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Experimental Investigation on the Effect of Industrial Byproducts on the Strength Properties of High Performance Concrete

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Abstract: *The present day research is focussed on development of alternative materials are incorporated with raw materials of Cement, Fine aggregate and Coarse aggregate due to scarcity of materials and enhancing the strength property with the production of High performance concrete. Silica fume, Bottom ash, Steel slag aggregate are the alternative admixture materials for replacing raw materials which can obtain high strength and performance based property. 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 thus there 3 materials may use as a partial replacement material in making HPC. In this present study, the compressive strength of concrete has been predicted using Artificial Neural Network (ANN). In addition scanning electron microscope was studied. Microstructure constitutes the nature of the solid portion and nonsolid portion.*
Keywords: *Bottom ash, HPC, Mechanical properties, Silica fume, Steel slag aggregate.*

I. Introduction

The development of eco friendly and sustainable construction materials has gained major attention by the construction field. 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. 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. There were 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 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.

II. Literature Collection

High performance concrete mixes containing different percentages of metakaolin were tested for strength and durability and have shown better resistances to the attacks of chemicals such as chloride and sulphates [1]. Vikan et al reported that the replacement of silica fume with different volume of well graded natural fine aggregate with the same water cement ratio with various proportions of natural pozzolan (0%, 5%, 10%, 15%) by weight of cement with naphthalene formaldehyde sulfonated superplasticizer in severe suphate environments [2]. Eehab Ahmed Badrelding Khalil et al developed fly ash and silica fume based high performance concrete mixes and found significant improvements in the property of fresh and hardened concrete [3]. Ozgur Cakir et al carried laboratory study on the properties of effects of incorporating silica fume in the concrete mix design to improve the quality of recycled aggregates in concrete and Portland cement was replaced with silica fume at 0%, 5% and 10% [4]. Sumit Kumar et al investigated that the significance of silica fume in enhancing the quality of concrete and found its effect on concrete after addition of silica fume. An experimental investigation on the flexural behaviour of reinforced high performance concrete was conducted by Paramasivam suresh kumar et al by using crushed stone sand replaced by fine aggregate and coarse aggregates in addition with silica fume and fly ash combination with superplasticizer [5]. A. Talah et al to assess the suitability of using marble powder as a partial substitute for Portland cement to produce high performance concrete having constant water binder ratio of 0.5 [6]. Pazhani et al produced High performance concrete by replacing 20%, 40%, 60%, 80% and 100% of fine aggregate with copper slag and 30% of cement with GGBS and tested to assess the durability parameters such as water absorption and chloride ion penetration [7]. Khalifa S. Al Jabri et al suggested that the effect of copper slag as a replacement of sand on the properties of high performance concrete [8]. A. Elahi et al presented an investigation of mechanical and durability properties of high performance concrete containing w/c ratio 0.3 which has used supplementary cementitious materials such as silica fume, fly ash, ground granulated blast furnace slag in binary and ternary systems. Portland cement was used with fly ash upto 40% and silica fume upto 15% and GGBS was replaced upto 70% performed the best amongst all the mixes to resist the chloride diffusion [9]. High performance concrete made with glass fibre with fly ash as the mineral admixture with the replacement level of 0%, 10%, 20%, 30% and glass fibre of 0%, 0.5%, 1%, 1.5% suggested by Dr. H. Sudarsana Rao et al [10]. Sung Won Yoo et al expressed autogenous shrinkage in High performance concrete with w/c ratio 0.3 with mineral admixtures fly ash 0%, 10%, 15%, 20% & 30% and silica fume 0%, 5%, 7.5%, 10% & 15% and chemical admixture shrinkage reducing agent and expansion agent. The autogenous shrinkage in high performance concrete with fly ash was decreased continuously with larger fly ash replacement and silica fume has increased when compared to that in OPC concrete and they explained both of these admixtures in adequate amount can provide decrease in autogenous shrinkage as well as improvement of the strength [11].

Table 1: Chemical Properties of materials

Constituent	**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	0.74	0.04
Na_20	1.5	0.22	0.09

Experimental Investigations

III. Materials

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 2.61 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 2.66 as per IS 363. Ordinary potable water was used. Silica fume shall confirm to the ASTM C 1240 specification as shown in Table No. 1. Silica Fume used was Elkem Micro Silica Grade 920-D (Non Combustible Amorphous S_i0_2 – Densified) in dry state and packed in 20 kg bags, obtained from thermal power plant, Neyveli Lignite Corporation Ltd., Neyveli, Tamil Nadu, India was used in this investigation. The Specific Gravity and Fineness modulus of Bottom ash was 2.36 and 2.39. The chemical composition of slag is usually expressed in terms of simple oxides calculated from electrical analysis determined by X-ray fluorescence.

Table 2: Physical properties of materials

Sl.No.	**Material**	**Specific Gravity**	**Fineness Modulus**
1	Cement	3.09	–
2	Fine Aggregate	2.60	2.92 (III)
3	Coarse Aggregate	2.68	3.06
4	Silica Fume	2.45	–
5	Bottom Ash	2.36	2.39
6	Steel slag aggregate	2.06	2.54

7	Superplasticizer	–	–

IV. Mix Design & Mix Proportion

As per the recommended procedure of Bureau of Indian Standards IS 10262–1982, mix ratio is designed with the test results of workability, specific gravity, water absorption for the materials. Design is stipulated for good degree of quality control and mild exposure. The mix proportions, by weight are 1:1.71:3.13 (Cement: fine aggregate: coarse aggregate) with a water cement ratio of 0.45. The compressive, split tensile and flexural strength of the specimens after replacing the cement by 5%, 10%, 15%, 20% with silica fume and fine aggregate, coarse aggregate by 10%, 20%, 30%, 40%, and 50% with Bottom ash and steel slag aggregate is studied after 28 days of curing. Using the designed mix, specimens are casted.

V. Test Details

In order to consider the effect of partial replacement of silica fume, bottom ash and steel slag aggregate, the proportion of water cement content, method of curing are kept constant. Cement is replaced by silica fume, fine aggregate is replaced by bottom ash and coarse aggregate is replaced by steel slag aggregate with the optimum replacement percentage is 5%, 10% & 10%. The test samples of 1:1.71:3.13 (Cement: fine aggregate: coarse aggregate) are produced with cement, fine aggregate and coarse aggregate. Subsequent test samples are produced with silica fume, bottom ash and steel slag aggregate progressively replaced by 5 and 10% intervals. The water cement ratio is kept constant at 0.45 throughout the investigation. 144 number of cubes 150mmx150mmx150mm cubes are cast for each mix, 72 cylinder dia 150mmx300mm height, 57 prisms of 100mmx100mmx500mm size are casted and cured in water at 28 days. The optimum percentage of replacement is found for every mix replacement. Further test procedure is carried out to determine the mechanical properties such as compression, tension, flexure test.

VI. Results And Discussion

Silica Fume Concrete:

Table 3: Mechanical properties of SFC:

Sl.No.	% of cement replacement	SFC COMPRESSIVE STRENGTH	SPLIT TENSILE	FLEXURAL STRENGTH
1	0%	34.795	2.77	7.11
2	5%	36.42	3.64	9.05
3	10%	34.15	3.35	8.62
4	15%	32.48	3.01	7.11
5	20%	31.95	2.89	6.68

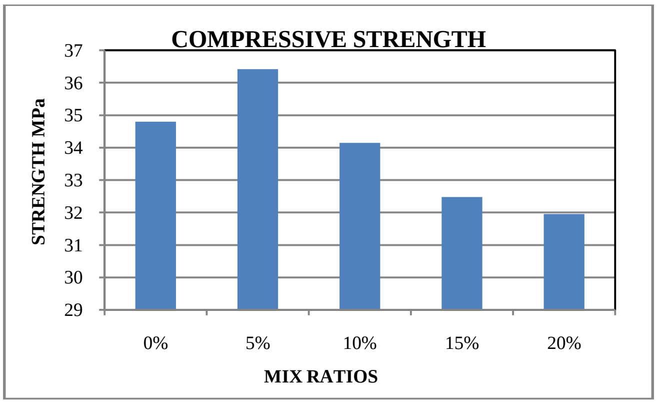

Fig 1: Compressive Strength of SFC

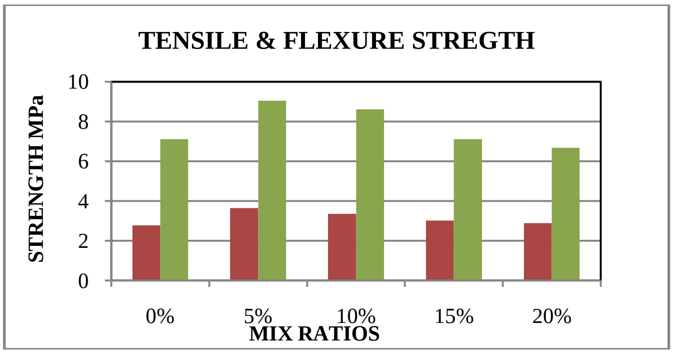

Fig 2: Tensile & Flexural Strength of SFC

Compressive Strength of silica fume concrete mixes was determined with the replacement ratio of 0 to 20% at 28 days curing period. The test results are given in Table 3 and Fig. 1 & Fig. 2. The gain of compressive strength, tensile and flexural strength is increased with the ratio of 5% silica fume mix of high performance concrete.

Bottom Ash Concrete:

Table 4: Mechanical properties of BAC:

Sl.No.	% of replacement	BAC		
		COMPRESSIVE STRENGTH	SPLIT TENSILE	FLEXURAL STRENGTH
1	0%	34.79	2.77	7.11
2	10%	35.32	3.80	8.94
3	20%	33.66	3.53	8.05
4	30%	32.15	3.37	6.46
5	40%	31.04	2.39	6.03
6	50%	29.41	2.38	5.82

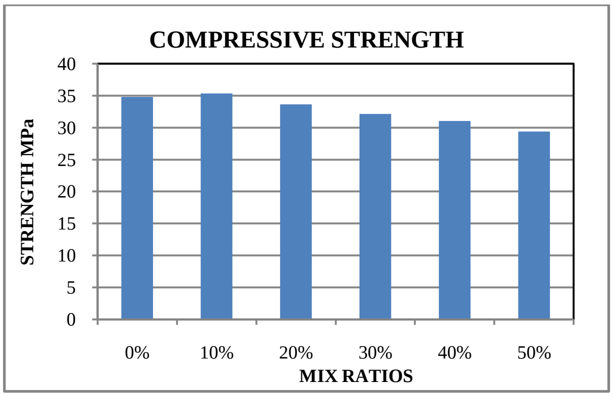

Fig 3: Compressive Strength of BAC

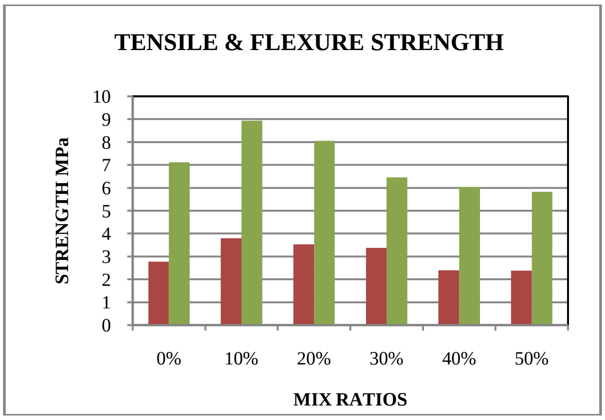

Fig 4: Tensile & Flexural Strength of BAC

Compressive Strength of bottom ash concrete mixes was determined with the replacement ratio of 0 to 50% at 28 days curing period. The test results are given in Table 3 and Fig. 1 & Fig. 2. The gain of compressive strength, tensile and flexural strength is increased with the ratio of 10% bottom ash mix of high performance concrete.

Steel Slag Aggregate Concrete:

Table 5: Mechanical properties of SSAC:

Sl.No.	% of replacement	SSAC		
		COMPRESSIVE STRENGTH	SPLIT TENSILE	FLEXURAL STRENGTH
1	0%	34.79	2.77	7.11
2	10%	39.55	3.88	8.67
3	20%	36.55	3.61	8.48
4	30%	35.86	3.28	7.11
5	40%	32.95	2.33	6.90
6	50%	31.39	2.21	6.25

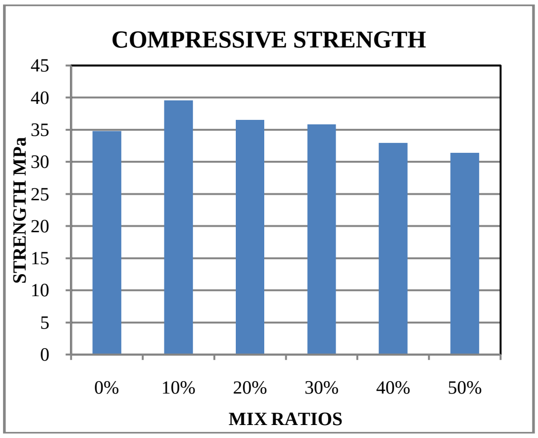

Fig 5: Compressive Strength of SSAC

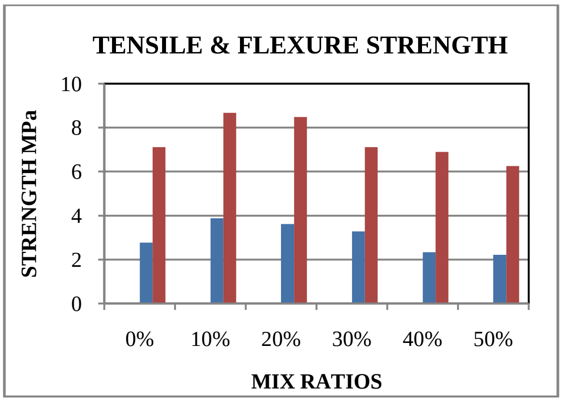

Fig 6: Tensile & Flexural Strength of SSAC

Compressive Strength of steel slag aggregate concrete mixes was determined with the replacement ratio of 0 to 50% at 28 days curing period. The test results are given in Table 3 and Fig. 1 & Fig. 2. The gain of compressive strength, tensile and flexural strength is increased with the ratio of 10% steel slag aggregate mix of high performance concrete.

Microstructural Study:

To understand the internal changes of concrete with the presence of silica fume of mineralogical material or supplementary cementitious material, industrial by-products of bottom ash and steel slag aggregate in high performance concrete. During curing period to found the micro structural changes of silica fume concrete, bottom ash concrete and steel slag aggregate concrete with SEM images were obtained. 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.

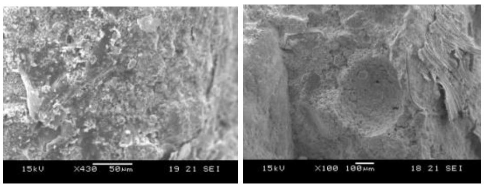

Fig. 7: SEM Image of CC at different magnification

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.

Silica fume concrete:

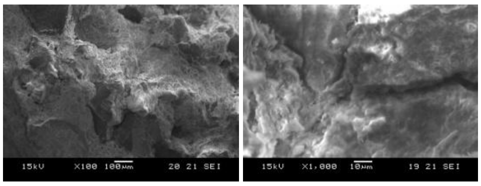

Fig. 8: SEM Image of SFC at different magnification

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. Figure 2 shows a silica fume particles in close nearness of the crack seem to be the small size of the silica fume particles and it is observed that the size of the silica fume particles was 0.9 to 1.2 µm. The CSH phase in this concrete produced at normal temperature is represented by gel structure ad it can range from poorly crystalline to crystalline.

Bottom ash concrete:

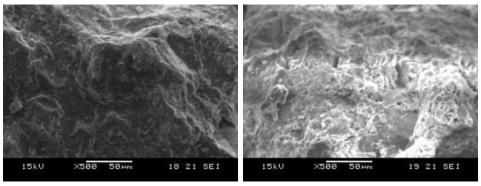

Fig. 9: SEM Image of BAC at different magnification

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. A thin micro cracks are formed due to the combination of bottom ash and materials. Figure 3 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.

Steel slag aggregate concrete:

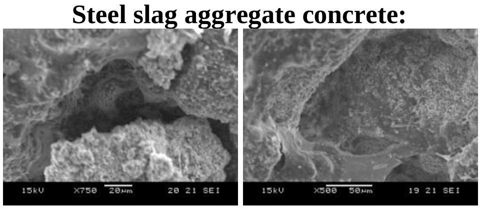

Fig. 10: SEM Image of SSAC at different magnification

In this type of concrete large areas are presents calcium hydroxide due to the present of three different by-products. A higher degree of densification is observed in the nearness of the aggregate phase. It illustrates that the presence of slag particles facilitates further dispersion of cement particles leading to the packing of the zone adjacent to the aggregate face.

Analytical Results

An artificial neural network is an artificial intelligence technique. It is a simulation of human brain-like architecture. An artificial neural network is a massively distributed processor made up of interconnection of simple processing elements i.e. neurons outputs are connected, through weights, to all other neurons including themselves, It resembles brain in mainly in the aspects of. The factors that determine, the behaviour of a given neural network are weights of the connections. In a large network the contribution of a single weight is often slight; it is the effect of combination of connection weights that determines the output. The process of training a network is that of finding a set of values for the weights that make the network do what you want it to do. Mathematicians are still working on this, but is appears that given enough hidden units and connections there is little that a net is unable to do. Then the problem is in finding the right box to train generalized regression neural networks to solve specific problems.

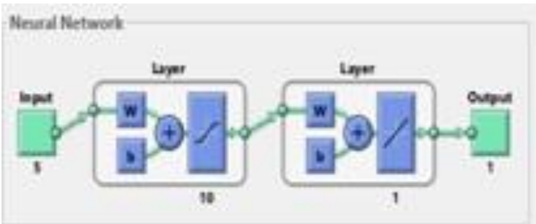

Fig. 11: ANN Network Output dialog box

Fig. 12: Network Training regression

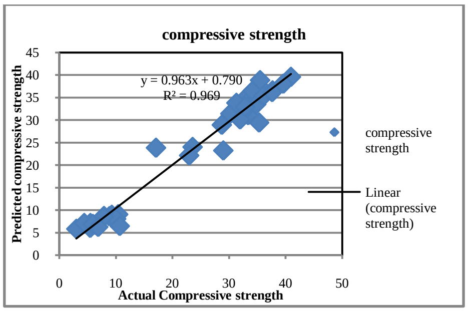

Fig. 13: Relationship between Actual & Predicted compressive strength of HPC at 28 days

VII. Conclusion

Experiments were conducted to study mechanical properties of high performance concrete with different percentage replacement of mineral admixture and industrial by-products such as silica fume, bottom ash and steel slag aggregate. The following are the general conclusions arrived from the above studies the mechanical properties of high performance concrete mixes of combination of silica fume and bottom ash and steel slag aggregate containing higher % of strength when compared with that of the ordinary 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 usage of combination mix of silica fume, bottom ash and slag by-products and presence of partially hydrated cement grains in conventional concrete matrix and the ITZ. It is widely reported that the permeability of concrete reduces drastically with inclusion of silica fume. Steel slag aggregate mix of concrete shows that the presence of ettringite in direct contact with aggregate of calcium hydroxide film in the ITZ of normal concrete. A combined model developed in ANN by using inputs from compressive strength of concrete predicts more accurately and it is recommended to be used alone to predict strength of concrete.

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