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Application of Fly Ash Cenosphere in Cement Composites: A Comprehensive Review

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Abstract- Fly ash cenosphere (FAC) is an abundantly produced waste material generated from the coal based thermal power plants in India. Its utilization has received a great deal of attention over the past two decades as sustainable solutions to disposal problems. The lightweight nature of the FAC makes it suitable for the design of light weight composite materials. A range of different composites have been evaluated starting from its incorporation into polymers and resins to concrete composite. This paper reviews the past works/research carried out on the use of FAC as a substitute of fine-grained aggregate in cement composite. The exhaustive overview on the utilization of cenosphere in cement composite include effect of FAC on the properties of cement composite such as density, workability, flexural strength, compressive strength, tensile strength, acoustic property, thermal conductivity etc. It is also concluded that the FAC can be utilized in cement composite without compromising the strength of the structures.

Keywords- Fly ash cenosphere; Cenosphere cement composite (CCC); Fine-grained aggregate; Acoustic property

INTRODUCTION

Coal fly ash (CFA) is an industrial by-product generated during the combustion of pulverised coal at 1200-1700 ^{O}C in coal-fired thermal power stations and recognized as an ecological pollutant [1-4]. CFA predominantly contains mixture of glass, quartz-mullite, Ca silicate-oxyhydroxide, char, iron and salt fractions including hollow spherical particles in a separable form called as cenospheres [5]. These fly ash cenospheres (FAC) are considered to be one of the most important value-added components of CFA [6]. Due to its sphericity, non-toxicity, high strength and low density relative to water, make it amenable to a variety of different applications such as in the fields of electromagnetic wave absorbance, electromagnetic interference shielding and high light reflectivity etc [7-9]. Fig. 1 shows a typical SEM image of cenopshere.

Although several reviews of FAC utilization have been carried out, the objective of this review is to examine its potential applications of cenosphere as a substitute of fine grained aggregates in cement composite. This work shall certainly provide an insight to the implementation of a most valuable component of CFA which shall enhance global industrial ecology practices and address a wide range of sustainability issues in the field of construction sector.

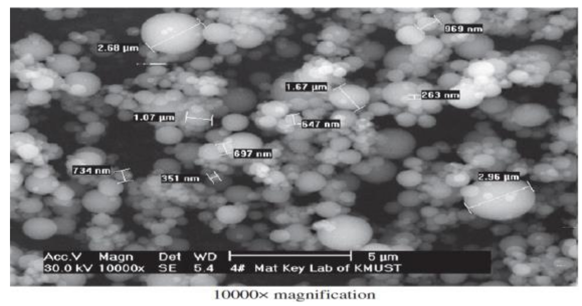

Fig. 1 SEM images of flyash cenosphere

EFFECT OF FAC ON CEMENT COMPOSITE

Effect on Workability

Wang et al. [10] conducted the flow spread test to assess the effect of FAC content on the workability of cenosphere cement composite (CCC). The FAC content was varied from 0 to 60 % with an increment of 20% by volume and the water content (W/C) ratio was varied between 0.1 and 0.3. The test results revealed that the flow spread increased with the increase in W/C ratio and FAC content. However, at a fixed W/C ratio, the flow spread increased with increase in FAC content up to 40 % and decreased thereafter. The slurry effect caused due to the flowing of FAC with water and ball bearing effect of FAC was reported to be the cause of increase of flow spread with increase in FAC content [11-13].

Effect on Density

The effect of FAC on the density of CCC was studied by varying the volume fraction of FAC from 0 to 70 % with a W/C ratio of 0.4 and found that the density varied from 1900 to 1110 kg/m^3 [14]. Brandt et al. [15] used polypropylene (PP) and polyvinyl fibers (PVA) to prepare CCC having fiber volume 0.67, 1.33, 2.67 and 20, 40, 60 % volume fraction of FAC. They concluded that the density of concrete reduced due to the increase of FAC and fibre content. The reduction in density of composite with poly propylene was more due to the lower density of the fiber as compared to polyvinyl fibres. With 60 % by volume of FAC added to CCC, the bulk density recorded was 1170 kg/m^3 which was 70 % of the density of composite without FAC. By using a constant mass of Type 1 Portland cement, Class F fly ash (FA), and PVA(polyvinyl alcohol) fibre with varying volume fraction of FAC showed a 18 - 31 % reduction in density of CCC as compared to normal concrete [16]. Wu et al. [17] established that even if the chemical admixtures were used, the density of CCC reduced with the increase in percentage of FAC and PE fiber in the composite.

McBRIDE et al. [18] used Portland cement type II, sand, 19 mm size coarse aggregate with W/C ratio 0.44 to prepare the CCC. They replaced the sand with 50 %, 75 % and 100 % of FAC to study the properties of CCC. The test result revealed that the 100 % replacement of sand with FAC reduced the density of concrete by 22 % as compared to the concrete without FAC. Liu et al. [19] carried out similar study using OPC type I cement, sand, and 20 mm size coarse aggregate with W/C ratio 0.45, to prepare the control cube. The test result showed that density due to the addition of FAC, silica fume and PVA fiber was reduced by 37.66 % as compared to the control cube.

Effect on Compressive Strength

The studies revealed that as the FAC content in the CCC reduced, the compressive strength of the composite also reduced [11-13]. The compressive strength also increased as the diameter of the FAC increased due to the higher volume of cement paste required to fill up the voids. Wu et al. [17] proved that a specific strength of 0.047 $MPa/kg/m^3$, equivalent to the compressive strength of normal weight concrete could be achieved by using FAC, cement, super plasticizer, shrinkage reducing admixture with water binder ratio of 0.35. Kwan and Chen [20] used ordinary Portland cement (OPC) of 52.5 grade, FAC, polycarboxylate ether-based polymer super plasticizer to prepare CCC. The test result revealed that with 20 % FAC and W/C ratio of 0.16 and super plasticizer, the 28 days cube strength of the specimen could be achieved up to a maximum of 153.5 Mpa which was 13.6 % more than the 28 days cube strength of the specimen with no FAC and W/C ratio 0.2.

When the coarse aggregates were used in CCC and fine aggregate replaced by FAC, then the specific compressive strength reduced but mode of failure was shear type failure [18]. This indicates a poor interfacial bonding between the FAC and cement binder. At same time the addition of 12 % silica fume by weight of cement to the CCC with 100 % FAC increased the specific compressive strength by 80 %. The reduction in compressive strength was 13.2 % as compared to the control specimen [19].

Effect on Flexural Strength

The flexural strength of the CCC decreased due to the decrease in cement paste content because of the increase in volume of voids [12]. Also the increase in the diameter of the FAC reduced the flexural strength. The increase in FAC in cement proportion reduced the flexural strength because the increase in FAC content increased the surface area of solid due to which the W/C ratio increased and simultaneously the capillary pore increased [13]. The addition of water proofing admixture formed a hydrophobic layer on the surface of unhydrated and partially hydrated cement grains which prevented the cement from hydration. Hence the addition of water proofing admixture again reduced the flexural strength.

Brandt et al. [15] studied that the inclusion of FAC reduced the flexural strength of CCC but the addition of fiber increases the flexural strength as the fiber can take the tensile stress developed after the cracking of the brittle cement matrix.

When the CCC was prepared by adding the cement, coarse aggregate, sand, FAC and silica fume, it did not show any reduction in specific flexural strength for the CCC with 50 % and 75 % FAC but the specific flexural strength reduced for 100% replacement of sand with FAC. The addition of 12 % silica fume by weight of cement to the CCC with 100 % FAC increased the flexural strength by 40 % [18].

Effect on Tensile Strength

Direct tensile tests were conducted for numbers of dogbone specimens with different percentages of FAC [20]**.** It was concluded that the specimen with FAC showed numbers of micro cracks which indicated the increase in tensile strain capacity.

The split tensile strength was conducted for the specimens prepared with cement, sand, coarse aggregate and FAC [18]. The specific tensile strength reduced for the specimen with 50 % FAC replacement but marginally increased for the specimens having 75 % and 100 % FAC as a replacement of sand. The popping out of aggregate in the failure plane indicated poor interface strength between FAC and binder. Latter on 12% silica fume by mass of cement was added to achieve an increase in tensile strength of 35 %.

Effect on Creep and Shrinkage

Losiewicz et al. [11] reported that the shrinkage in CCC increased as the cement content in CCC increased. The creep and shrinkage of CCC up to 450 days were compared with that of the normal weight concrete having similar 28 days compressive strength. They concluded that almost 95% of the autogenous shrinkage occurs within 28 days. The total shrinkage of CCC before 180days was more than the concrete prepared with expanded clay but beyond 180 days the CCC has the lowest shrinkage. The CCC has a total creep strain of 80 % with a basic creep to total creep ratio of 70 % at 450 days. By comparing with the normal concrete, it was found that the 450 days creep coefficient of CCC had 47 % lower value than normal weight concrete.

Effect on alkali aggregate reaction

Wang et al. [21] evaluated the deleterious nature of cenoshoeheres and CCC due to alkali–silica reaction (ASR).

The expansion of the CCC bar with N_2O_{eq} of 0.80 and 1.25 % found to be less than the prescribed limit of 0.05 in 3 months and 0.10 % in 6 months. Similarly, the expansion at 14 days of CCC conditioned in 1N NaOH was found to be less than 0.1 %. It was concluded that the FAC was not deleterious to alkali silica reaction.

Effect on chloride ion penetration

Liu et al. [19] prepared the normal weight concrete and CCC specimens by curing it for 7 and 28 days in moist condition respectively. The test results showed that the chloride penetration was more in normal weight concrete compared to CCC specimens. The higher resistance to chloride ion penetration of CCC as compared to normal weight concrete may be due to the longer duration of curing and the use of silica fume in it.

Effect on Thermal Conductivity

Losiewicz et al. [11] found that the thermal conductivity of CCC to be in the range of 0.11 $Wm^{-1}K^{-1}$ to 0.15 $Wm^{-1}K^{-1}$, which increased with decrease in percentage of FAC. Blanco at al. [12] conducted the thermal conductivity test on different specimens with different size of FAC. They concluded that the thermal conductivity reduced with decrease in diameter of FAC. Use of FAC with wider range of diameter can reduce the thermal conductivity. Kwan and Chen [20] observed that the thermal conductivity of FAC (0.065W m^{-1} K^{-1}) was lower compared to the thermal conductivity of quartz (3.826 W m^{-1} K^{-1}) which might be due to the hollow structure of the FAC. The comparison of thermal conductivity of CCC with normal cement paste and concrete showed that the thermal conductivity of CCC is 54% and 80% of that of cement paste and concrete respectively.

The effect of fiber volume in composite has very small effect on the thermal conductivity as compared to the effect of FAC [15]. The use of 60 % FAC by volume and PP fiber in CCC can reduce the thermal conductivity by 67 %.

Effect on Acoustic Property

Blanco et al. [12] performed the sound proofing test and reported that the property of CCC was similar to the property of concrete manufactured with expanded clay and to the property of wall of same thickness prepared with traditional material. The sound absorption or noise reduction property of CCC was optimum when the FAC content in FAC was 40 % volume fraction of cement [14].

CONCLUSIONS

In this review, the use of fly ash cenospheres (FAC) in different composites of cement are summarised as follows:

- Replacement of coarse or fine aggregate of cement composite can eliminate the ill effect of sand/gravel mining, crusher dust on environment and human health.
- Reduction in density of cement composite will impart lesser self weight on the structure, which leads to an economical structure.
- Compressive and tensile strength of the CCC similar to normal concrete can be achieved by using silica fume.
- The flexural strength of CCC can be enhanced by addition of fibers along with FAC.
- The thermal resistance, noise reduction property can be improved as compared to normal concrete.
- Better creep and shrinkage property then normal concrete.

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