Effect of Bottom Ash and Silica Fume on Compressive Strength and Resistance to Chloride Ion Penetration

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Abstract -- Portland cement is a highly energy intensive material and continuous mining of sand causes environmental problem. Therefore, considerable effort is being made to find substitutes for partial replacement of cement and sand in concrete. This paper reports the results from experimental studies on the compressive strength and resistance to chloride ion penetration of bottom ash concrete (BAC) containing silica fume (SF) and bottom ash (BA). In this study the industrial wastes BA and SF in the proportions of 40% by volume of sand and 10% by volume of cement respectively. The mix proportions of BAC had water binder ratios of 0.3 to 0.5 and the volume of super plasticizer (SP) was kept constant for all the mixes. The concrete specimens were cured on normal moist curing under normal room temperature. The compressive strength and the resistance to chloride-ion penetration were measured at different ages up to 90 days. The results indicate that the concrete made with these proportions generally show excellent strength and durability properties. BAC made with silica fume and bottom ash was found to increase the compressive strength of concrete when compared to conventional concrete (CC). Moreover, the incorporation of bottom ash and silica fume in concrete increases the resistance to chloride ions and produced concrete with low permeability.

Indexed Terms: bottom ash, chloride permeability, replacement, silica fume, super plasticizer.

I. INTRODUCTION

Due to increasing energy demand, thermal power plants become more widespread around the world. However, these plants cause significant technical, environmental and economic problems due to the waste products of electric generation. During Lignite-fired electric power generation, two main types of waste products are obtained, (i.e.) fly ash and bottom ash. The annual ash production is about 380 million tones which is more than the rest of all industrial wastes in India and china. Although fly ash is a valuable mineral admixture for blended Portland cement and concrete, the bottom ash is not considerably yet utilized for making the concrete. Utilization of such waste material bottom ash in construction industry reduces the consumption of natural aggregate –sand and provides economic and environmental benefits. Bottom ash has a rough surface texture and is comprised of angular and porous particles. The irregular and angular shape and very porous surface necessitated the use of higher water content to achieve the degree of lubrication needed for a workable mix. Due to the higher water-cement ratio, the strength properties of the bottom ash mixtures without admixture are slightly lower than those of the control samples [1].

The strength development of concrete made with bottom ash can be accelerated to achieve the desired performance at early ages by adding accelerating agents such as Metakaolin, slag, silica fume etc., [2]. SF is a co product of the ferrosilicon and silicon alloy industry. Initially the use of SF was as a cement replacement, due to its very high pozzolanic reactivity: but as more data came in from testing and field work, the material became an additional cementitious component giving increased performance in both fresh and hardened states [3]. When SF added to concrete, SF acts as both fillers, improving the physical structure by occupying the spaces between the cement particles and as a pozzolana, reacting chemically to impart far greater strength and durability to concrete [4]. The major difference between conventional concrete (CC) and BAC is essentially the use of chemical and mineral admixtures.

Due to extreme fineness of SF, it has high water demand and behaves more efficiently in concrete mixes having higher water-cement ratios. The increased water demand associated with SF addition requires the use of High range water reducing agents (HRWR) or super plasticizer (SP) to maintain the water-cementitious ratio required to achieve the desired strength [6]. Use of chemical admixtures reduces the water content, thereby reducing the porosity within the hydrated cement paste [7]. One of the main advantages of mineral admixtures in concrete is reducing the cement content, which is not only economic and environmental benefits but also means reducing the rise in temperature in the concrete, at the same time increasing the compressive strength and durability properties.

As a rule of thumb, the total temperature rise produced by the pozzolanic reactions involving mineral admixtures is considered to be half as much as the average heat produced by the hydration of Portland cement. This paper reports the results of an experimental investigation in which the performance of concrete containing supplementary cementing materials was studied after curing regimes. Ten concrete mixtures were made in this investigation. These included five control mixtures, five BAC mixtures for varying w/c ratios. All the mixtures were prepared on volume basis. In HPC mix, 40% of bottom ash was replaced in the volume of sand and 10% of silica fume in the volume of cement was added. The water-cement ratio was varied from 0.30 to 0.50. SP was added in mixing the concrete and the dosage of SP was kept constant for all the mixes to maintain the workability.

A large number of cylinders and cubes were cast and subjected to normal curing at room temperature. The compressive strength was determined at various ages, and the resistance to chloride-ion penetration was measured.

II. MATERIALS AND METHOD

Ordinary Portland cement 53 grade confirming to IS 12269-1987 [14], and river sand of specific gravity 2.56 and fineness modulus 2.43, confirming to IS 383-1970 [13] and crushed granite coarse aggregate of maximum size 20 mm confirming to IS 383-1970 [13] having the specific gravity 2.77 were used in both BAC and CC mixes.

A. Industrial wastes

Bottom ash: Bottom ash (Fig.1.) obtained from thermal power plant, Neyveli Lignite Corporation Ltd, India was used in this investigation. The specific gravity and fineness modulus of bottom ash was 2.35 and 1.90.

Silica fume: Silica fume (Fig.2.) used was Elkem Micro silica, obtained from “Elkem India Private Limited – Mumbai, India. The specific gravity was 1.93.

Superplasticizer (SP): A new generation Sulphonated Napthalene Polymers based super-plasticizer was used. This super -plasticizer is available as a Dark brown medium colored aqueous solution with standard specifications of ASTM C 494 Type G.

Figure 1: Bottom ash

Figure 2: Silica fume

Table 1: Chemical analysis of the materials

Description of test	Silica Fume	Bottom ash
Silicon dioxide (SiO_2)	85.72	52.71
Aluminium oxide (Al_2O_3)	0.06	1.53
Ferric oxide (Fe_2O_3)	0.45	29.36
Calcium oxide (CaO)	-	-
Magnesium oxide (MgO)	-	1.76
Sulphur trioxide (SO_3)	-	2.07
Sodium oxide (Na_2O_3)	-	0.23
Potassium oxide(K_2O)	-	0.41
Loss of Ignition (LOI)	1.96	11.93

Table 2: Proportioning of Concrete Mixtures

Mix	Cement	SF	FA	BA	CA	Water (lit)
CC 300	300	--	817	--	1119	160
CC 350	350	--	775	--	1119	160
CC 400	400	--	734	--	1119	160
CC 450	450	--	692	--	1119	160
CC 500	500	--	650	--	1119	160
BAC 300	300	19	474	290	1119	160
BAC 350	350	22	448	274	1119	160
BAC 400	400	25	420	257	1119	160
BAC 450	450	28	393	240	1119	160
BAC 500	500	31	365	223	1119	160

B. Mixture Proportions

Totally 10 mixes were prepared for this test by absolute volume method for different cement contents 300 to 500 Kg/m3. Out of which five were BAC mixes (BAC 300, BAC 350, BAC 400, BAC 450, and BAC 500) and five were Conventional Concrete mixes (CC 300, CC 350, CC 400, CC 450, and CC 500). All the five CC mixes were designed by varying the volume of cement and sand while the volume of water and coarse aggregate were kept constant. BAC mixes were obtained by adding 10% of silica fume in the volume of the cement and replacing 40% of the volume of the sand by Neyveli bottom ash. The mix proportions are given in Table 2. To obtain a homogeneous mix, fine aggregates river sand and BA were mixed and binders (cement and SF) were added to the system and then CA was added. After mixing the materials, 75% of water in the estimated quantity of water was added to the dry mix. Finally, super plasticizer was mixed in the remaining 25% of water and added to the wet mixture.

C. Casting and Testing of Specimens

The cylinders and cubes were cast in three equal layers and each layer was compacted by using a vibrating table.

After casting, the molded specimens were left in the casting room at 23 ± 1.7°C for 24 h. They were then demoulded and cured. For each mix of concrete, nine concrete cube specimens of size 100mmx100mmx100mm and six 100 mm diameter and 200 mm height cylinders were cast. Totally 60 numbers of cylinders and 90 numbers of cubes were cast. Cylindrical specimens were used to determine the chloride ion penetration depth and cube specimens were used to determine the compressive strength. All the test specimens were cured for 28 days, 56- and 90-days period and were tested at these ages. The cylindrical specimens were cut into four equal pieces of thickness 50 mm using a circular cutting saw. Out of the four pieces the middle two pieces were used for Rapid Chloride Penetration Test (RCPT).

III. RESULTS AND DISCUSSION

The results of compressive strength test specimens up to 90 days and chloride penetration depths up to 90 days for all the mixes and are discussed in the following paragraphs.

A. Compressive Strength

Compressive strength of all the cube specimens were determined in accordance with IS 516, 1959 [12]and the test results are given in Table 3. The results were compared with the results of conventional concrete specimens. The compressive strength development of BAC and CC mixes is shown in Fig 3and Fig 4. From the results it is observed that incorporating SF and BA accelerates the strength considerably when compared to control concrete. All mixes show strength gain at 90 days when compared to CC mixture. From the Fig 5 and Fig 6 it was observed that the higher the silica fume content and lesser the bottom ash content, the strength will be higher with time. However, it is clear that, it is possible to produce a concrete with a compressive strength value of 51MPa with 10% silica fume add with cement and 40% replacement fine aggregate with bottom ash.

Table 3: compressive strength of concrete (Mpa)

Mix	28 days	56 days	90 days
CC 300	23	24	25
CC 350	29	30	32
CC 400	34	35	37
CC 450	40	42	45
CC 500	46	48	51
BAC300	26	28	30
BAC350	32	34	38
BAC400	38	43	45
BAC450	44	49	52
BAC500	50	53	56

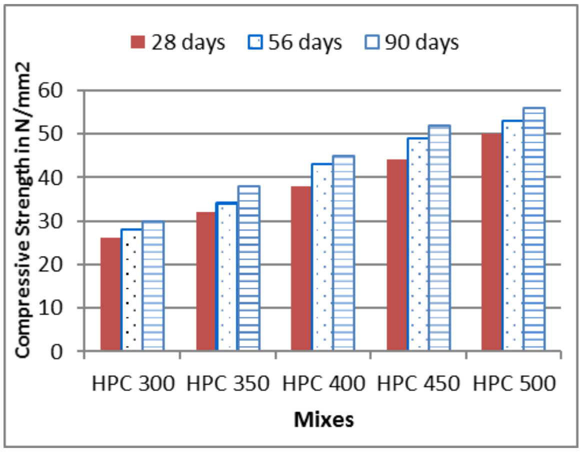

Figure 3: Compressive strength for BAC mixes

C. Resistance to the Penetration of Chloride Ions

RCPT was conducted to determine the resistance of the concretes to the penetration of chloride ions in accordance with ASTM C 1202. This test consists of monitoring the amount of electrical current passed through a 100mm diameter x 50-mm thick concrete disc, when a potential difference of 60 V DC is maintained across the specimen for a period of 6 h. Chloride ions are forced to migrate out of a sodium chloride (NaCl) solution subjected to a negative charge through the concrete into a sodium hydroxide (NaOH) solution maintained at a positive potential. The experimental arrangement is shown in figure 7.

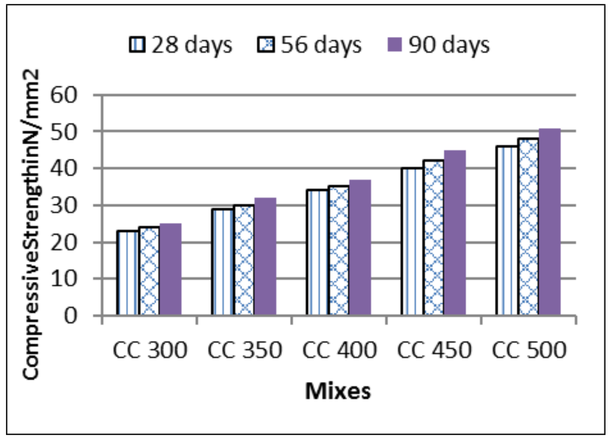

Figure 4: Compressive strength for CC mixes

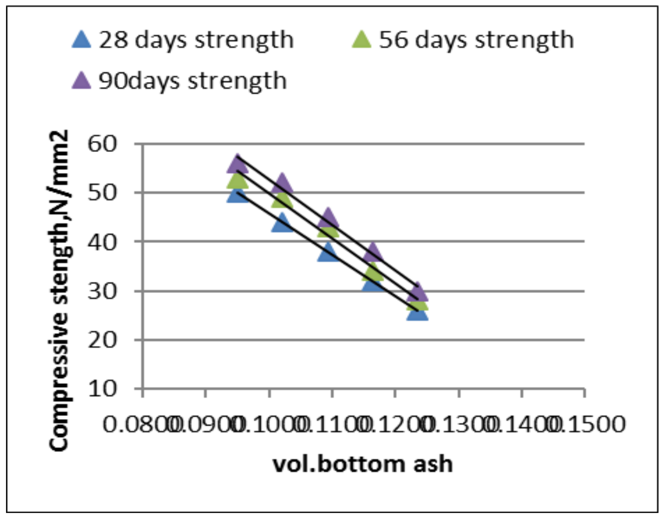

Figure5: Volume of BA –Compressive strength for BAC mixes

The total charge passed, in coulombs, is a measure of the resistance of the concrete to the penetration of chloride ions has been found to be related to the resistance of the specimen. The resistance to chloride ion penetration limits are determined as per ASTM C 1202 standards and given in Table 4 which provides a qualitative relationship between the results of the test and the chloride ion penetrability of concrete. The total charge passed during this period was calculated in terms of coulombs using the ASTM C 1202-97 [16]. From Table.5 it is observed that the chloride ion permeability values fall in the range of moderate for all the five mixes CC, HPC mixes falls in the range of low for all the five mixes and in all ages of curing.

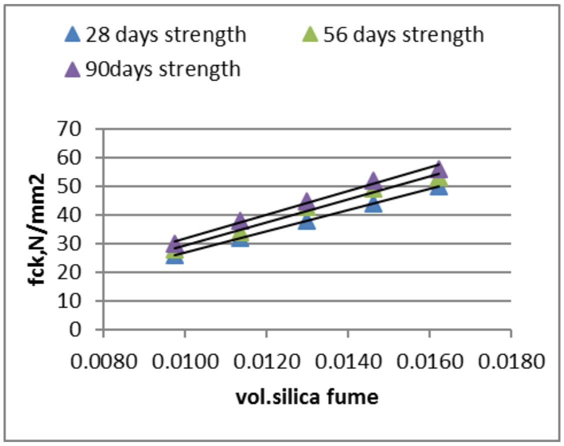

Figure 6: Volume of SF –Compressive strength for BAC mixes

Most concretes, if properly cured, become progressively and significantly less permeable with time. The decrease in the permeability with time in these concretes is due to the change in the pore structure of the hydrated cementitious system due to the use of supplementary cementing materials. The use of SF and BA in a concrete showed low penetration depth compared to the CC mixes.

Figure 7: Experimental arrangement of RCPT

Table 4: Chloride ion penetrability based on charge

Charge Passed (Coulombs)	Chloride ion penetrability
>4000	High(H)
2000-4000	Moderate(M)
1000-2000	Low(L)
100-1000	Very Low (VL)
<100	Negligible(N)

Table 5: Chloride ion penetrability for BAC and CC mixes

Mix	Resistance to Chloride-ion penetration(C)					
	28 Days		56 Days		90 Days	
CC300	2629	Mod	2512	Mod	2428	Mod
CC350	2525	Mod	2389	Mod	2294	Mod
CC400	2426	Mod	2287	Mod	2226	Mod
CC450	2284	Mod	2189	Mod	2130	Mod
CC500	2197	Mod	2072	Mod	2018	Mod
BAC300	1782	Low	1731	Low	1686	Mod
BAC350	1603	Low	1561	Low	1475	Low
BAC400	1246	Low	1202	Low	1165	Low
BAC450	1163	Low	1106	Low	1066	Low
BAC500	1067	Low	1031	Low	1002	Low

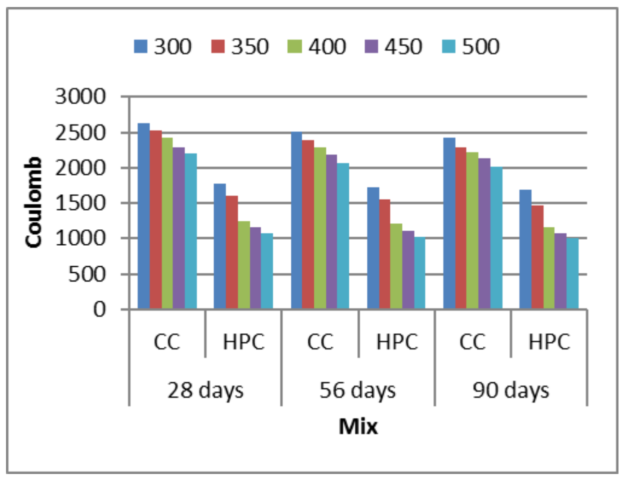

Figure 8: Coulomb charges for the CC and BAC mixes

IV. CONCLUSION

From the above experimental study, the following conclusions can be arrived;

1. Concrete made with silica fume and bottom ash increases the compressive strength significantly up to 13% than the conventional concrete.
2. Good resistance to chloride ion penetration can be obtained with HPC made with Bottom ash and silica fume. Chloride

penetration depth of all HPC mixtures has considerably smaller penetration than the Conventional concrete mix.

3. The combination of silica fume and bottom ash is complementary; the silica fume improves the early age performance of concrete with the bottom ash continuously refining the properties of the hardened concrete as it matures. In terms of durability, such admixtures are superior to Ordinary Portland cement concrete.
4. Partial replacement of sand with bottom ash in concrete mixes would lead to considerable savings in consumption of natural sand.
5. Addition of silica fume with cement increases the binder volume in concrete mixes and increases the performance of concrete. This would also reduce the consumption of cement.
6. Therefore, addition of 10% of silica fume in the volume of cement, and replacement of sand with 40% of sand would render the concrete strong and durable.

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