International Journal of Emerging Technologies in Engineering Research (IJETER)
Volume 4, Issue 9, September (2016) www.ijeter.everscience.org

Experimental Study on Mechanical Behavior of Engineered Cementitious Composites

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Abstract – Engineered Cementitious Composite (ECC) is a ductile fiber reinforced cementitious mortar composite. Unlike conventional concrete, ECC has fiber, mineral admixture and chemical admixtures along with the basic constituents (i.e.) cement, fine aggregate and water. No coarse aggregate is used in ECC to avoid brittle failure. PVA fibers are known for their low modulus of elasticity, ductility, tensile strength and bonding strength, whereas, Steel fiber increases the flexural, impact and fatigue strength of composite. Hence a combination of these two fibers is used in this work. Fly ash is a material that was proved to be a good replacement for cement, from the previous studies. It occupies the void space in the matrix which would otherwise be occupied by water. GGBS consists of silicates and aluminates of calcium and hence is a good substitute material for cement and hence these two mineral admixtures are used for the experimental studies. In this project, a series of investigations has been carried out to employ hybrid ductile fibers (PVA and steel fibers) in ECC with high volume of mineral admixture (fly ash) replaced for cement. The amount of mineral admixtures is again replaced by 10%, 20%, 30% and 40% of GGBS and the performance of the resulting composite is studied.

Index Terms – Flyasht; GGBS; PVA fibre; steel fibre;ECC.

1. INTRODUCTION

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 primary objective of this project is to design a kind of green ECC containing high volumes of combination of mineral admixtures and charactering excellent ductility and high strength, especially at early age. Four ECC mixtures with constant W/B of 0.25 are prepared with combined inclusion of FA and GGBS as constant cement replacement level of 70%. The laboratory measurements are carried out, including compressive strength, flexural strength and splitting tensile strength tests.

Behavior of ECC

The characteristic ECC strain hardening after matrix first cracking is attended by sequential development of multiple micro-cracking and the tensile strain capacity is 300–500 times greater than that of normal concrete. The formation of multiple micro cracking is necessary to achieve high composite tensile ductility. By quashing cracks in the presence of large imposed structural deformations, ECC can offer structural durability improvements in addition to water-tightness and other serviceability enhancements. These properties, together with a relative ease of production including self-consolidation casting and shotcreting, make ECCs suitable for various civil engineering applications. ECC with low fibre volume contents offer smaller crack width, superior tensile strength, significantly higher ductility, and self-healing characteristics. Since stone chips are not used, skyscrapers and other load bearing ECC structures would be comparatively light weight than conventional RCC or steel fibre reinforced concrete structures.

2. MATERIALS

The materials used for ECC mix are ordinary Portland cement, fine aggregate, Fly ash, GGBS, PVA fibre, Stainless Steel fibre and super plasticizer. 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. Ground-granulated blast-furnace slag is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Stainless steel fibers are manufactured fibers composed of stainless steel. Composition may include carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulphur (S), and other elements.

PVA fiber 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. Super plasticizer used is Melamine Formaldehyde Sulphonate. This is used to control rheological properties of fresh concrete. Super plasticizers are additives to fresh concrete which help in dispersing the cement uniformly in the mix.

Fig 2.1 Stainless steel fibre

Fig2.2 PVA fibre

3. EXPERIMENTAL INVESTIGATION

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. Various mix proportions used for the investigation is shown in Table 3.1

Table.3.1. Mix Proportion for Various Replacements (kg/m^3)

RATIO	CEMENT	FLYASH	GGBS	SAND	SP(%)	W/C RATIO
R_0	381.6	890.4	0	462	1.3	0.5
R_1	381.6	763.2	127.2	462	1.3	0.5
R_2	381.6	636	254.4	462	1.3	0.5
R_3	381.6	508.8	381.6	462	1.3	0.5
R_0 – 70-0% , (70% FA, 0% GGBS)						
R_1 – 60-10%, (60%FA, 10% GGBS)						
R_2 – 50-20%, (50% FA, 20% GGBS)						
R_3 – 40-30%, (40% FA, 30% GGBS)						

Workability test

Marsh Cone Test

This test is done to determine the relative fluidity of cement pastes with super plasticizer. It is a simple and practical method for obtaining a relative measure of the paste fluidity, as the inverse of the flow time, by measuring the time taken for a certain volume of paste to flow through a cone with a small opening; the longer the flow time is, the lower the fluidity. Two kg of cement is taken as a constant for all percentages of Super plasticizer (SP). First SP is mixed thoroughly with 70% of water and then mix it with remaining 30% of water. Then SP and water is mixed with the cement which form a paste. And poured it in the marsh cone apparatus to measure its fluidity. The time taken for 500ml paste into the beaker is measured. The paste is mixed to prevent it from settling for 60 min and again measure the time taken for the flow. The procedure is repeated for several ratios of SP (like 1.2%, 1.3%, 1.4%, 1.5%,..)

Fig 3.1 Marsh cone apparatus

Table3.2 Result of Marsh Cone Test

SP(%)	Volume of SP (ml)	At 0 Seconds	After 1 hour
1.2	24	5.01	6.18
1.3	26	5.9	6.2
1.4	28	6.03	6.24
1.5	30	5.4	6.3
1.6	32	4.7	5.1

After fixing the ratio of SP, casting can be done with that ratio as a constant for all replacement levels. First all the cementitious materials (cement, FA, GGBS) is mixed thoroughly and then mixed them with sand. water and SP is added separately. PVA fiber and steel fiber is added to the cementitious materials and thoroughly mixed them. Then the mould is filled with concrete mix in three layers and compacted them well as it is a cementitious mix to find the mechanical behavior of ECC. For every replacement levels, three specimens of cube(70.6x70.6x70.6)mm, cylinder and prism were cast. Curing is done for 7 days and 28 days by immersing in the water. Before testing of specimens, they were dried.

4. TEST RESULTS AND DISCUSSION

The mechanical properties such as compressive strength, split tensile strength and flexural strength are assessed by testing the companion specimens after 28 days curing.Table.4.1, 4.2 and 4.3 shows the mechanical properties of ECC for different replacements of fly ash and GGBS. Fig.4.1, 4.2 and 4.3 represents the mechanical properties of ECC.

Table.4.1. Compressive strength of ECC

Replacement level	Average compressive strength (N/mm2)	
	At 7 days	At 25 days
R_0	10.05	21.2
R_1	19.4	23.65
R_2	11.7	15.6
R_3	10	13.4

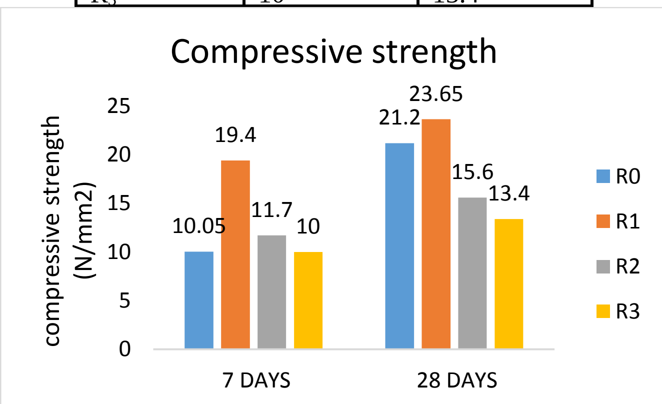

Fig 4.1 Compressive strength at 7 & 28 days

Table.4.2. Split tensile strength of ECC

Replacement level	Average split tensile strength (N/mm2)	
	At 7 days	At 28 days
R0	1.82	3.1
R1	1.92	3.6
R2	1.63	2.81
R3	1.61	2.6

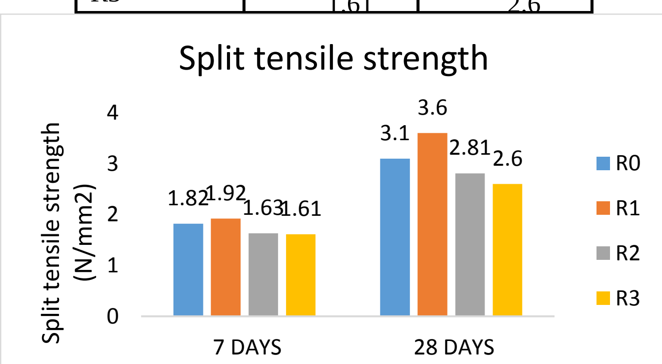

Fig 4.2 Split tensile strength at 7 & 28 days

Table.4.1. Flexural strength of ECC

Replacement level	Average flexural strength (N/mm2)	
	At 7 days	At 28 days
R0	1.9	3.6
R1	2.7	4.4
R2	2.4	3.9
R3	2.1	3.68

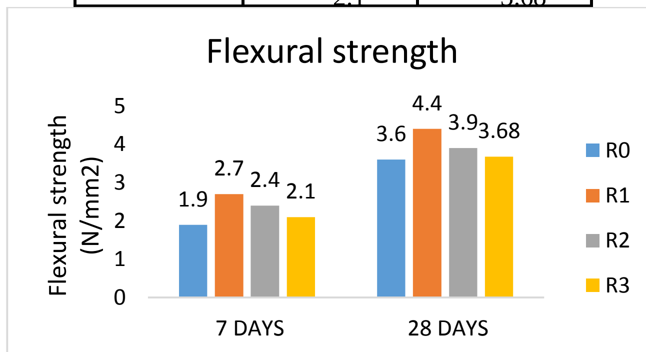

Fig 4.3 Flexural strength at 7 & 28 days

5. CONCLUSION

An experimental investigation has been carried out to check if the replacement of cement by admixture of fly ash and GGBS can satisfy the properties of ECC. 70% of the total cementitious content is replaced by mineral admixture (fly ash) and further fly ash is replaced by GGBS. Further to analyze the composite behavior 0.5% of steel fibre and 1% of PVA fibre were additionally added to the matrix. The following conclusions were drawn from the experimental work.

- ✓ The mixture used here achieved the requirements to be satisfied for ECC. Usage of steel fibres increased the strength properties whereas PVA fibre increased the micro cracking mechanism and also increased the flexural strength.
- ✓ However, the quantity of total fibre used here is only 1.5% of total volume of the matrix and hence the cost incurred for fibre is comparatively low than HPFRCC.
- ✓ Increasing the percentage of GGBS results in an increase of mechanical properties (i.e.) compressive strength, flexural strength and split tensile strength.
- ✓ GGBS when added separately has no impact on the strength properties but when combined with PVA, shows good improvement in the strength. This is due to the formation of a chemical bond between them which enhances the strength of ECC.

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