HIGH STRENGTH LIGHTWEIGHT CONCRETE USING SINTERED FLYASH AGGREGATES FOR STRUCTURAL APPLICATIONS

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ABSTRACT

This paper presents the development of high strength lightweight concrete for structural applications using sintered fly ash aggregates. The performance of lightweight concrete was evaluated by conducting comprehensive series of tests on fresh and hardened properties as well as durability. Fresh and mechanical properties of lightweight concrete such as slump, compressive strength, tensile strength, flexural strength and density are described. The investigation suggests the production of lightweight concrete for structural applications having satisfactory characteristics.

1.0 Introduction

Concrete is the second most consumed material after water. It is estimated that 25 billion tonnes of concrete is produced each year globally. Concrete usually contains 60 to 75% of aggregates out to which 50 to 60% are coarse aggregates. Implying, 8 to 10 billion tonnes of coarse aggregates are being utilized each year globally to produce such enormous quantities of concrete and these aggregates are natural resource. On the other hand, 300 million tonnes of fly ash is generates globally from thermal power plants and disposal of such huge quantities is also an environmental concern. Mostly, fly ash is consumed by cement and concrete industry as a supplementary cementitious material. In addition to this, it can also be absorbed by concrete industry in the form of coarse aggregates. Fly ash coarse aggregates are produced by sintering fly ash at high temperatures and these aggregates are known as sintered fly ash aggregates. If these artificially manufactured aggregates are used, the exploitation of natural resources can be minimized and also it is an effective solution for efficient utilization of waste.

Aggregates manufactured by sintering are generally porous, consequently the particle and bulk density of sintered fly ash aggregates are lesser compared to conventional aggregates. This enables to produce lightweight concrete of densities lesser than 2000 kg/m^3 without compromising its mechanical and durability performance, so that it can be used for structural applications. Utilization of lightweight concrete for structures reduces the dead weight of structure as well as reduces the risk of earthquake damages to a structure as the earthquake forces are dependent on weight of structures. Also, reduction in the dead weight of a construction could result in a decrease in the cross-section of columns, beams, plates and foundations. Additionally, higher strength/weight ratio, better tensile strain capacity, lower coefficient of thermal expansion and superior heat and sound insulation characteristics due to air voids of the lightweight aggregates are some of the many advantages of structural lightweight concrete.

Owing to the above advantages coupled with the increasing scarcity of good quality natural aggregates in many parts of the world and the emphasis on more efficient use of materials in structures has widely increased the application of structural lightweight concrete in the past two decades. In spite of all these advantages, the use of lightweight concrete for structural applications is limited in India. This study focuses on producing high strength structural lightweight concrete and to utilize it in construction of a building so that its awareness can be improved. Also, this paper will discuss on the production of lightweight concrete for structural applications using sintered fly ash aggregates with compressive strength of 40 MPa at a density less than 2000 kg/m^3 and evaluation of its mechanical properties.

2.0 Experimental Program and methodology

2.1 Materials

The materials used for producing structural lightweight concrete are reported with their specifications in this section.

2.1.1 Cement

In the present investigation, a commercially available UltraTech 53 grade ordinary Portland cement conforming to IS 12269 (1993) is used for all the mixtures. The cement composition and properties are provided in Table 1 and Table 2, respectively while the particle size analysis is presented in Figure 1.

Table 1 Chemical composition of 53 grade cement used in the study

Composition	Percent by mass
Calcium oxide (CaO)	60.50
Silica (SiO2)	19.50
Alumina (Al2O3)	4.10
Iron oxide (Fe2O3)	6.10
Magnesia (MgO)	1.50
Sulphur anhydrite (SO3)	2.50
Insoluble residue	1.50
Total loss on ignition	3.40
Total chloride content (Cl)	0.01
Available Alkali Na2O K2O	 0.05 0.30

Table 2 Properties of 53 grade cement used in the study

Properties	Value
Blaine's fineness	320 m^2/kg
Specific gravity	3.14
Standard consistency	34%
Initial setting time	100 minutes
Final setting time	190 minutes

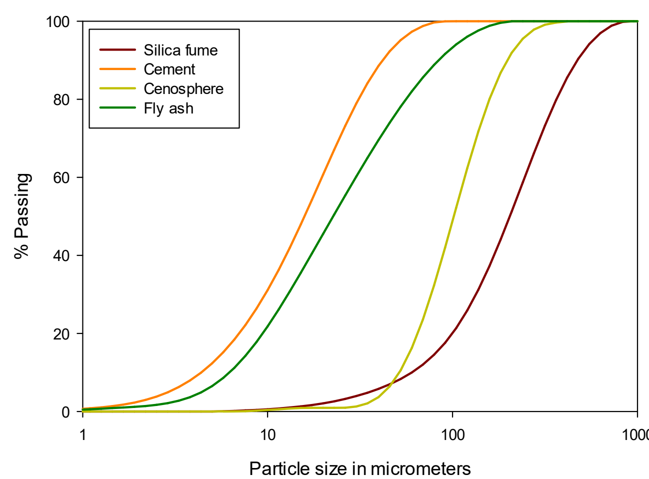

Figure 1 Particle size analysis of cement, fly ash and copper slag

2.1.2 Fly ash

Class F fly ash conforming to IS 3812: Part 1 is used as a supplementary cementitious material in the concrete. The Blaine's specific surface area, specific gravity and oxide composition of the mineral admixtures are provided in Table 3. The particle size distributions of the mineral admixtures determined by laser diffraction are also given in Figure 1

Table 3 Properties and composition of fly ash

Material	Fly ash
Specific gravity	2.22
Blaine's fineness	275
Oxide composition in percentage by mass	
Calcium oxide (CaO)	1.28
Silica (SiO_2)	59.32
Alumina (Al_2O_3)	29.95
Iron oxide (Fe_2O_3)	4.32
Magnesia (MgO)	0.61
Sodium oxide (Na_2O)	0.16
Potassium oxide (K_2O)	1.44

2.1.3 Aggregates

Manufactured sand (M-Sand) with a specific gravity of 2.65 and fineness modulus of 2.64 is used as the fine aggregate, while sintered fly ash lightweight aggregates from JINDAL Angul are used as a coarse aggregate; two different size fractions of 10 - 4.75 mm and 20 – 10 mm were used in designed proportions of the total weight of coarse aggregate. Some of the physical and mechanical properties of the sintered fly ash aggregates are listed in Table 4.

Table 4 Physical and mechanical properties of 10 and 20 mm aggregates

Property	10 mm aggregates	20 mm aggregates
Loose density (kg/m^3)	895	905
Compacted bulk density (kg/m^3)	950	930
Specific gravity	1.64	1.62
Water absorption (%)	25	24
Impact value (%)	32	25
Sulfate content (%)	0.0019	0.0018
Chloride content	0.0018	0.0018

2.1.4 Densified silica fume

Silica fume is a by-product of the manufacture of silicon or of various silicon alloys. Silica fume, which contains more than 80–85% SiO2 in amorphous form, is suitable to use in the cement and concrete industries. The typical particle size of silica fume is around 0.1–0.5 µm and the nitrogen BET surface is 20,000 m2/kg. Silica fume is light and has a low bulk density, which may cause difficulty in transporting and handling. In order to improve the handling and transport properties of material, commercial suppliers have responded by processing silica fume using different methods of densification and compaction, such as densified, slurried or pelletized to increase its bulk density. Densified silica fume is used in the study has median particle size of 234 µm and specific gravity of 2.28. The particle size distribution of silica fume by laser diffraction is shown in Figure 1. It is clear from Figure 1 that the size of silica fume agglomerates is much coarser than cement particles; many silica fume agglomerates have sizes larger than 100 µm.

2.1.5 Chemical admixtures

The superplasticizer used in this study is a polycarboxylate ether based, with 41% solids content and a specific gravity of 1.21. The superplasticizer is incorporated in all the mixes and the maximum content is limited to 1% (by weight of cement).

2.2 Mix proportions

For the experimental investigation, structural lightweight concrete was designed using light weight aggregate with binder content of 500 kg/m^3 and water binder ratio of 0.35. To additional reduce the density of the structural lightweight concrete fine aggregate was replaced with cenospheres. In order to compensate the reduction in strength due to incorporation of cenospheres, densified silica fume was added to the concrete. As the densities of fly ash, cenosphere and silica fume are lower than that of ordinary Portland cement, the lightweight aggregate content is slightly modified to achieve same yield. The mix proportions the control mix and other concretes are presented in Table 5.

Table 5 Concrete mix proportions

Mix ID	CM	SF	FASF	CNSF
Cement (kg/m^3)	500	460	310	460
Flyash (kg/m^3)	0	0	150	0
Silicafume (kg/m^3)	0	40	40	40
Cenosphere (kg/m^3)	0	0	0	136
20 mm aggregate (kg/m^3)	353	351	339	351
10 mm aggregate (kg/m^3)	318	315	306	315
Fine aggregate (kg/m^3)	684	678	657	236
Water (kg/m^3)	175	175	175	175
Theoritical density (kg/m^3)	2031	2019	1977	1713

Note: CM – Control Mix; SF – mix with 8% (mass percentage) of silica fume, FASF – mix with fly ash and silica fume, CNSF – mix with cenosphere and silica fume

2.3 Mixing procedure

Concrete was prepared using a pan mixer with a capacity of 40 liter. The lightweight aggregates were pre-soaked for 24 h to better control the workability and effective water content of the concrete. The aggregates were then surface dried and placed in the mixer followed by 10mm aggregates and cementitious material (cement, fly ash and silica fume). Sand was spread over cement and then mixer was started for dry sample to get mixed for about 2 minutes. After this, the required quantity of water along with superplasticizer was added slowly into the mixer and allowed to mix for 2 minutes. In case of mixes with cenosphere, it was added with the cementitious material. During the mixing process the walls and bottom of the mixer were scraped well to avoid sticking of mortar. The entire process of mixing was carried out for a period of 5 minutes. The fresh properties of the concrete, namely workability and density were determined as per IS 1199: 1959 while setting of concrete was determined as per IS 8142-1976. Workability of concrete was measured in terms of slump and determined at regular intervals of 30 minutes after an hour of mixing. Finally the fresh concrete was placed in the various oiled moulds as soon as 100 mm slump is achieved and compacted using table vibration. After the initial setting of concrete, the surface of the specimen was finished smoothly using a trowel. The concrete specimens in the moulds were then removed after 24 hours and kept in a water tank for the required curing period. The hardened concrete properties were determined for all the concrete mixes after 28 days. The concrete specimens cast for compressive strength are cubes of 150 mm. For tensile and flexural tests, cylindrical specimens of size 20×10 cm and prisms of size10×10×50 cm were cast, respectively.

2.4 Experimental methods - Fresh and hardened properties of concrete

The determination of fresh concrete properties was performed to evaluate the followability of the concretes. Workability is a control parameter most often used for fresh concrete. In the present study, workability was determined using slump cone. The slump cone test was performed as per

ASTM C143 (2006). For measuring fresh density of concrete, a steel container of a known volume is filled with freshly mixed concrete in three approximately equal layers. Then, the same consolidation practice in slump test is utilized. Each layer is rodded 25 times. During rodding 2nd and 3rd layer, rod is penetrated approximately 2.5 cm into previous layer. After the container is filled, excess concrete is struck off. Then, the container filled with fresh concrete is weighed (M_c). Knowing the self-mass (M_m) and volume of the container (V_m), density of the concrete can be calculated as follows:

$$\text{Density} = (M_c - M_m) / V_m$$

Compressive strength tests were carried out at the end of 3, 7, and 28 days of curing for various concrete cube specimens using Controls compression testing machine of capacity 1000 kN as per IS 516 (1959). Additionally, splitting tensile and flexural tests were carried out as per IS 5816 (1999) and IS 516 (1959), respectively.

3.0 Results and Discussion

3.1 Fresh and air dry density

As seen in the Figure 2, the unit weights of fresh mixtures varied between 2100 kg/m^3 and 1750 kg/m^3. When the unit weights in the fresh state and in dry condition are compared, it can be seen that the dry unit weight is only 4% less than (i.e. 2050 to 1700 kg/m^3) the unit weight at the fresh state. Control mix with lightweight aggregate resulted in a density of 2050 kg/m^3. 30% replacement of cement with fly ash in FASF mix resulted a density of 1950 kg/m^3. The mix, CNSF, with 65% replacement of fine aggregate with cenosphere resulted in a density of 1750 kg/m^3 to 1850 kg/m^3. Generally, the unit weight of normal weight concrete is 2400 kg/m^3, from the study the least density obtained is 1750 kg/m^3, which is 25% lower than the density of normal weight concrete.

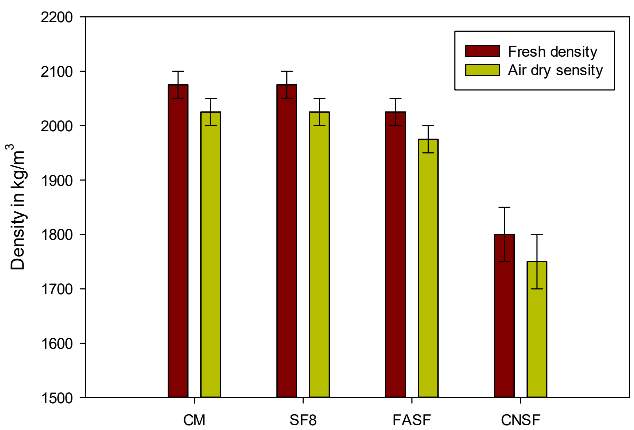

Figure 2 Fresh and air dry densities of lightweight concrete mixes

3.2 Slump

All the concretes were designed for a minimum slump of 200 mm. Required quantity of superplasticizer was added to attain the target slump of 200 mm and the cubes were cast after the slump dropped to 100 mm. The dosage of the superplasticizer used for various mixes varied from 0.6 to 1%. The maximum dosage of superplasticizer was restricted to 1% as addition of superplasticizer beyond 1% led to segregation of the mixes.

3.2 Strength of lightweight concretes

The control mix produced with lightweight aggregate without any other additives exhibited 28 day compressive strength of 43.3 MPa and with incorporation of 8% of silica fume strength increased marginally by 5 Mpa. Replacement of 30% of cement with fly ash decreased the compressive strength to 40 Mpa. The mix with 65% of fine aggregate was cenosphere resulted a compressive strength of 34 Mpa. The compressive strength results are presented in Table 6. The tensile and flexural tests were carried out on control mix (CM) only. The approximate 28 days flexural and tensile strengths were found to be 15 MPa and 8 MPa, respectively. From the above results, it can be seen that lightweight concrete with compressive strength of 40 Mpa can be easily obtained using sintered fly ash aggregates at density of 2000 kg/m^3. Further, its density can be reduced by using lower density materials like cenospheres. In the current study, 65% of fine aggregate has been replaced to attain a density of 1750 kg/m^3. Hence it can be inferred that, the percentage incorporation of ceneosphere as a replacement to fine aggregate can be varied from 0 to 100% based on the required density or strength.

Table 6 Compressive strength results

Mix ID	3 day	7 day	28 day
CM	25.3	36.73	43.30
SF8	28.01	40.44	48.25
FASF	14.2	27.86	40.08
CNSF	26.99	29.82	34.19

4.0 Conclusions

From the study, it is clear that workable and non-segregating structural lightweight concrete was produced to have a fresh and densities lower than 2000 kg/m^3 with compressive strengths beyond 40 MPa. The unit weight of concrete as low as 1750 kg/m^3 with compressive strength of 34 MPa has been obtained by replacing normal aggregates by sintered fly ash lightweight aggregate and low density materials like cenosphere. In addition, the obtained tensile and flexural strengths of lightweight concrete are on par with the normal concrete. Hence, such reductions in unit weight can have important benefits on the performance of structures. The weight reduction in a concrete structure decreases the stresses in the structural elements and, since the stresses generated due to seismic loads are also dependent on the weight of the structure, reduction of the structural weight is beneficial in terms of earthquake resistance. Forces acting on the foundations of the structure are also reduced. Thus, with a lower total weight of the structure, the structural details of the elements can be optimized; lower amounts of reinforcing steel and reduced cross sections can be obtained, which is important from an economical point of view, too. Lower overall cost of the structure can be obtained as a result of the reduced weights. Reduced formwork pressure due to lower unit weight of the concrete is also beneficial in terms of formwork cost.