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Value added utilization of industrial by-products in producing high performance concrete

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Abstract

The objective of this study is to evaluate the effect of various industrial by-products on the fresh and hardened properties of high-performance concrete with micro structural analysis on mechanical characteristics and durability characteristics. High performance concrete (HPC) is developed gradually over the last 15 years with respect to production of concrete with higher and higher strength. It is defined as the concrete with improved constructability, improved durability and improved mechanical properties. The experimental investigation on the effective use of silica fume, bottom ash & steel slag aggregate as a replacement of cement, fine aggregate & coarse aggregate on the properties of high-performance concrete. An effort has been made to concentrate on the mineral admixture of silica fume towards their pozzolanic reaction and industrial by-product of bottom ash and steel slag towards their hydration reaction can be contributed towards their strength and durability properties. The durability studies such as acid resistance, salt resistance and RCPT were conducted. There was a total of 15 mixes created with different material contents. Out of 14 were HPC mixes and 1 were conventional concrete mixes by many trial mixes. Finally, strength has enhanced with the mix of silica fume can replaced by cement with 5% and bottom ash and steel slag can be replaced by fine and coarse aggregate with 10% can be achieved higher strength when compared with other percentage of mixes. The combination mixes can be classified as binary and ternary mixes. Binary mixes involved combinations of silica fume and bottom ash (SF+BA), silica fume and steel slag aggregate (SF+SSA), bottom ash and steel slag aggregate (BA+SSA) and Ternary mixes involved combination of three materials such as silica fume, bottom ash and steel slag aggregate (SF+BA+SSA) in High performance concrete. The investigation revealed that the combined use of silica fume, bottom ash and steel slag aggregate improved the mechanical properties of HPC and thus there 3 materials may use as a partial replacement material in making HPC. In addition, scanning electron microscope and EDAX were studied. Microstructure constitutes the nature of the solid portion and nonsolid portion. Some factors of micro structural features are physical and chemical nature of the cement, type and amount of admixture etc. From the experimental investigation, it was observed that mineral admixture of silica fume and industrial by-products of bottom ash & steel slag aggregate plays a vital role in improving the strength and durability parameter itself.

Keywords: HPC, Durability, Silica fume, Bottom Ash, Steel slag aggregate, Microstructure

1. Introduction

Given the many advantages of high-performance concrete and its increased use in structural applications, it is essential that the fundamental heavier of HPC on durable aspects. High performance concrete is defined as the concrete with improved constructability, improved durability and mechanical properties. The term high performance means high strength and low permeability. According to ACI definition, concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials. Use of chemical admixtures reduces the water content, thereby reducing the porosity within the hydrated cement paste. Mineral admixtures, also called as cement replacement materials, act as pozzolanic materials as well as fine fillers, thereby the microstructure of hardened cement matrix becomes denser and stronger. Silica fume improves the properties by pozzolanic reaction and by reactive filler effect. It contains a very high percentage of amorphous silicon dioxide which reacts with large quantity of Ca(OH)2 produced during hydration of cement to form calcium silicate hydrate (CSH) gel. Materials selection will play a large part in the improved concrete of the new century. Industrial by-products such as silica fume, bottom ash and steel slag aggregate improve the engineering and performance properties of high performance concrete when they are used as a mineral additive or as partial raw material replacement. In HPC, it is necessary to reduce the w/c ratio and which in general increases the cement content. To overcome these low workability problem, different kinds of mineral admixtures of industrial by-products like silica fume, bottom ash and steel slag aggregate can be used. Also at the same time, chemical admixtures such as high range water reducers are needed to achieve the required workability, to ensure that the concrete is easy to transport, place and finish and to ensure that the concrete meets the specified performance.

Materials and Specimen Configuration

In the experimental study, generally a good quality of cement like 43 grade cement is preferred but it may vary according to the grade of HPC needed. Natural sands crushed and rounded sands and manufactured sands are suitable for HPC. River sand of specific gravity 2.65 and conforming to zone II of IS 363 was used for the present study. The shape and particle size distribution of the aggregate is very important as it affects the packing and voids content. The moisture content, water absorption, grading and variations in fines content of all aggregate should be closely and continuously monitored and must be taken into account in order to produce HPC of constant quality. Coarse aggregate used in this study had a maximum size of 10mm. Specific gravity of coarse aggregate used was 2.75 as per IS 363. Ordinary potable water was used. Super plasticizers are high range water reducing admixtures an essential component of HPC. Conplast SP 430 was used as super plasticizer. Silica fume imparts very good improvement to rheological, mechanical and chemical properties. The silica fume is collected from ELKM INDIA (P) Ltd, Mumbai. Bottom ash obtained from thermal power plant, Neyveli Lignite Corporation Ltd, Neyveli, TamilNadu, India was used in this investigation. Steel slag is the by-product of metal smelting and hundreds of tons of it are produced every year all over the world in the process of refining metals and making alloys. When the metal is smelted to satisfaction, the slag is skimmed from the top and disposed of in a slag heap to age. In this experimental investigation an attempt is made to study the effect of partial replacement of cement by silica fume and partial replacement of fine aggregate and coarse aggregate by bottom ash and steel slag aggregate for making high performance concrete.

Table 1: Physical properties of raw materials and industrial byproducts

Proper ties	Specific Gravity	Water absorption	Fineness Modulus
FA	2.60	11%	2.97
CA	2.68	1.03%	3.06
SF	2.45	-	-
BA	2.36	17%	2.85
SSA	2.06	-	-

Table 2: Chemical properties of industrial byproducts

Chemical Composition	Silica fume	Bottom ash	Steel slag
$Si0_2$	92	28.4	29.3
Al_20_3	0.7	8.54	3.16
Fe_20_3	1.2	1.51	26.48
Ca0	0.3	50	33.2
M_g0	0.2	4.72	6.4
$S0_3$	0.3	3.44	0.71
K_20	1.8	1.8	0.04
Na_20	1.5	0.22	0.09

1Silica fume, the data provides by Ahmed Fathi, et al., (5), 2Bottom ash, the data provides by Purushothaman, et al., (3), 3Steel slag, the data provides by Kothari. P.S, et al., (4)

Experimental Investigation

Durability Tests:

Acid Resistance

The acid resistance tests were carried out on 150mm size cube specimens at the age of 28 days curing. The cube specimens were weighed and immersed in water diluted with one percent by weight of sulphuric acid for 30 days continuously. Then the specimens were taken out from the acid water and the surfaces of the cubes were cleaned. Next the weight and the compressive strengths of the specimens were found out and the average percentage of loss of weight and compressive strengths were calculated.

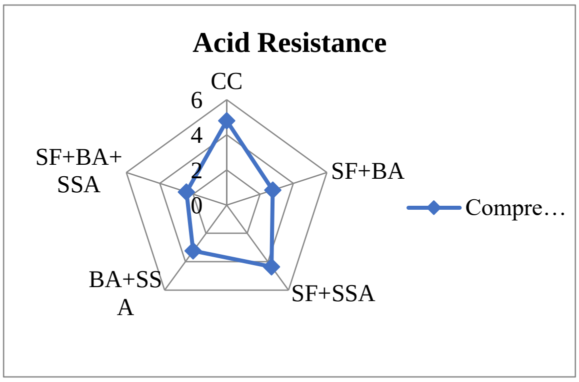
Salt Resistance

The salt water resistance tests were performed the resistance of concrete cubes subjected to salt water attack which might have resulted from the sea water. The concrete specimen cubes of 150mmx150mmx150mm size were cast for finding the weight loss and strength loss due to the salt water attack. The cubes were cured in water for 28 days. The specimens were taken out from the water were weighed and immersed in salt water with 3% diluted sodium chloride solutions. Then the specimens were taken out from the salt water and the surfaces of the cubes were cleaned.

Rapid chloride permeability test

This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. The RCPT method is the fastest method and is often used for specification and quality control purposes. The digital LED displays indicates the voltage available across the concrete specimen under test. The diffusion cell consists of two chambers. NaCl solution concentration 2.4 M and NaOH solution concentration 0.3M are prepared. NaCl solution concentration 2.4 M is filled in one chamber and in another chamber 0.3 M NaOH solution is taken. The chloride ions were forced to migrate through the centrally placed vacuum saturated concrete specimen under an impressed DC voltage of 60 volts.

Sl.No	Mix name	Curing days	% of Acid	Weight Loss	Strength Loss
1	**CC**	28 days	0%	3.4	4.8
2	**SF+BA**	28 days	1%	2.6	2.76
3	**SF+SSA**	28 days	1%	1.3	4.35
4	**BA+SSA**	28 days	1%	2.7	3.23
5	**SF+BA+SSA**	28 days	1%	4.2	2.4



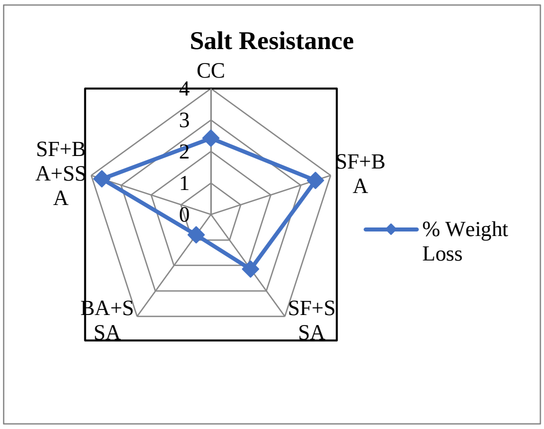
Results and Discussion

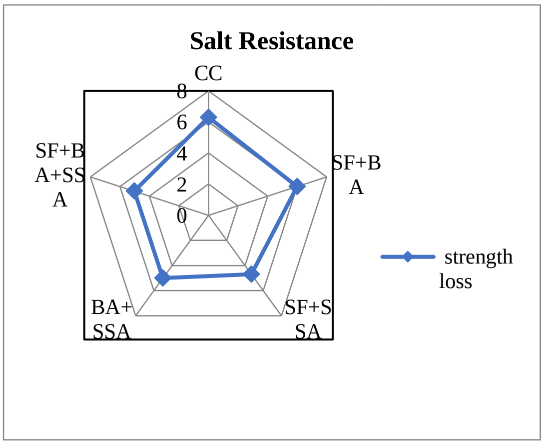
The results of the acid tests of various concrete mixes after soaking the cubes in acid are given in Table 3. The acid attack of various mixes after immersed in acid for 30 days are found experimentally. From the results, it was observed that the weight loss and strength loss was found in acid immersion. The obtained values of the percentage mass loss were 3.4%, 2.61%, 1.38%, 2.79% & 4.2% for CC, SFBA, SFSSA, BASSA, SFBASSA mixes of concrete and the strength percentage loss were 4.8%, 2.76%, 4.35%, 3.23% & 2.4% respectively. The results showed that SFSSA mixes of concrete the mass loss were lower but strength losses were higher than the conventional concrete.

Sl.No	Mix name	Curing days	% of Acid	Weight Loss	Strength Loss
1	**CC**	28 days	0%	2.36	6.3
2	**SF+BA**	28 days	1%	3.38	6.0
3	**SF+SSA**	28 days	1%	2.1	4.7
4	**BA+SSA**	28 days	1%	0.8	5.0
5	**SF+BA+SSA**	28 days	1%	3.51	5.2

Salt Resistance

The weight loss and strength loss was found in salt water immersion. The obtained values of the percentage mass loss were 2.42%, 3.5%, 2.15%, 0.8% & 3.64% for CC, SFBA, SFSSA, BASSA, SFBASSA mixes of concrete and the strength percentage loss were 6.3%, 6%, 4.7%, 5% & 5.02% respectively. The results showed that BASSA mixes of concrete the mass loss were lower but strength losses were higher than the conventional concrete.





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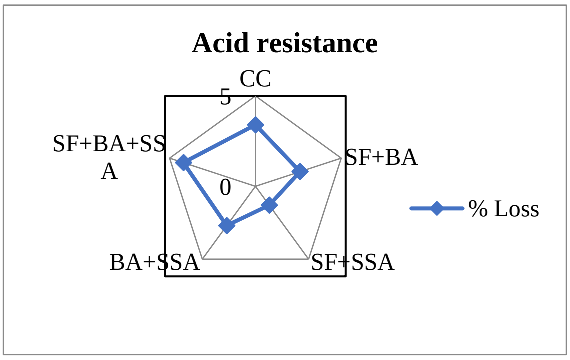
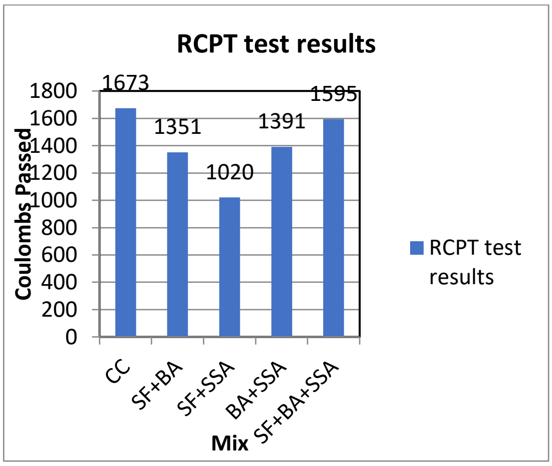
RCPT Test



Chloride ion penetrability test were conducted on cylinder specimens for each concrete mixture at 28 days for M30 grade of concrete. The results of chloride permeability in coulombs for different mix of concrete with same age are given in Table 3. The test results for the rapid chloride penetration into CC, SFBA, SFSSA, BASSA, SFBASSA concrete specimens of M30 grade at 28 days age are given in table. Test results proving the effectiveness of the applied sealer in reducing the ingress of chlorides into the concrete. Test results show that, the concrete containing silica fume and steel slag materials in high performance concrete have permeability reduction. These test results point out the importance of proper curing and that chloride permeability can be significantly reduced with concrete age.

Sl. No.	Grade of the Concrete	Name of the Mix	Mix details	chloride penetration in coulombs	Remarks
1	M30	Mix 1	CC	1673	Low
2	M30	Mix 2	SF+BA	1351	Low
3	M30	Mix 3	SF+SSA	1020	Low
4	M30	Mix 4	BA+SSA	1391	Low
5	M30	Mix 5	SF+BA+SSA	1595	Low



Microstructure analysis of HPC mixes

High performance Concrete samples were derived from the specimens after testing the cubes for compressive strength at 28 days age. The samples were immediately washed with acetone and before undergoing scanning electron microscope, a thin gold coating was applied on the samples to enable proper conduction. A Leo model scanning electron microscope was used to investigate the transition zone in the three types of HPC concrete exhibiting similar compressive strength at 28 days age. SEM observations on the concrete mixes with 28 day cube strength have been reported in the study presented here. Whereas the capillary voids are irregular in shape, the air voids are generally spherical. Air can be entrapped in the fresh cement paste during the mixing operation. Entrapped air voids may be as large as 3 nm and entrained air voids usually range from 50 to 200 µm.

HPC with CC mixes

Figure 1(a) shows a typical SEM micrograph obtained with binding material as conventional mixes alone. It shows presence of a large quantity of calcium hydroxide crystals and voids presents in the Interfacial transition zone. The hydrated cement paste in a conventional concrete consists of cement hydration products that include calcium silicate hydrate (CSH). Figure 1(b) shows occupied by calcium sulfoaluminate hydrates incompletely hydrated cement particles and paste porosity presence in solid CSH.

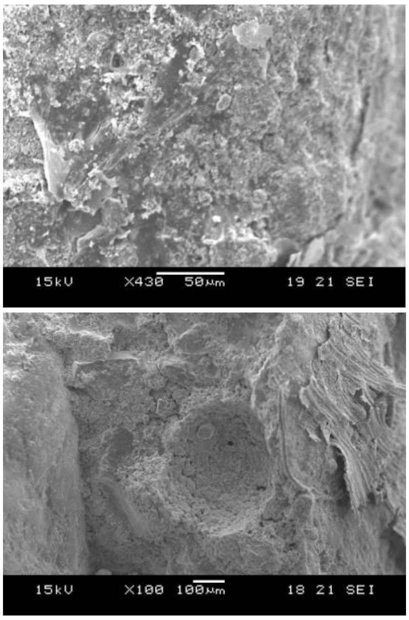
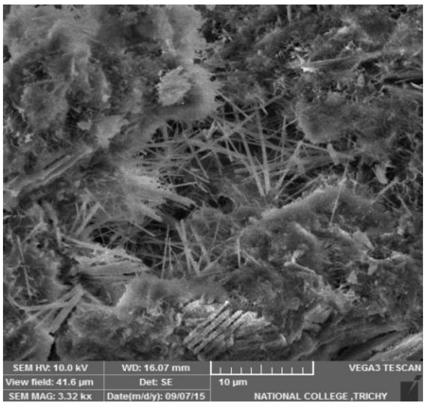
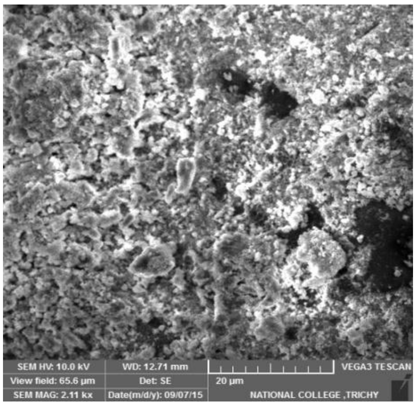


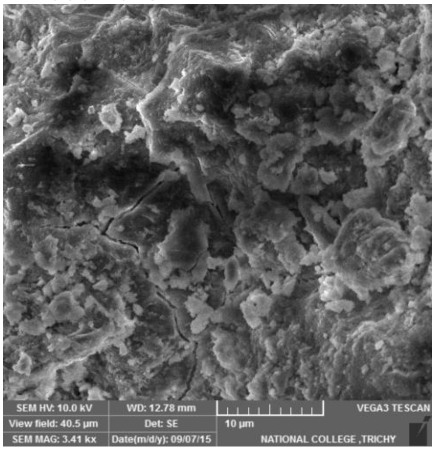
Figure1(a) & 1(b) Conventional concrete mix with extensive CH

Acid Resistance Cubes

Figure shows a typical SEM obtained in a binary mix concrete of silica fume and bottom ash with conventional concrete mix, where the silica fume percentage used was 5% of volume of cement and bottom ash percentage used was 10% of volume of fine aggregate. CSH and hydrated cement paste is seen in abundance in Figure. The amount of hydrated cement paste depends on cement and silica fume fineness, w/c ratio and degree of cement hydration. It is observed that the homogeneity has increased in the 40 to 50 µm region near the aggregate face due to the addition of silica fume. The CSH phase in this concrete produced at normal temperature is represented by gel structure ad it can range from poorly crystalline to crystalline.

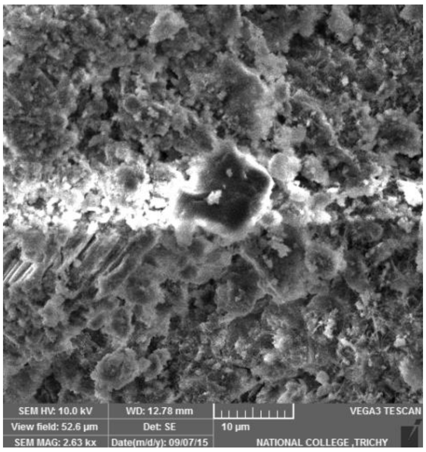






Salt Resistance cubes

A thin micro cracks are formed due to the combination of bottom ash and steel slag materials. Figure 4 (b) shows that the hydrated cement paste contains small capillary pores representing areas which were originally occupied by water in between the unhydrated cement grains and slag aggregate, but now appear as vacant spaces between the hydrated CSH gels. Figure 4 (a) shows that the calcium hydroxide crystals appear in many different shapes and sizes, starting from massive, platy crystals often tens of microns across with distinctive hexagonal prism morphology, large thin elongated crystals, and blocky masses to finely disseminated crystals.



Conclusions

Experiments were conducted to study acid resistance, salt resistance and RCPT with different percentage replacement of mineral admixture and industrial by-products. The following are the general conclusions arrived from the above studies the acid resistance of high performance concrete mixes of combination of silica fume and bottom ash and steel slag aggregate containing higher % of water loss and % of strength loss when compared with that of the concrete mixes without having mineral admixtures. The weight loss and strength loss was found in salt water immersion. The results showed that combination of bottom ash and steel slag aggregate mixes of concrete the mass loss were lower but strength losses were higher than the conventional concrete. The use of Silica fume, bottom ash and steel slag and proper curing are essential to produce concrete with significantly lower chloride permeability. Test results proving the effectiveness of the applied sealer in reducing the ingress of chlorides into the concrete. Presence of calcium hydroxide layer at the aggregate surfaces as reported extensively for conventional concrete is not seen in high performance concrete because of use of ternary mix of combination of silica fume, bottom ash and slag by-products.

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