of coarse aggregate and fly ash used in place of cement. Bendable Concrete or ECC is more stronger, durable and long lasting than conventional concrete. It prevents more Cracking. ECC has high energy absorption capacity, so, it is a critical element in seismic

zone. This paper describes on bendable concrete and its advantage, disadvantage, application. Differences between conventional concrete and Bendable concrete are also highlighted.

2. SCOPE

In present day, various types of research are being done on Bendable concrete. Fiber is playing an important role in bending of concrete. Bendable Concrete shows effective results than Conventional Concrete. It is highly flexible as the ratio of water to cement decreases. So strength of bendable concrete increases and fly ash also improves the workability. Bendable Concrete is more durable and it has a very good self healing property. In future it will give efficient result in construction sector.

Fig-1: Conventional Concrete(left) vs Bendable Concrete(Right) after a bend test

3. MAKING ECC

ECC is usually made of materials found in concrete, including cement, sand, fly ash, super plasticizer. No coarse aggregates are added and no air entrainment. Microfiber is added instead of that. The type, size, amount of all materials and the order of their mixing is done carefully.So that the resulting composite keep their self-consolidating nature during casting and also ductile behavior after hardening. Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation to develop ECC. The components of an ECC mix design have been adapted on which process the fiber, mortar matrix and the interface between them communicates under mechanical loading using micromechanics. As a result, Fragile fracture failure is eliminated. The design of the ECC is similar to the design of a well-engineered structure That employs, load-bearing behavioral of structural elements like beams, column and connections. In ECC the design of composite with fiber, The matrix and the interface are on a smaller length scales but conceptually equal.

Fig-2: ECC or Bendable Concrete

4. COMPOSITION

The most important is material collection for construction, else we can't go ahead for any type of construction like building construction , pavement construction etc. Neenu SK (2019)[4] done an experimental investigation for composition using in bendable concrete . The availability of resources or materials must be checked before starting any construction. Name of some materials regularly used in our construction-

1. Cement
2. Fly ash
3. Fine Aggregates
4. Fibers
5. Water

1. CEMENT:

Cement is used as a binder or a powdery substance prepared by calcining lime and clay and by mixing water to form mortar and sand, gravel to make concrete. Mostly, the raw materials used for manufacturing of cement are of lime, silica, alumina and iron oxides.There are different types of cement like Ordinary Portland cement, Portland pozzolana cement, Rapid hardening cement, Quick setting cement, Sulphate resisting cement, Low heat cement, Hydrophobic cement, Air entraining cement, Expanding cement, High alumina cement, Blast furnace slag cement, White cement, Colored cement.

2. FLY ASH:

Fly ash is result of pulverized coal burningat electric power generating plants.Mineral impurities in the coal combine in suspension throughout combustion and float

out of the combustion chamber with the evacuate gases. After rising merged material it cools and solidifies into Spherical glassy particles that is called fly ash. Fly ash contains exhaust gas together electrostatic precipitators .The fine powder is chemically different but similar to Portland cement .The chemical reaction between cement and water release calcium hydroxide that chemically reacts with fly ash to form additional cementations products that improve many desirable properties of concrete .Class C and Class F type fly ash are frequently used in concrete.Class C are generally high-calcium fly ashes with carbon satisfied less than 2%; whereas, Class F are low calcium fly ashes with carbon contents with a reduction of than 5% but sometimes as high as 10%. Generally class C ashes bitter from flaming sub-bituminous or lignite coals and Class F ashes bituminous or anthracite coals. Depending upon the chemical and physical properties of the ash and how it interacts with cement in concrete properties along with class C and F ashes are different. Reacting with water Class C ashes become hard just like cement, but not Class F ashes .In this project 30% of cement is replaced with Class C fly ash.

Table -1: Physical properties of fly ash

Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation on Physical Properties of fly ash.

Fineness	Retained on 45 micron sieve
Specific gravity	1.90 - 2.96
Shape	Spherical glassy shaped
Color	Depends upon the chemical composition
Constituents	Mineral

Table -2: Chemical properties of fly ash

Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation on Chemical Properties of fly ash.

Sl no	**Description Property**	**Average Range of Values (%)**
1	SiO2	**44-58**
2	Al2O3	**21-27**
3	Fe2O3	**4-18**
4	CaO	**3-6**
5	MgO	**1-25**
6	SO3	**0.3-1.7**

3. Fine aggregate:

Fine aggregates are the problem arising from the separation of mineral grain storage rocks. The difference between fine aggregate and Gravel is only the size of the grains or particles. It is separated from clays containing organic materials. Normally, From river beds or from sand dunes commercial sand is obtained, formed by the action of winds. Silica sands above 98% purity are most commercial used sand. Beach sands are free of organic matter. For mortar ,concrete, polishing and sand blasting sand is used.

4. Fibers:

So many fibers are used to provide the flexibility of concrete like Jute fibers, Coir fibers, Steel fibers, Asbestos fibers, Recron fibers, Polyvinyl alcohol fibers etc. In this paper, jute and coir fibers are used for composition.

4.1 Jute Fibers:

Jute fiber is obtained from white corchorus capsular plants.. It is a natural fiber generally knownas "Golden fiber". Jute fiber is manufactured by hand harvesting of the source plant, drying in the field fordefoliation, retting for periods up to a month, stripping and sun drying in the field.

Table-3 Chemical Properties of jute fiber

Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation on Physical Properties of Coir Fiber.

Length	0.6mm
Diameter	0.1-1.5mm
Density	1.40 g/cc
Tenacity	10
Breaking	30%
Elongation	27.4%
Tensile strength	210 MPa
Specific Gravity	0.87

4.2 Coir fiber:

After extracting from the husk of coconut coir or coconut fiber is used in products such as floor mats, door mats, brushes and mattresses. After 6 to 12 months harvesting

coconuts palm contain pliable white fibers. We obtain brown fiber when the nutritious layer nearby the seed is ready to be processed into copra and desiccated coconut in completely harvested full grown coconuts.

To estrange the fibrous stratum of the fruit from the hard shell drive the fruit down onto a spike to split it (dehusking).

Fig-3: Coir fiber

Table-4 Physical properties of Coir

Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation on Physical Properties of Coir Fiber.

Length	0.6mm
Diameter	0.1-1.5mm
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Tensile strength	210 MPa
Specific Gravity	0.87

5. TESTING OF MATERIALS

Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation on testing of composition of bendable cement[8] . Material testing is a test done to determine the propertiesof a substance in comparison with a standard orspecification and to test the behavior of building materials.The following are the tests based on the standard orSpecification.

1. Tests on cement:

A. Fineness test

B. Specific Gravity of Cement 3.14

C. Determination of Normal Consistency of Cement

Table-5 Normal Consistency of cement

Sl No	Percentage of water	Amount of water added in ml	Penetration depth of needle
1	26	78	16
2	28	84	5

Yadavalli Sandeep et al.(2019)[8] carried out an experimental investigation on normal consistency test on cement.

Determination of Initial & Final Setting time of Cement

Initial setting time =48 minutes

Final setting time = 600 minutes

2.Tests on fine aggregate:

A. Particle Size Distribution:

Fineness modulus of a given sample of fine aggregate is 1.04, bulking Of Sand

3. Tests on Fly Ash:

The fineness test of the fly Ash is carried out by using thesieve size of 90 microns such that it is fine enough to beused as the admixture for the replacement of cement. The specific gravity of the fly ash is carried out by usingthe Lechartliers flask. The procedure is similar to that ofthe specific gravity of cement test.

By using the sieve size of 90 microns fly ash fineness test is done to use the admixture for replacement of cement that it is fine enough to be used. By using the Lechartliers flask specific gravity of fly ash is executed. This test is same as the specific gravity of cement test.

6. SELF HEALING PROPERTIES

The self-healing process generally takes advantage of pre-existing materials.Even in ordinary concrete a significant percentage of the cement grains stay behind unused and inactive because they never be hydrated. The unhydrated grains chemically with water and carbon dioxide in the air to form a strong compounds known as calcium carbonates.The fractures in conventional concrete are generally so large that even when calcium carbonates do form they provide virtually no benefit.

However, when the cracks are small adequate no more than 50 μm these compounds can accumulate in such a way as to fill the cracks, thus repairing the concrete and exit behind nothing but a scar. the self-healing concrete repairs its properties, counting its ductility, its stiffness, and its ability to withstand the intrusion of such corrosive agents as water and road salt.

7. APPLICATION OF BENDABLE CONCRETE

1. Construction of Roads & Bridges :- Expansion and contraction of joints can be avoided in building roads and bridges using bendable concrete. This is because bendable concrete has the ability to change its shape.

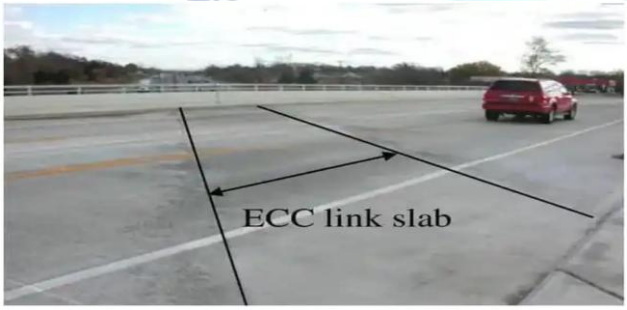

Fig-4: ECC Link Slab

2. Construction of Earthquake Resistance building :- Buildings made of flexible concrete have the ability to withstand more tensile stresses. That's why it can resist high vibration like earthquake.

Fig-5: Earthquake resistance building made with ECC

3. Construction of Concrete Canvas:- Concrete canvas is specially made for military purposes which is extremely strong and durable which can be achieved efficiently using bendable concrete.

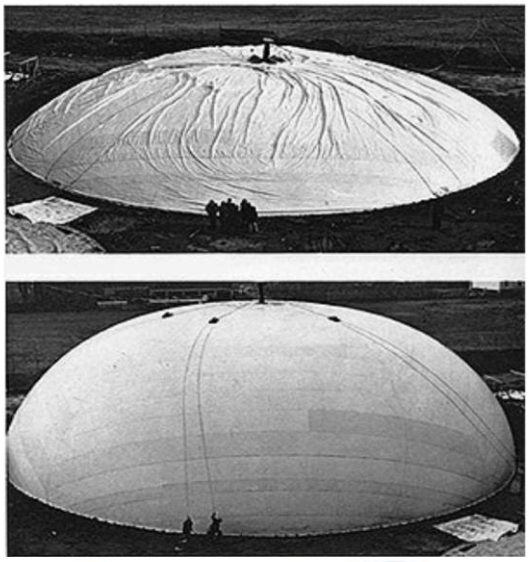

Fig-6: Concrete Canvas made with ECC

Structural Application :-

1. Firstly, When the 60 year old Mitaka dam (Japan) was damaged, had cracks and water leakages in 2003 it was renovated. about 600 m^2 surface area was covered by a 20 mm thick layer of ECC.
2. Second incident also took place in 2003 in Japan. An earth retaining wall in Gifu was repaired by using ECC. it was cracked largely ECC was applied instead of Portland cement.
3. As Japan has to face earthquake regularly. The 95m heigher apartment building contain 54 ECC coupling beams to resist earthquake. Same structure has been used in 41 storey nabeaure Yokohama Tower (4-Coupling Beams per floor).
4. The Mihara Bridge in Hokkaido which is about 1 km long also witnessed the use of 800 m^3 of ECC materials. ECC has some properties like its tensile ductility and selfhealing which can decrease 40% weight.
5. Finally, one more instance is a bridge in Michigan in 2005. ECC is applied for its exclusive mechanical properties instead of Portland cement. The University of Michigan and the transportation department of Michigan monitored it and verify the durability of ECC. 4 year passed but the concrete remained undiminished.

8. ADVANTAGES AND DISADVANTAGES

Advantages:-

1. Bendable concrete has more durability than normal concrete.
2. It has more ductility than normal concrete.

3. Strength of bendable concrete is higher than normal concrete.
4. It can resist the crack most.
5. It emits fewer amounts of harmful gases than normal concrete.
6. In comparison of weight it is 20 to 40% lighter than normal concrete.
7. By using bendable concrete we can diminish steel reinforcement and cost.
8. It has possessions of self-healing
9. In making of precast concrete and jointless bridge we can use it.
10. For reducing the crack width it can be used.
11. To increase the concrete flexural strength it can be used.
12. To increase life span and durability of pavement it can be used.
13. ECC is a material for conducting green construction.
14. ECC produce 39% less carbon dioxide and consumes 40% less energy compared to normal concrete.
15. To decrease the emission of green house gases it can be used.
16. As a earthquake resistant it can be used in structures

Disadvantages:-

1. Skilled labor is needed for flexible cost.
2. It is costly for flexible concrete construction at its initial stage.
3. It is difficult to get special materials for flexible concrete.
4. It has low compressive strength than normal concrete.
5. Quality of flexible concrete varies depending upon its materials quality and atmospheric condition it is built.

COMPARISON

Vipul Solanki et al.(2021)[7] carried out a comparison between conventional concrete and bendable concrete.

Table-6 comparison between Conventional concrete and bendable concrete

Point Of Difference	Conventional Concrete	Engineered Cementitious Composite (ECC)
Durability	For the application of normal concrete structures are less durable than the application of flexible concrete.	For the application of bendable concrete the structures are more durable & reliable.
Earth Quake Resistance	When the structure made with the normal concrete the possibility of cracks or may collapse during earthquake is more than flexible concrete.	When the structure made with the bendable concrete dose not break easily by the earthquake motion. So the structures made with the bendable concrete enough capable to resist the earthquake.
Self Healing Property	Self healing property of normal concrete is very low and it is very low free cement concrete.	By the reaction of carbon-dioxide and water the bendable concrete heal the micro cracks itself. So we say that bendable concrete has a very good self healing property.
Repair & Maintenance	Due to develop cracks and other defect the repair and maintenance cost of normal concrete structure is very high.	The repair and maintenance cost of the bendable concrete is very low because there are no cracks and any defect in the bendable concrete structure.
Self Weight	The self weight of normal concrete is higher than self weight of flexible concrete.	The weight of bendable concrete is 30-40% lighter than normal concrete.
Reinforcement	For normal concrete steel bar reinforcement is required for taking a tensile load.	For bendable concrete fiber reinforcement cannot provide the required tensile strength to the concrete so steel reinforcement is required to provide tensile strength of the structure.

Curing Time	Normal concrete structure generally required more curing time almost 28 days.	The bendable concrete generally requires less curing time. (maximum 7 days)
Labor	For normal concrete structure skilled labor is necessary.	For bendable concrete structure more talented and skilled labor is required.
Cost	The cost of construction of normal concrete structure is less because normal concrete structures are generally made with the common material.	Initial cost of construction of the bendable concrete structure is more.

9. Conclusion

Continuous pursuit of bendable concrete to address the brittle nature of the ubiquitous building material of modern human history. 'Engineered Cementitious Composites (ECC) – Bendable Concrete' is an essential work by Prof. Victor C. Li of University of Michigan. Bendable concrete is having best outputs when compared with conventional concrete. Therefore its proved that the ECC Concrete or bendable concrete has more strength than the conventional concrete. It is more flexible so it can reduce cracks and acts more efficiently in seismic regions. ECC as a high performance cementitious composite adds the important ductile behaviour with greater crack control property that promises to transform the future of built infrastructure. In future ECC will be a material with the potential multi-functional properties that could address critical challenges, namely resilience, durability and sustainability faced by infrastructure sector on a global scale. Lots of research scope remains for further improvement and development of ECC for efficient and cost effective application.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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