ENGINEERED CEMENTITIOUS COMPOSITES-A REVIEW.

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Abstract - This paper presents current scenario about various active research that are taking place around the world on study of behavior of Engineered Cementitious Composites (ECC) by incorporating Polyvinyl Alcohol (PVA) and other kinds fibers and by using various mineral ad-mixtures. Engineered Cementitious Composites is mainly designed based on paradigm of micro-mechanical interaction with exceptional strain capacity of about 3 to 5% compared to 0.01% of normal concrete. The volume fraction of the fiber used is also less than 2 percent and showing an extensive strain hardening behaviour of the composites.

Keywords- ECC, fibers, mineral ad-mixtures.

1 INTRODUCTION

Concrete is the most popular construction material because of its special properties such as versatility, durability and easy to handle, due to these special properties more than 11.4 billion tons of concrete consumed annually worldwide. Ordinary Portland cement, though costly and energy intensive is the most widely used ingredient in the production of concrete mixes.

The creation of ECC is mainly motivated on micromechanical interactions that occur between ingredients and way of processing. Interaction occurs between fibers and matrix is recognized as key factor which governs ECC behaviour, resulting in interfacial zone modification techniques so as to design desired properties. Fiber ruptures in ECC are prevented and pull-out of fiber from matrix is achieved by the use of suitable mineral admixtures. Thus improving tensile strain capacity 3-7% for ECC containing 2% fiber by volume. Micromechanical interaction recounts macroscopic properties of the microstructure of composite, and forms spine for ECC material design theory. Especially, books for microstructure tailoring of ECC along with material optimization. The Micromechanical models were constructed on the basis of fracture mechanics and deformation mechanism these are the parameters which are provide an opportunity for tailoring micromechanical parameters so as to control failure mode, tensile strength and various other parameters.

2 OBJECTIVES

- To investigate the properties of ingredients of Engineered Cementitious composites (ECC)
- To investigate the Mix Design procedure of ECC

3.INGREDIENTS OF ECC CONCRETE

3.1 Ordinary Portland Cement

Ordinary Portland cement (often referred to as OPC) is the general type of cement in use around the world ,because it is the basic key ingredient for making concrete, mortar, stucco and most of the grouts specially prepared for specific purpose. It is made by intergrinding of argillaceous and calcareous materials .

Physical properties of OPC

1. Fineness

Particle fineness of Portland cement affects rate of hydration, which affects the rate of strength gain. Smaller is the particle size, the greater is the surface area-to-volume ratio, means more area is available for the reaction of water-cement per unit volume.

2. Soundness

The ability of a hardened cement paste to retain its shape after setting is known as soundness. The cement samples containing excessive amounts of free lime are subjected to volume change. Soundness of cement is determined by using Le chartliars equipment.

3.Consistency

The ability of cement paste to flow is known as consistency. The cement paste consistency is determined by using Vicat apparatus when the plunger penetrates by 10±1 mm and the corresponding water-cement ratio is reported as the Std consistency of cement.

4. Setting Time:

Initial setting time is defined as the time that elapsed from the instant of adding water until the pastes behave as plastic material thus offering resistance against the penetration. Whereas final setting time referred to be the time that is required for the cement paste to reach a certain state of hardness to bear some load and is tested by using Vicat apparatus.

5. Specific gravity:

The particle density which is measured by excluding the air between particles of OPC is found to be in the range of 3.1 to 3.25. The density of cement is determined by density bottle apparatus and here kerosene is used.

3.2 Sand

- Good river bank sand in absence of any earthy matter and organic matter.
- Particles are angular in shape passing 250 micron and retaining 150 micron standard sieve.
- Sample is washed in water to get free from silty and earthy and other organic content and dried over a period of 48 hours of sunlight.

3.3 Water

Water which fits for drinking purpose is considered for mixing the ingredients, and should be free from suspended impurities and foreign matters such as acids, alkalis. Water plays two key roles in a concrete mix. Firstly, it chemically reacts with constituents of cement to form paste where paste holds aggregates in suspension phase until paste hardens. Secondly, it act as lubricant in mixing of ingredients.

3.4 Flyash

In the coal powered power generating plants the exhaust gases which comes out after burning is treated with electrostatic precipitators and the fine particles that collected in it is known as flyash and the ash which doesn't comes out with the exhaust flue gases is termed bottom ash. Fly ash constitutes substantial amount of silicon dioxide (SiO_2) in the form of both amorphous and crystalline form and calcium oxide (CaO), both being effective ingredients in many coal-bearing rock strata.

3.5 Super plasticizer

This is used to improve the rheological properties of fresh concrete. Super plasticizers are the additives to fresh concrete which helps in dispersing constituents uniformly throughout the mix. This is achieved by their deflocculatiion action on cement particles by which water entrapped is released and is available for workability. Super plasticizer increases slump properties from 5cm to 20cm without addition of water and thereby reducing the water requirement by 15 to 20 percent. This results in improvement of vital properties like density, water tightness. Where sections are having closer reinforcements, the use of super-plasticizer increase workability and no compaction is required. The permeability of concrete is key property which contributes to durability ,the use of superplasticizer increases workability maintaining low water to cement ratio. The permeability of cement paste reduces considerably with reduction in water to cement ratio. Thus super plasticizer can be used effectively to improve various properties of concrete and to avoid defects like honeycombing.

3.5 Fibers

The high performance fiber reinforced cementitious composite is characterized by the presence of fibers in a less quantity compared to FRC .Generally the fiber used in ECC is PVA ,One of the remarkable characteristics of this fiber is capable of strong bonding with cement matrix. The layer of $Ca(OH)_2$ called as Interfacial transition zone is formed round PVA fiber and is formed as white part, and in case of poly propylene, and glass it is not observed . It is known PVA makes complex cluster with the metal hydroxide of cement matrix. It is pursued that Ca^+ and OH^- two different ions in the cement slurry are attracted by PVA fibers and makes layer of $Ca(OH)_2$ around the fibers and hence the $Ca(OH)_2$ layer plays an important role for bonding strength between the fiber and the matrix. However there is an absence of some surface coating around the Poly propylene fibers and glass fibers which are possessing high tensile strength but they are not coated with any epoxy and they are susceptible for alkali environment of matrix this makes us to do an experimental study by selecting these fibers.

4. REVIEW OF EXPERIMENTAL INVESTIGATIONS ON ECC

The mix design for ECC Concrete is mainly based on Micromechanics design. The principle of Micromechanics is useful at the material constituent level which has a outstanding mechanical interaction among the fiber, mortar matrix, and fiber–matrix interface. Naturally, fibers are of the order of millimeters in length and tens of microns in diameter and they may have a surface coating on the nanometer scale. The heights of the PVA fibers used by various researchers vary between 8 mm and 12 mm diameter of 40μm. The ideal mix proportion given in the literature determines the proportion of various constituents. The tests on ECC are carried out to assess the various wet properties as well as hardened properties. The tests on hardened property mainly include flexural tests. The focus has been made to present information about the work performed by various pioneers in developing this type of ductile concrete.

Major physical properties of ECC

Compressive Strength (MPa)	First Crack Strength (MPa)	Ultimate Tensile Strength (MPa)	Ultimate Tensile Strain (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Density (g/cc)
20 – 95	3 – 7	4 – 12	1 – 8	18 – 34	10 – 30	0.95 – 2.3

Table 3.3: Mix design for experimental work on ECC taken

	Cement	Fly Ash/ Metakaolin	Sand	Water	HRWR*	Fiber (Vol %)
Ratio	1.0	1.2	0.8	0.56	0.012	0.02
Kg/m3	587	704.6	469.9	299.7	17.31	Based on density of fiber
Per cube	166gms	199gms	132.8gms	87.89ml	5ml	

The ECC was developed and here the PVA fibres are used, the percentile of fibres was varied from 1.2% to 2.2% in the interval of 0.2%. In the experimental programme the ECC was prepared for two different mineral ad mixtures such as fly ash and rice husk ash. The beam specimens were casted for size of 304.8mmx76.2mmx12.2mm for a particular mix of PVA and different ad mixtures and were cured by poly ethylene sheet covered for 48 hrs,and then water cured for 14, 28 and 56days and mainly tested for flexure .They found controlled mixes show no deflections whereas fly ash based mix with the fibre content of 1.4% resulted in best load carrying capacity and with maximum deflections, whereas the rice husk based mix was resulted in taking up very less load and deflections these observations were reported by **Dr.M.Rame Gowda ,Ms Uma Devi et al** .

The cost of ECC is almost 3 times the cost of normal concrete hence it was generally not used for mass construction works , hence the test was conducted for the development of ECC in the mix design ratio of cement : sand : fly ash in the range of 1:1:1 and fibres by 1.2%. and they casted the cubes ,cylinders and beams for determining compressive, tensile capacity and flexural behaviours of the specimens according to IS standards and are cured in water for 7,14 and for 28 days .The test were indicted improvement in compressive ,tensile and flexural behaviour compared with the normal concrete mixes hence they found the suitable mixes that can be incorporated for large volume structural applications without loss of any ductility. Reported by **Dr.A.W.Dhawale et al**

There is a lot of innovative research were taking place around the world in studying and developing the various parameters of ECC. The mix proportioning of ECC was mainly based on micro mechanical modelling of constituents of ECC. The different researchers had proposed different mix proportions based on the various rheological parameters of ECC and this paper illustrates important facts of various research activities that are going around the world on studying various rheological and hardened properties of Engineered Cementitious Composites (ECC). Engineered Cementitious Composites design is mainly based on micromechanical modelling with strain capacity exceeding 3 to 5% compared to that 0.01% of normal concrete and volume fraction of the fibre is also less than 2% compared large amount of fibres say 5-10% in FRCC. The various experiments reviews reported by **Srinivasa. C. H. et al.**

Sustainable material designing process incorporates microstructures that interwoven with analysis of the life cycle, with special focus on parameters such as social, economic and environment. The new innovations has been made in the developments of engineered cementitious composites with distinctive features of extreme ductility which was judged to be better in some of the features than fibre reinforced concrete (FRC). But the major demerit of Engineered Cementitious Composites (ECC) is about the lack of design based load bearing capacity as structural members of building components. Rather, it is mostly designed for infrastructural applications where it is majorly fit comfortably for the repairs and retrofitting of existing structures. In the research work, some preliminary experimental work was done with the use of natural sand

and with the cement substitution of natural mineral admixture, metakaolin, added with Nano silica and epoxy without any fibre. The fresh properties show some features that are way better than the features of the base design M45 ECC. Since Metakaolin is possessing high pozzolonic reactivity which modifies the microstructure of concrete and enhance the overall mechanical and durability performance of ECC .By using metakaolin in the presence of Nano silica, epoxy can produce a better cementitious composite which possessed higher standard than ECC M45 at ages 28 and 56. The addition of Nano silica is also resulted increase in the strength of concrete made of metakaolin. reported by **Alonge O. Richard and Mahyuddin Ramli**

Studying the property of FRC shown, its dependence on one or two parameters at a time, typically the fiber volume fraction, or fiber length. However, it is now well-known that composite materials properties depend on three groups of constituent properties they are – the fiber, matrix and interfacial properties the importance of this recognition is the fiber volume fraction, for example, is representing the one of more than ten constituent parameters under our control for material engineering. Composite material optimization requires the combined influence of all relevant parameters on composite to be known. Composite with excellent performance with only moderate fiber volume fraction, thus meeting the favourable characteristics of ideal FRC representing latest family known as ECC. Fibre is added to counteract the high brittleness behaviour of the dense matrix and this dense matrix forms the strong bond with the fibre thus resulting in a high post crack resisting strength as long as fibre retains its strength. For ECC, approach is to create synergy between the composite materials thus to maximize the tensile ductility by the development of closely spaced multiple micro cracks by minimizing fiber content generally 2% or less by volume, for the better workability mix proportion they proposed in the mix ratio of 1:1.2:0.8 parts of cement: fly ash: sand, for improved rheological properties and hardened properties reported by **Dr Victor c. Li.**

In this paper an initial attempt has been made by using iron ore tailings by replacing the cement in ECC to develop the greener engineered cementitious composites (ECCs). ECC is representing a unique class of high-performance fibre-reinforced cementitious composites possessing high tensile and durability properties. However, the usage of high cement content in ECC limits the material greenness property and increases the cost of ECC compared to normal concrete. In this research paper, IOTs in amorphous form is used and the partial replacement of cement with IOTs so as to develop the environmental friendly ECC. The newly developed versions of ECC in this research paper involves the cement content of 117.2–350.2 kg/m3, which exhibit the tensile ductility in the order of 2.3%–3.3%, tensile strength in the order of 5.1–6.0 MPa, and the compressive strength in the order of 46–57 MPa for a period of 28 days. The replacement of cement with IOTs resulted in comparative reduction in energy consumption upto 10–32% and reduction in carbon dioxide emissions upto 29–63% in green ECC compared with energy consumption made for production of cement used in typical ECC production. Thus, the feasibility of producing of greener ECC with significantly reducing the impact environment using IOTs, and maintaining the properties of typical ECC reported by **Xiaoyan Huang, Ravi Ranade and Victor C. Li.**

Engineered cementitious composites (ECCs) are representing the latest generation of fiber-reinforced cementitious composites (FRCC) with noticeable improvement in strain-hardening behaviour. As ECCs possess high tensile and durability properties, due to the high usage cement in the mixture resulted vast environmental and economical impacts. In this mentioned paper, the study of mechanical properties of ECCs by incorporating the high volume bottom ash and fly ash is reported. Importance is focussed on the influence of fly ash content which promotes the key micromechanical properties relevant to composite ductility. It is revealed that a high volume faction of fly ash tends to reduce the polyvinyl alcohol fiber and matrix interface and matrix toughness is in the favour of attaining high tensile strain capacity. The cement substituted with bottom ash and fly ash is subjected to a constrained parameter i.e. compressive strength. The micromechanical interaction parameter study revealed the general descending trend of interface frictional stress and chemical bond with increase of fly ash content, which in turn modifies the PVA fiber-matrix bridging. In addition, an increase of fly ash content also leads to lowering of the matrix toughness both trends are favourable for strain hardening. Strong correlation between the matrix and fiber strain capacity was observed, which is a good indication of composite strain hardening potential. It is mentioned that a proper mixture proportioning process can achieve high material performance even when using locally available low quality waste products as cement substitutions, as long as the governing micromechanics parameters were carefully checked. Although the study is mainly focused on flexural ductility of cementitious composites, the researchers believe that this approach is broadly applicable to other sustainable material design practice. reported by **Shuxin wang and Victor c. Li.**

This paper reports on the development of ECC, taking into account environmental sustainability considerations. ECC is representing a unique class of high-performance fibre-reinforced cementitious composites possessing high tensile and durability properties. With the ultra-high volumes of fly ash up to 85% by weight of cement replacement, are proposed in this research paper.

While micromechanical modelling is applied in the material design process, main focus of this study is placed on the fly ash content effect on material microstructure and mechanical properties altering process. Experimental results shown that HVFA ECCs, while addition high volumes of recycled fly ash, which can retain an approximately 2 to 3% of long-term tensile ductility. Significantly, both the free drying shrinkage and crack width are reduced with an increasing volume of the fly ash amount, which results in the improvement of long-term durability of structures made by HVFA-ECC. Micromechanical modelling analysis indicates the increase in fiber and matrix interface behaviour is responsible for the tight crack width. HVF-ECCs show an improvement robustness by achieving more saturated multiple cracking while the use of industrial waste stream material instead of cement resulted in reducing environmental impact through the use. Reported by **Yingzi Yang, En-Hua Yang, and Victor C. Li**

Concrete is one which extremely accepted as vital component of today's society and is being used in various and different infrastructures that are very critical for the flawless and comfortable function of the world. Due to the property of very strong in compression yet comparably weak in tensile nature of cement concrete resulted in Fiber Reinforced Concrete, very little can be done in terms of load bearing and high tensile strains applications. Engineered Cementitious Composite solves the resulting problems and provides even more better advantages in application through its unique and distinctive properties of self-healing, high, tensile strength and ductility where tensile strength is almost 500 times that of standard concretes. Application of ECC on the commercial level resulting benefits are many, based on the concept that the standard repair cost structural life cycle has increased dramatically, the superior compressive strength of the concrete can possibly improve the structural integrity of the structures it's used in, and average maintenance cost and time as a whole is decreased. This not only improves durability and safety, but also cuts down on cost of materials used for maintenance of structures which in turn decrease negative impact on environment. The initial investing cost may be high results in proposal of an alternate to the general use of Engineered Cementitious Composite, however the long term savings from its application, will surpass initial expense that occur. Experimentation with Engineered Cementitious Composite is latest innovation on-going, and the fields of application are tremendous and forever expanding for Engineered Cementitious Composite. The seemingly exciting characteristics of this bendable, self-repairing concrete are being proven to be more and more applicable to society as application and testing continues, and in the future, the Engineered Cementitious Composite is going to become more prevalent in commercial concrete projects. Reported by **Jayne Marks, Jon Conklin**

Over the past decade, various experiments had been made in field of creating engineered cementitious composites (ECC) with superb performance in tensile ductility, in the range of several hundred times than the normal concrete or fiber reinforced concrete (FRC).On-going latest ECC research investigations include application in the field of load carrying structural members in modern infrastructure systems, as well as the repair and rehabilitation of existing structures. ECC design has been built on the basis of the relationship between the material microstructures, properties, processing and materials performance. This concept of material microstructures modeling was worked out very well in creating the various versions of ECC that can be prepared by using different materials as self-consolidating, casting, extrusion, and spraying. This research describes the initial attempt in creating greener ECCs, ECCs that maintain the extreme tensile ductility characteristics, but which also incorporate adopting various environmental considerations in the design and development of these materials for infrastructure applications. Sustainable ECC material design adopts the microstructure design tailoring based on various social, environmental, and economic aspects. The framework for developing green ECC has been described. Some preliminary experimental results of the cement substitution with various mineral ad mixtures and also the fiber substitution with industrial by-products and their effects on the mechanical properties are reported. Concrete and ECC show very significant differences in both fresh and mechanical properties . ECC production is resulting in a greater environmental burdens than concrete due to high content of cement usage of standard ECC, and the inclusion of various synthetic fibers. ECC material is made only sustainable in terms of the usage of solid waste produced, flyash which is an industrial waste produced from coal-based power plants. The analysis suggests that the reduction in the usage cement content of ECC and PVA fibers may be the possible methods of increasing the economy and sustainability of greener ECC material. In this research one type of bottom ash and Two types of fly ash i.e. Fine fly ash is representing a two special type Class C fly ash and class F fly ash .The Class C fly ash with particle size of average 2 μm and high calcium content, whose particle size is much smaller than general class F fly ash of average 13 μm are investigated, and the Fine fly ash is representing a special type of Class C fly ash with high amount calcium content, and particle size of average 2 μm which is much are much smaller than class F fly ash of average 13 μm and the bottom ash of average particle size 50 μm is used. Bottom ash, due to its low pozzolonic reactivity, this leads to both lower early but long-term strength in the ECC. Mapping of the greener ECC properties to the required properties for specific interest of infrastructural applications resulted to a minimum performance reduction in the performance of infrastructure, while greatly enhancing the life and sustainability indices. . **Reported by Victor C. Li, Michael Lepech et al**

3. CONCLUSIONS

Concrete is one which extremely accepted as vital component of today's society and is being used in various and different infrastructures that are very critical for the flawless and comfortable function of the world. Due to the property of very strong in compression yet comparably weak in tensile nature of cement concrete resulted in development of Engineered Cementitious Composite with unique and distinctive properties of self-healing, high, tensile strength and ductility where tensile strength is almost 500 times that of standard concretes.

The various investigations carried out by several authors related to the development of Engineered Cementitious Composite (ECC) and its applications in the real world proves to be one of the best sustainable concrete materials of the future generations.

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