Impact of Fine aggregate Characteristics on Performance of Engineered Cementitious Composites

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Abstract

Engineered Cementitious Composite (ECC) is one of the worldwide using high performance-based construction composites. It consists of various materials including fine aggregates that can influence the characteristics of ECC. In this paper, the river sand of Indian Zonal-II category is used in place of silica sand at different fly ash to cement dosage (F/C is 1.4,2.0) to study the impact on the performance of composite. For this, four ECC mixtures as F\_1.4\_SS, F\_1.4\_RS, F\_2.0\_SS, and F\_2.0\_RS were considered. The specimens were casted and cured for 28, 56, 90 and 120 days of curing period. The test results revealed that flowability of the composite decreased by the usage of 4.75mm grain size sand and that was improved with the increasing dosage of fly ash. Mechanical characteristics of ECC not effected with the size of aggregate up to 4.75mm but impacted with increased fly ash content. The durability of 28 days cured specimens with a higher dosage of fly ash and river sand (F\_2.0\_RS) showed higher chloride ion penetration compared to silica sand based normal ECC mixture. Chloride ion penetration in the composite reduced with the increased curing period. Cost analysis revealed that the utilization of high dosage of fly ash and river sand reduced the cost of construction.

Keywords: Engineered Cementitious composite, Grain size of fine aggregate, Fly ash, Fresh properties, Mechanical characteristics, Rapid chloride penetration test

1. Introduction

Engineered Cementitious Composite (ECC) is a versatile construction material. This was introduced by Victor C.Li for the stability of the structural elements in the late 1990s [1-3]. ECC consists of various materials such as cement, PVA fibers, silica sand, fly ash, superplasticizers namely Polycarboxylate ether, etc [4-6]. These materials are responsible for the tremendous properties of the composite that are self consolidation, self-healing properties, and résistance at elevated temperatures, etc [8-12]. The tensile strain of this composite will increase more than 3% by using optimum dosage (2%) of polyvinyl alcohol fibers (PVA) and this is higher than fiber reinforced and conventional concrete [13-16]. These fibers are also responsible for resistance to cracking. However, once the cracks formed that will expand and results failure of structural elements [17, 18]. The crack propagation in the structural elements is mainly due to the addition of aggregates. In conventional concrete, the major portion is occupied with aggregates for economic reasons [19, 20]. Aggregates especially large sizes will badly affect the aggregate-cement paste interlocking bond in concrete and that is responsible for crack propagation. Therefore, the exclusion of aggregate will reduce this problem.

Victor c.li [21] excluded the coarse aggregates and limited to fine aggregates with smaller particle size in the preparation of composite and it termed as ECC. The silica sand of grain size 200μm was used for self-consolidation of the composite but the cost is more compared to local available fine aggregates. So need to use local fine aggregates without affecting the characteristics. Mohamed A.A. Sherir et al. [20] investigated the influence of 1.18mm gain size of motor sand as fine aggregate on the performance of ECC. Replacing silica sand with motor sand decreased the slump flow but not significantly affected the mechanical characteristics of ECC. The durability of ECC decreased with increased voids due to the utilization of large size motor sand. Therefore, replacing silica sand with 1.18mm grain size of motor sand will decrease the slump flow and durability but no significant effect on mechanical properties. So, proper care to be considered while the selection of the cost-effective fine aggregate that should not affect the performance of ECC. Very limited studies done related to the impact of fine aggregate on the properties of ECC. In the present paper, Indian zonal-II Category River sand with maximum grain size of 4.75mm used in place of silica sand to investigate the fresh properties and mechanical characteristics. The rapid chloride penetration test (RCPT) was conducted to study the durability characteristics of ECC. Cost analysis was done for choosing of better ECC mixture.

2. Experimental Program

2.1. Constituents

In this present work, Ordinary Portland cement (OPC-53) was used according to IS 12269-1987 [22]. Fly ash according to ASTM C 150 Class-F category (ASTM 2012a) is utilized [23]. The chemical characteristic of the cement and fly ash was mentioned in the table-1. PVA fibers of 12mm length, diameter of 39μm were used. The density, tensile strength and stiffness of the PVA fibers are 1300kg/m3, 1600MPa, and 40Gpa, respectively. Fine aggregates according to IS 383-2016 [24] was used and its physical characteristics and chemical composition were mentioned in table-1, 2. Silica sand of mean size 100μm and maximum size of 200μm was used. Polycarboxylate ether type Turbopol CEA50 was used for the required slump flow according to ASTM C494 [25].

Table-1: Chemical composition of ECC Constituents

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Chemical composition (%) | Cement | Fly ash | Silica sand | River sand  (Indian zone-II category) |
| Cao | 64.35 | 2.78 | 0.015 | 0.61 |
| Sio2 | 20.23 | 59.07 | 99.83 | 88.75 |
| Al2o3 | 4.67 | 25.63 | 0.020 | 2.92 |
| Fe2o3 | 3.98 | 4.57 | 0.007 | 3.27 |
| Tio2 | 2.56 | 0.83 | 0.001 | 0.46 |
| Mgo | 0.45 | 1.22 | 0.003 | 0.21 |
| others | 3.76 | 5.9 | 0.124 | 4.51 |

Table-2: Sieve analysis for fine aggregates

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| IS sieve size (mm) | Weight retained | | Cumulative % retained | Cumulative %passing | Limit as per Is 383-2016 | Remarks |
| (gm) | % |
| 10 | 0 | 0 | 0 | 100 | 100 | Confirmed to Zone-II category sand |
| 4.75 | 17 | 1.7 | 1.7 | 98.3 | 90-100 |
| 2.36 | 176 | 17.6 | 19.3 | 80.7 | 75-100 |
| 1.18 | 181 | 18.1 | 37.4 | 62.6 | 55-90 |
| 0.6 | 256 | 25.6 | 63 | 37 | 35-39 |
| 0.3 | 189 | 18.9 | 81.9 | 18.1 | 8-30 |
| 0.15 | 152 | 15.2 | 97.1 | 2.9 | 0-10 |

2.2 Mixing process

The mixing process is one of the parameters that need to be considered while mixing ECC. If proper mixing not done that may lead to material segregation. In this investigation, the mixing process followed based on past researchers [26-29]. Pan Mixer with 120L capacity was used to mix the ingredients with constant rotation speed for proper mixing. Initially cement, fine aggregates fly ash, and PVA fibers were mixed for 5min. Water and Polycarboxylate ether added later and mixed for 3min for consistency of ECC. This mixture placed in the moulds to cast specimens and removed after 2days.These specimens were immersed under water curing for 28, 56, 90 and 120 days.

2.3 Mixing proportions

Four ECC mixtures as mentioned in table-3 were considered to test the impact of fine aggregate size/type on the performance of ECC. The first and third set of specimens were casted with silica sand at F/C of 1.4, 2.0 respectively. Second and fourth set of specimens were casted with river sand at F/C of 1.4, 2.0 respectively. Slump flow (T50) conducted and Cube, prism, cylindrical specimens were casted with these mixtures for analysis the performance.

Table-3: Mix proportions of composite

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mix ID | Ingredients(kg/m3) | | | | | | | | |
| cement | FA | Water | Silica sand | River sand | PVA | PCE | FA/C | w/b |
| F\_1.4\_SS | 487 | 682 | 320 | 431 | - | 26 | 4.55 | 1.4 | 0.27 |
| F\_1.4\_RS | 483 | 676 | 317 | - | 427 | 26 | 4.55 | 1.4 | 0.27 |
| F\_2.0\_SS | 391 | 782 | 317 | 425 | - | 26 | 4.20 | 2.0 | 0.27 |
| F\_2.0\_RS | 387 | 774 | 312 | - | 416 | 26 | 4.20 | 2.0 | 0.27 |

PVA: Poly Vinyl alcohol, FA: fly ash, PCE: Polycarboxylate ether, w/b: water to binder ratio

2.4. Experimental Tests

2.4.1. Fresh characteristics

T50 slump test was conducted to investigate the flowability and self-consolidation of the SS-ECC and RS-ECC mixtures according to ASTM C1611 [30]. The slump cone with lower diameter/upper diameter (D0/D1) is equal to 200/100mm and height 300mm was placed on the steel plate of 900 ×900mm that had a circle 500mm at the center. After placing of ECC mixture, raised the slump cone and allowed to spread. The distance between the diameters of two orthogonal (D2) was measured after complete spreading of the mixture.

The characteristic deformability factor mentioned in the below equation used to know about self-consolidation

For good consolidation; Deformability factor must be less than 2.75 (according to 2007, Lepech and Li)

2.4.2 Hardening characteristics

2.4.2.1. Compressive strength

The cube specimens of size 70.7×70.7×70.7mm were casted to analyze the compressive strength of ECC. These specimens were placed for testing to analyze the strength. The specimens were tested with the rate of loading is140kg/cm2/min as per IS: 516-2013 [31]. The compressive strength can be determined with formulae mentioned below.

Where P= Compressive load, A=cross-sectional area

2.4.2.2 Split tensile strength

The Ø150mm×300mm size cylindrical specimens were casted with different ECC mixtures. These specimens were placed under testing as given in figure-1 to test split tensile strength according to IS 5816-1999[32]. All the specimens were subjected to 1.2N/mm2/min rate of loading. The strength can be find by the formulae mentioned below.

Pa=split tensile load; d=depth, l=length of the specimen

P

Cylindrical specimen

P

‘

Failure ( or) cracking pattern of specimens

Fig.1, (a) Specimen before loading Fig. 1(b) Specimen after loading

The schematic representation of specimens under loading was mentioned in fig-1(a), fig.1.(b).

Where P=Loading on the specimen (N/mm2)

2.4.2.3. Flexural strength

The flexural strength test was conducted for determination of flexural strength under general loading as per IS: 516-1959 [33]. The size of the specimens of 100×100×500mm was considered. All these specimens were placed under the flexural testing machine (100 Ton loading frame) as shown in figure-2 and rate of loading 140kg/cm2/min was applied. The flexural strength can be determined with formulae is mentioned below.

Pb=flexural load; b=breadth, d=depth, l=length of the specimen

100

100

Prismatic specimen

Pb

400

50

50

Fig.2.Schematic representation of prismatic specimen under flexural loading (specifications in mm)

2.4.2.4. Durability

To analyze the durability of ECC mixtures (SSECC and RSECC), the test RCPT was conducted as per ASTMC1202 [34]. For this, composite specimens of 100mm diameter ad 50mm height were used. NaOH and NaCL solutions were poured into the RCPT reservoirs that are present two sides of the composite for measure the penetration level of chloride ions into the composite.

2.5. Results and Discussion

2.5.1Fresh properties

The T50Slumpcone test conducted for all ECC mixtures at different fly ash ratios (F/C 1.4 to 2.0) with silica sand and River sand of Indian zonal-II. The orthogonal dimensions of spread mixture and flow time after lifting of slump cone on steel plate were taken and that was mentioned in table-4. The slump flow decreased by 28% from F\_1.4\_SS to F\_1.4\_RS and 20.2% from F\_2.0\_SS to F\_2.0\_RS and flow time increased with the replacement of silica sand. The increasing fly ash content is improved the flowability of ECC.

|  |  |  |
| --- | --- | --- |
| Mix Id | Slump flow  (mm) | T50(sec) |
| F\_1.4\_SS | 695 | 1.87 |
| F\_1.4\_RS | 540 | 2.25 |
| F\_2.0\_SS | 715 | 1.32 |
| F\_2.0\_RS | 570 | 1.55 |

Table-4: Flowability of composite

The deformability factor for ECC mixtures was given below

For F\_1.4\_SS is 2.475, F\_1.4\_RS is 1.7, F\_2.0\_SS is 2.575, F\_2.0\_SS is 1.85

All the ECC mixtures had deformability factor <2.75 it indicates good self-consolidation

2.5.2. Compressive strength

The 70.7 ×70.7 ×70.7mm size cube specimens were tested after 28days of curing for determination of compressive strength. That value for different ECC mixtures is mentioned in the figure-3. The compressive strength of 28 days cured ECC specimens is increased by 3.48% from F\_1.4\_SS to F\_1.4\_RS and decreased slightly 1.06% from F\_2.0\_SS to F\_2.0\_RS. Increasing curing period from 28days to 120days of specimens showed the similar behaviour that is compressive strength maximum for F\_1.4\_RS mix.

Fig.3. Compressive strength of ECC mixtures

2.5.3 Split tensile strength

The Ø150×300mm of size cylindrical specimens were casted to test the split tensile strength. All the specimens were tested under split tensile testing machine. That value for 28 days cured ECC mixture F\_1.4\_SS is 7.74N/mm2 is increased to 7.81N/mm2 for F\_1.4\_RS. The split tensile strength showed almost same value for F\_2.0\_SS and F\_2.0\_RS. The split tensile strength is high for F\_1.4\_RS at all curing periods is expressed in figure-4.

Fig.4. split tensile strength of ECC mixtures

2.5.4 Flexural strength

The prism specimens of size 100 ×100 ×500mm were casted to test the flexural strength of ECC mixtures. That was tested under the flexural testing machine (100 Ton loading frame).F\_1.4\_RS showed flexural strength of 12.26N/mm2 and this is 8.9% more than the F\_1.4\_SS. The ECC mixtures F\_2.0\_SS and F\_2.0\_RS showed approximately the same strength. The Flexural strength is high for the mix F\_1.4\_RS at all curing periods as shown in figure-5.

Fig.5. Flexural strength of ECC mixtures

2.5.5 Rapid chloride permeability

RCPT test was performed for four ECC mixture specimens of Ø100×50mm size under the influence of NaOH and NaCL solutions. The permeability of chloride ions measured in terms of coulombs and that was mentioned in figure-6.The chloride ion penetration not impacted with the grain size of 4.75mm sand and silica sand of 200μm.Increasing fly ash content in ECC increased the penetration of chloride ions due to unhydrated fly ash particles. This indicated that the grain size of fine aggregate up to 4.75mm not influenced the durability but affected with increased fly ash content. But increasing curing period of specimens showed the reduction in chloride ion penetration into the ECC mixtures.

Fig.6.RCPT test results for ECC mixtures

3. Cost Analysis

The approximate cost of materials used in this investigation mentioned below.

Table-5: Cost of different materials used in composite

|  |  |  |
| --- | --- | --- |
| Constituents | units | Rate(₹) |
| Cement | Bag(50kgs) | 400 |
| FA | MT | 1000 |
| SS | MT | 1500 |
| RS | MT | 1000 |
| Water | kiloliter | 25 |
| PVA fibers | kg | 450 |
| PEC | Liter | 200 |

The cost of all the materials for ECC was taken from the local suppliers.

FA: fly ash, SS: silica sand, RS: river sand, PVA fibers: Poly vinyl alcohol fibers, PEC: Polycarboxylate ether

The cost of ECC mixtures mentioned per cubic meter in table-6 and that was calculated based on table-5

Table-6: Cost of four ECC mixture prism specimens

|  |  |
| --- | --- |
| Mix Id | Cost(₹) |
| F\_1.4\_SS | 17842 |
| F\_1.4\_RS | 17584 |
| F\_2.0\_SS | 17095 |
| F\_2.0\_RS | 16834 |

The cost of ECC mixture is reduced by 5.65% from F\_1.4\_SS to F\_2.0\_RS. It indicates that cost of composite reduced with the utilization of high volume FA and locally available aggregates.

4. Conclusion

In this investigation, Indian Zone-II category River sand used in place of silica sand to study the characteristics of the composite at two different fly ash ratios (F/C is 1.4,2.0). According to the test results, below conclusions were mentioned.

Increasing the size of fine aggregate in ECC that decreased the flow ability by 22.40% at F/C is 1.4 and increased with the addition of fly ash (F/C is 2.0). It indicates that the size of sand will influence the flowability but it improves with the increase of FA. The mechanical characteristics of ECC not influenced with the river sand but high fly ash dosage negatively impacted. The chloride ion penetration in the composite is also not influenced by aggregate size/type up to 4.75mm. But increasing fly ash dosage negatively impacted the durability due to unhydrated particles. The cost of composite reduced by 5.65% by utilization of river sand and high dosage of fly ash. This indicates that the strength of ECC not influenced by 4.75mm size of sand but negatively impacted with higher fly ash dosage. Increasing curing period, the specimens showed the reduction in chloride ion penetration to the ECC specimens. The cost of composite is reduced by the usage of higher FA content and river sand.

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