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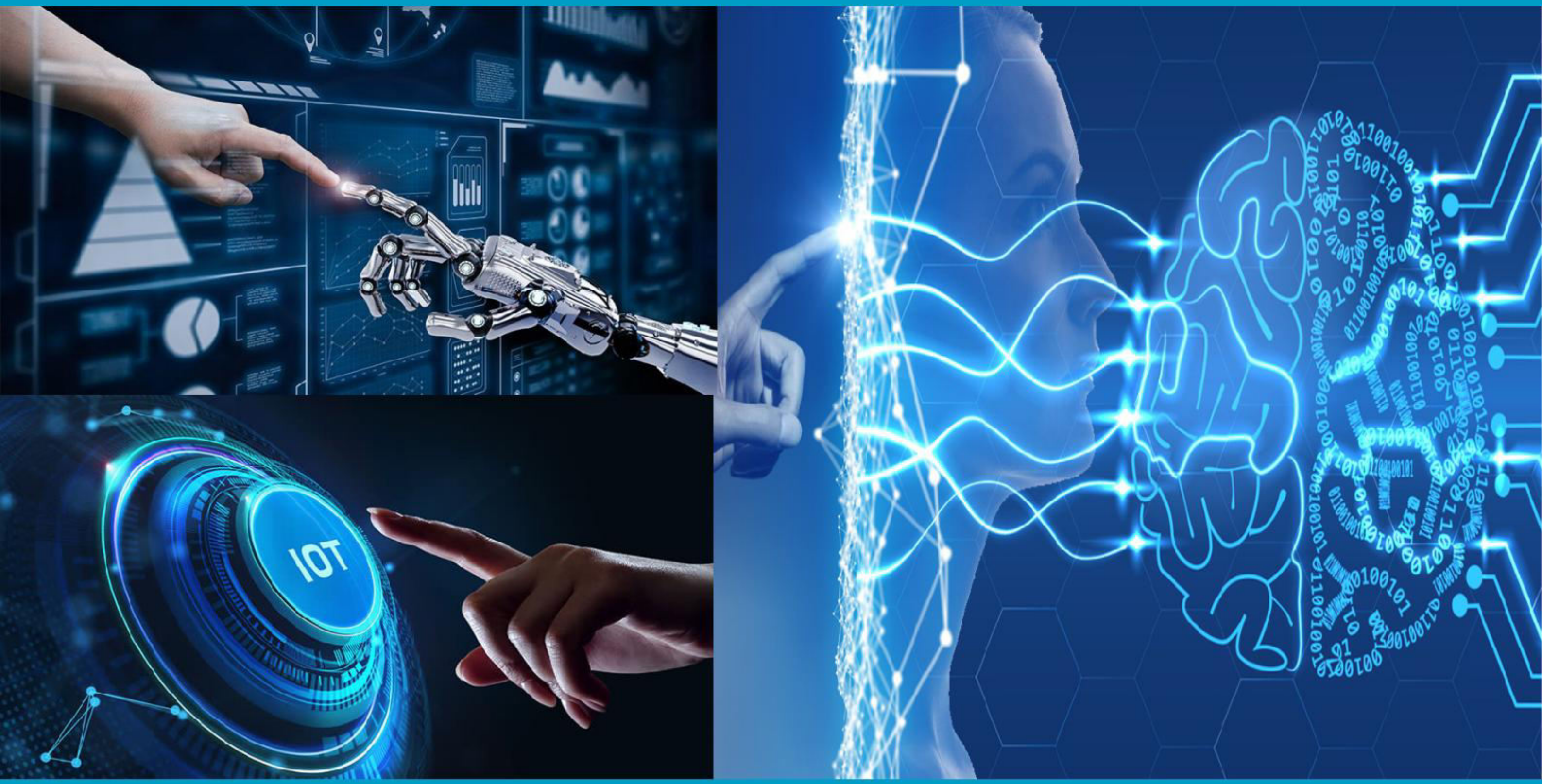

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Flexural Study on Reinforced High Performance Concrete Beams

Mohit, Neetu

Structural Engg, MRIEM, Rohtak, India

ABSTRACT: This study intended to develop a technique for employing industrial by-products to improve the strength, durability, and flexural behavior of reinforced HPC beam members compared to standard concrete. Silica fume, bottom ash, and steel slag are utilized to make high-performance concrete. The research shows that the 5 percent silica fume substitution of cement increased compressive strength by 4.46 percent after 28 curing days. Concrete with 10% bottom ash substitution of fine aggregate reached 35.32 MPa at 28 curing days, 1.486% higher than CC. Concrete with 10% steel slag aggregate substitution of coarse aggregate has greater compressive strength at 28 curing days than CC by 12.02 percent. SFC's tensile and flexural strengths increased by 23.9% and 21.4%, respectively. Split tensile strength improves with 5% SF content and declines beyond that. BAC's tensile and flexural strengths increased by 27.10% and 20.46% over CC. SSAC's tensile and flexural strengths increased by 28.6% and 17.99% compared to CC. Single-combination findings determined the optimal replacement % for binary and ternary combinations. Compressive strength rose after 180 days for all blends of CC, SFBAC, SFSSAC, BASSAC, SFBASSAC by 47.40 MPa, 62.30 MPa, 62.79 MPa, 56.52 MPa, and 51 MPa, respectively, compared to 28 days. Pozzolanic reaction of industrial byproducts in concrete increased strength. For split tensile strength, SFSSAC averaged 3.898 MPa, a 40.72 percent improvement over CC. Maximum flexural strength was achieved in the SFSSAC mix at 8.15 MPa, an increase of 14.62 percent above CC. SFSSAC had 11.63 percent more elasticity than CC. Before and after immersion, compressive strength was tested for CC, SFBA, SFSSA, BASSA, and SFBASSA. In 1% sulfuric acid, HPC mixtures exhibit high acid resistance. For acid resistance tests for all mixes, mass loss in SFSSAC mix was 2.75 percent and strength loss were 5.53 percent compared to CC. For salt resistance test for all mixtures, BASSAC mix had better mass loss (4.30%) and strength loss (8.60%) compared to CC. BASSAC concrete had good sulphate resistance in 5% sodium sulphate solution and was the best of other varieties since its mass loss was 1.63 percent and its strength loss was 5.58 percent compared to CC. SFBAC, SFSSAC, BASSAC, and SFBASSAC absorbed 10.56, 9.12, 8.97, and 3.58 percent less water than CC. For RCPT, the quick chloride penetration values were 19.24%, 39.03%, 16.85%, and 4.666% compared to CC.

KEYWORDS: Silica Fume, Compressive Strength, High Performance Concrete Beams

I. INTRODUCTION

Concrete is undoubtedly the most extensively utilized construction material for all types of activity in the building industry worldwide, and it will stay so for the foreseeable future. Concrete's appeal stems from the raw material's superior strength and durability, inexpensive production and maintenance costs, adaptability in molding diverse shapes, and its limitless structural applications in conjunction with steel structures. Nonetheless, the building industry faces a significant issue due to the importance of cement. Cement manufacture is an energy-intensive operation, and the emission of large amounts of carbon dioxide during cement production contributes to global warming. Cement causes anguish in concrete under hostile environmental circumstances nowadays. As a result, there is a need to reduce cement usage and increase research into the possibilities of improving strength and durability qualities through the use of mineral admixtures. Many poor countries are working on producing alternative building materials based on local elements. The use of extra cementitious ingredients or mineral admixtures for making high performance concrete has been one of the key trust areas of concrete research. Concrete is undeniably the most widely utilized construction material for all types of activity in the building industry worldwide, and it will stay so for the foreseeable future. Concrete's appeal stems from the raw material's superior strength and durability, inexpensive production and maintenance costs, adaptability in molding diverse shapes, and its limitless structural applications in conjunction with steel structures. Nonetheless, the building industry faces a significant issue due to the importance of cement. Cement manufacture is an energy-intensive operation, and the emission of large amounts of carbon dioxide during cement production contributes to global warming, and cement causes anguish in concrete under hostile environmental circumstances nowadays. As a result, there is a need to reduce cement usage and increase research into the possibilities

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of improving strength and durability qualities through the use of mineral admixtures. Many poor countries are working on producing alternative building materials based on local elements. The use of extra cementitious ingredients or mineral admixtures for making high performance concrete has been one of the key trust areas of concrete research.

The use of mineral admixtures and industrial by-products such as fly ash, silica fume, metakaolin and Ground Granulated Blast Furnace(GGBS)is to conquer the inimical effect of calcium hydroxide. These mineral admixtures produce less percentage of calcium hydroxide when compared to ordinary Portland cement. Their use in concrete, to replace cement, partially conserves cement and power, improves strength, durability and helps to protecting the environment. So far, the production of high-performance concrete with these supplementary materials is highly recommended by the researchers. Investigations divulged that many industrial by- products can be used to replace the concrete materials to improve the economic condition and minimize the construction cost.

Aggregates are considered one of the important constituents of concrete since they occupy more than 70% of the concrete mix. Generally, the river sand is used as fine aggregate in concrete and it is obtained by mining the sand from river bed. In order to do this, mining not only affects the aquifer of the river bed but also causes environmental problems. The utilization of industrial by-products or secondary materials has encouraged the production of cement and concrete in construction industry. New industrial by-products and secondary materials are generated by various industries. Concrete prepared with such materials showed improvement in workability, mechanical property and durability when compared with conventional concrete. Over recent decades, intensive research studies have been carried out to explore all possible reuse and by-products such as waste foundry sand (WFS), coal bottom ash (CBA), cement kiln dust (CKD) and wood ash (WA) in making cement- concrete and controlled low-strength material (CLSM).High consumption of natural sources and high amount production of industrial by-products and environmental pollution require obtaining new solutions for a sustainable development.

Silica fume in High Performance Concrete

The incorporation of silica fume in concrete leads to improve the strength and makes the mix more mobile yet cohesive. The use of silica fume in conjunction with super plasticizer has been the backbone of modern High-Performance Concrete. When silica fume is added to the concrete, simultaneously the water demand increases and therefore, use of super plasticizer or water reducing agent is mandatory. This is the consequence of the better dispersion of the cementitious particles and due to the surface characteristics of the silica fume particles, which are smooth and absorb little water during mixing. The mix containing silica fume has very low to permeable, good resistance to chloride ion penetration, and reduced freeze and thawing effect. The siliceous compound in a finely divided form reacted with the calcium hydroxide to form highly stable cementitious substances of complex composition involving water, calcium and silica. The characteristic feature of pozzolanic reaction is initially slow, with the results that heat of hydration and strength development will be very high due to the curing days. The reactivity of a pozzolanic can be quantified by measuring the amount of calcium hydroxide in the concrete paste.

Role of Bottom ash in HPC

Bottom ash is the companion to fly ash in process of coal-burning with an approximate amount of 20% by volume of the total ash, depending on the type of boiler, dust collection system, burning temperature and the type of coal. Its particle is porous, irregular and coarser than that of fly ash but its chemical composition is not much different. Some studies on the usage of bottom ash in concrete had been focused on its potential capability to replace or partially replace fly ash due to its similar particle size to that of normal sand. Disposalin landfills and surface impoundment is most commonly used coal combustion residues management option. The utilization of coal combustion residues in these productive alterative has been increasing steadily. Information regarding the physical, chemical and engineering properties of coal combustion residues is required before these materials can be safely effectively utilized. Most of the researchers accentuated that bottom ash has quite alterable physical, chemical and engineering characteristics. It is not only varying from plant to plant, but also from day-to-day production within a single plant over time.

On Indian scenario it is observed that at very few places good quality of sand may be available in plenty. All metro and mega cities in India are facing acute shortage of good quality sand. At some places sand available is coarser than zone I sand and henceforth not suitable for construction activity. In contrast to the sand, bottom ash is available in huge quantity due to more and more thermal power plants in India. Usually, bottom ash is formed from coal furnaces and it is made from agglomerated ash particles that are too large to be carried in the flue gases and fall through open grates to an ash hopper at the bottom of the furnace. Bottom ash is mainly comprised of fused coarser ash particles, so it could

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increase the strength as well as durability properties of concrete.

Role of Steel Slag Aggregate in High Performance Concrete

Aggregates are important constituents in the concrete combination that help to reduce shrinkage and impact economy to concrete production. Most of the coarse aggregates are used as naturally occurring aggregates, but some artificial aggregates can also be added to concrete production. These artificial and natural aggregates react with the cement paste and chemically combine to improve the mechanical properties of concrete.

Steel slag is the by-product of the steel making process, which is produced during separation of the molten steel from impurities in the steel-making furnaces. Due to environmental impacts associated with aggregate extraction, considerable efforts have been made towards the utilization of indigenous by-products in concrete. The main uses of adding by-products in concrete from the various sources are the elimination of scraps and a reduction in the overexploitation of quarries. Steel slag aggregate is an industrial product that is manufactured under extensive quality management, and contains no organic impurities, clay, shells, or similar materials.This aggregate contains no reactive silica, which is one cause of chemical reaction with alkali aggregates. It reduces environmental impacts, preserves precious natural resources needed to maintain ecosystems, and can reduce the energy that is consumed in mining, stone crushing, and other activities. As a result of growing environmental awareness, steel slag is highly regarded as a recycled material that can reduce impacts on the environment due to its resource-conservation and energy- saving effects.

II. RESEARCH METHODOLOGY& EXPERIMENTAL INVESTIGATIONS

The goal of this study is to find an effective approach to produce high-performance concrete using industrial byproducts like as silica fume, bottom ash, and steel slag aggregate. Using the mix design in IS 10262:2009, an attempt will be made to establish the best mix proportion of the replacement materials in place of cement, fine aggregate, and coarse aggregate. The specimens are 150mm x 150mm x 150mm for cubes, 150mm x 300mm for cylinders, and 100mm x 100mm x 500mm for prisms. The experimental test results will reveal the compressive strength, split tensile strength, and flexural strength of the concrete with replacement materials. The best replacement level mixes for the concrete must be selected based on the compressive strength of a single combination mix for further inquiry. A total of 135 specimens will be cast for experimental testing of conventional concrete and replacement material concrete, including 45 cubes for testing.

Concrete has 45 cylinders for compressive strength, 45 prisms for split tensile strength, and 45 prisms for flexural strength.The selected three binary combinations mixes SFBAC, SFSSAC, BASSAC and one ternary combination mix SFBASSAC willbe obtained from single combination results. With the optimum replacement level for the binary and ternary combination mixes,the compressive strength at the age of 28, 56, 90 and 180 days, split tensile strength and flexural strength at the age of 28 days curing are to be found. Totally 115 of specimens are to be cast for experimental testing of conventional concrete and HPC mixes such as 60 cubes for compressive strength test, 15 cylinders for split tensile strength testand 15 cylinders for modulus of elasticity and 15 prisms for flexural strength testof concrete.

In order to achieve the durable concrete even its performance in strength aspects is much better as the durability of concrete is the main criterion for the life of structure of the concrete. Keeping the above in mind, the durability tests such as acid resistance, salt resistance, sulphate resistance, water absorption and rapid chloride penetration test are conducted.TheNon-Destructive Tests such asRebound Hammer test and Ultrasonic Pulse Velocity tests will becarried out before and after durability tests. Totally 75 specimens were cast for experimental testing of conventional concrete and HPC mixes: 60 cubes for acid resistance test, salt resistance test and sulphate resistance test, 15 sliced cylinders of size 100 mm x 50 mm for rapid chloride penetration test.

MATERIALS USED IN CONCRETE

A material plays an important role in the production of high-performance concrete. In developing the concrete mix of HPC, it is an important to select proper ingredients, evaluate their properties and understand the interaction among different materials for optimum usage. The ingredients used for this investigation were cement, fine aggregate, coarse aggregate, water, chemical admixture (superplasticizer), industrial by-products such as silica fume, bottom ash and steel slag.

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Cement

Ordinary Portland cement of 43 grade conforming to IS: 8112-2013 was used for the present experimental investigation. The Ordinary Portland Cement named as Chettinad Cement was obtained from the supplier and it was satisfactory as per codal recommendations. The specific gravity of cement was 3.09.

Cement Replacement Material - Silica fume

Silica fume, also referred to as micro silica or condensed silica fume, is a by-product material used as a pozzolana. This by-product is a result of the reduction of high- purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapour at 20000 C (36300F) from the furnaces. When it cools, it condenses and is collected in huge cloth bags. Thecondensed silica fume is then processed to remove impurities and to control particle size. In this investigation, the silica fume obtained from ELKEM India (P) Ltd., Mumbai in dry densified form was used. The chemical composition of cement and silica fume is mentioned in Table 1 as given by the supplier. The specific gravity of silica fume was 2.45.

Table 1: Chemical Composition of OPC 43 Grade of Cement and Silica Fume

Sl. No.	Compound	OPC 43 Grade	Silica Fume
1	Silicon Dioxide (SiO_2)	24.30	97.14
2	Aluminum Oxide (Al_2O_3)	4.80	0.01
3	Ferric oxide (Fe_2O_3)	3.80	1.09
4	Calcium Oxide (CaO)	55.30	0.02
5	Sulphur Trioxide (SO_3)	2.20	0.01
6	Magnesium Oxide (MgO)	4.20	0.01
7	Sodium Oxide (Na_2O)	0.15	0.20
8	Potassium Oxide (K_2O)	0.84	0.70
9	Loss of Ignition	2.40	1.36
10	Insoluble Residue	0.20	-

III. ANALYTICAL INVESTIGATIONS

Artificial Neural Network (ANN) technologies, a sub-field of artificial intelligence, are used to solve a wide variety of problems in Civil Engineering field. A Neural network modelling was carried out to predict the strength properties of the conventional concrete, Silica fume concrete (SFC), Bottom ash concrete (BAC), Steel slag aggregate concrete (SSAC), combination of silica fume and bottom ash (SFBAC), combination of silica fume and steel slag aggregate concrete (SFSSAC), combination of bottom ash and steel slag aggregate (BASSAC), and combination of silica fume, bottom ash and steel slag aggregate (SFBASSAC) concrete. These were aimed at demonstrating the possibilities of using artificial neural network for predicting the compressive strength of cubes and were compared with the experimental results.

ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network is an Artificial Intelligence technique. It is a massive distributed processor made up of interconnection of simple processing elements i.e., neurons outputs are connected, through weights, to all others including themselves. The objective is to apply neural network concept in creating an intelligent system for finding the compressive strength of concrete cubes by different materials of SF, BA, SSA and conventional concrete for 28, 56, 90 and 180 curing days.

Formation of Input Patterns

The input patterns are chosen according to different types of concrete used with different quantities of admixture and industrial by-product materials. Hence, the input patterns were taken asAge of specimen, Cement, Fine aggregate, Coarse aggregate, Silica fume, Bottom ash, Steel slag aggregate, Water-cement ratio, Observed compressive strength, Dry weight, Wet weight, Percentage of weight loss, Moment, Length of the beam and Experimental Ultimate load.

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INPUT AND OUTPUT PARAMETERS USED

In training and testing of the models constituted with two different architectures, the age of specimen, quantity of cement, fine aggregate and coarse aggregate, silica fume, bottom ash, steel slag aggregate, water-cement ratio used as input and for the second set of input were dry weight and wet weight for durability test and for the third set of input were moment and length of the beam while compressive strength, durability percentage of mass loss and ultimate load for beam were used as output.

The input and output quantities and the values of parameters used in ANN Model I for predicting the compressive strength are presented in Tables 2 to 5. The input and output quantities and the values of parameters used in ANN Model II for predicting the durability values of mass loss in percentage are presented in Tables 6 to 10.The input and output quantities and the values of parameters used in ANN Model III for predicting the ultimate load for beam are presented.

Table 2 Input and Output Quantities Used in ANN Model I (Single Combination)

Variables	Data used in training and testing the models	
	Minimum	Maximum
Input Variable		
Age of specimen (Day)	28	28
Cement (kg/m^3)	306.40	383
Silica fume (kg/m^3)	19.15	76.6
Fine aggregate (kg/m^3)	327.5	655
Bottom ash (kg/m^3)	65.5	327.5
Coarse aggregate (kg/m^3)	600	1200
Steel slag aggregate (kg/m^3)	120	600
Water (l)	172.4	172.4
Output variable		
Compressive strength for CC (N/mm^2)	30.1600	34.7950
Compressive strength for SFC(N/mm^2)	31.9505	36.4220
Compressive strength for BAC(N/mm^2)	29.4102	35.3212
Compressive strength for SSAC(N/mm^2)	31.3905	39.5517

Note: CC – conventional concrete, SFC – silica fume concrete, BAC – bottom ash concrete, SSAC – steel slag aggregate concrete

Table 3 Values of Parameters Used in Models for Finding Compressive Strength (Single Combination)

Parameters	ANN
Number of input layer neurons	8
Number of hidden layer	1
Number of first hidden layer neurons	10
Number of second hidden layer neurons	20
Number of output layer neurons	1
Momentum rate	0.7
Learning rate	0.3
Error after learning	0.00100
Learning cycle	4000

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Table 4 InputandOutputQuantitiesUsedinANNModelI(BinaryandTernaryCombination)

Input variable	Data used in training and testing the models	
	Minimum	Maximum
Age of specimen (Day)	28	180
Cement (kg/m³)	363.85	383
Silica fume (kg/m³)	0	19.15
Fine aggregate (kg/m³)	589.50	655
Bottom ash (kg/m³)	0	65.5
Coarse aggregate (kg/m³)	1080	1200
Steel slag aggregate (kg/m³)	0	120
Water (l)	172.4	172.4
Output variable		
Compressive strength for CC(N/mm²)	30.1610	45.4977
Compressive strength for SFBAC(N/mm²)	31.9944	62.3014
Compressive strength for SFSSAC(N/mm²)	37.5955	62.7914
Compressive strength for BASSAC(N/mm²)	36.6813	56.5272
Compressive strength for SFBASSAC(N/mm²)	28.4846	51.0324

Table 5 Values of Parameters Used in Model I

Parameters	ANN
Number of input layer neurons	5
Number of hidden layer	1
Number of first hidden layer neurons	7
Number of second hidden layer neurons	15
Number of output layer neurons	1
Momentum rate	0.7
Learning rate	0.3
Error after learning	0.00100
Learning cycle	4000

Table 6 Input and Output Quantities Used in ANN Model II (Acid Resistance)

Variables	Data used in training and testing the models	
	Minimum	Maximum
Input variable		
Dry Weight (kg) Before immersion	8.128	8.610
Wet Weight (kg) After immersion	8.540	8.973
Output variable		
Acid Resistance in terms of mass loss (%)	4.9099	7.4937

Table 7 Input and Output Quantities Used in ANN Model II (Salt Resistance)

Input variable	Data used in training and testing the models	
	Minimum	Maximum
Dry Weight (kg) Before immersion	8.128	8.623
Wet Weight (kg) After immersion	8.497	8.999
Output variable		
Salt Resistance in terms of mass loss (%)	5.8033	7.5014

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MODEL I: ANALYSIS AND TRAINING OF CC AND HPC

The training procedure was carried out by presenting the network with the set of experimental data in a patterned format. Each training pattern includes an input set of eight parameters representing (age of concrete, cement, fine aggregate, coarse aggregate, silica fume, bottom ash and steel slag aggregate and water) and a corresponding output set representing the compressive strength of concrete cubes. Totally forty-five cubes were cast for finding the compressive strength of single combination.

The curing period for single combination of Model I had 28 days for finding compressive strength. The curing period for binary and ternary combination had 28, 56, 90 and 180 curing days for finding compressive strength. In this study, 4000 training cycles have been obtained to minimize the error and to reach the goal point.

Compressive Strength of Conventional Concrete

The comparison between experimental and predicted values through ANN values of compressive strength is shown in figure 1. The experimental and predicted values showgood agreement with each other and the performance between experimental and predicted results was very closer. In this study, cycles have been obtained to minimize the error to reach the goal point.

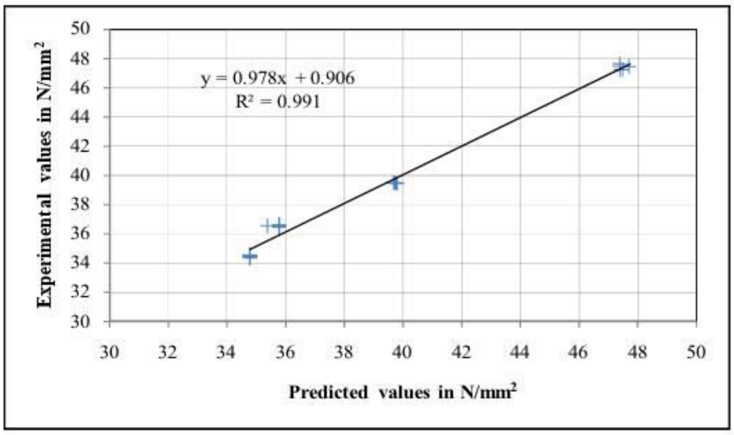

Fig. 1 Comparison of Experimental Vs Predicted Values of CC

The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 1.

$$y = 0.978\,x + 0.906$$

Compressive Strength of Cement Replacement Concrete

Similarly the replacement material concrete mixes of equations were arrived for similar pattern of conventional concrete. The comparison between experimental and predicted values through ANN modeling compressive strength of silica fumeconcrete was arrived. The experimental and predicted values show that theperformance for concrete strength was superior to the experimental results. The experimental and predicted values for SFC with percentage of error were found. The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 2.

$$y = 0.713\,x + 9.648$$

Compressive Strength of Fine Aggregate Replacement Concrete

The comparison between experimental and predicted values through ANN modelling of compressive strength of bottom ash concrete was arrived. The experimental and predicted values show that the performance for concrete strength was superior to the experimental results. The experimental and predicted values for BAC with percentage of error were found. The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 3.

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$$y = 1.051\,x - 1.519$$

Compressive Strength of Coarse Aggregate Replacement Concrete

The comparison between experimental and predicted values through ANN modelling of compressive strength of steel slag aggregate concrete was arrived. The experimental and predicted values show that the performance for concrete strength was superior to the experimental results. The experimental and predicted values for SSAC with percentage of error were found. The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 4.

$$y = 0.959\,x + 1.501$$

Overall performance of Single Combination

The overall performance training graph of CC, SFC, BAC, and SSAC concrete mixes through ANN modelling is shown in figure 2 and experimental and predicted.

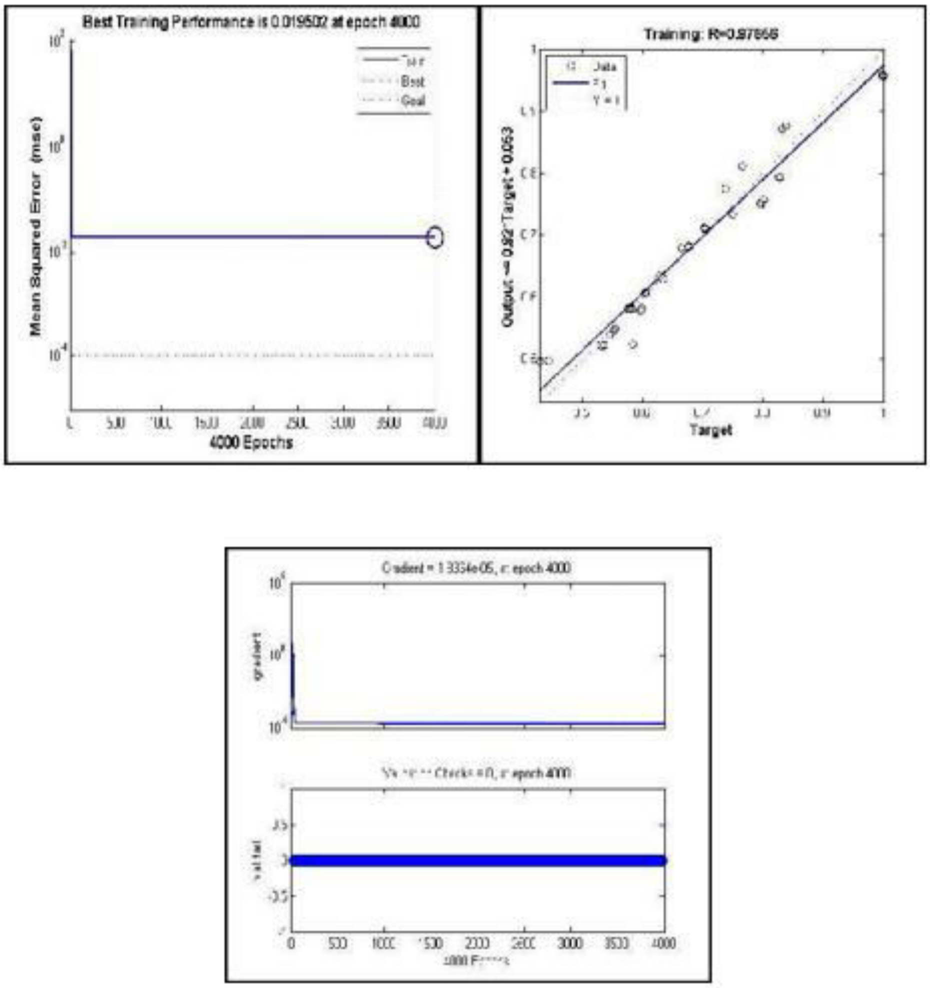

Fig. 2 Overall Performances, Training Graph and Validation of Test Values (Single Combination)

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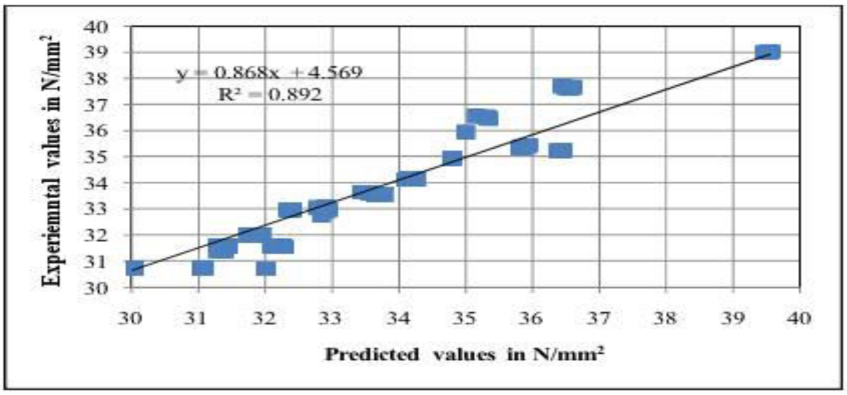

Fig. 3 Comparison of Experimental Vs Predicted Values of All Mixes (Single Combination)

The performance of training, validation and testing values is 1.8364e-05. To train the network, the weights of connections are modified according to the information.The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression.

$$y = 0.868\,x + 4.569$$

The network leans by comparing its output for each input pattern, and then calculating the error and propagating an error function backward through the network. To run the network after it is trained, the values for the input parameters for the project are presented to the network. The process for running the network is extremely rapid because system of coefficient determination R2 is adopted. The equation of training outputs is A = 0.92 (T) + 0.053 and its R value is 0.97656.

MODEL II: ANALYSIS AND TRAINING OF DURABILITY RESULTS

The term durability is used to characterize in broad area of resistance of concrete to a variety of physical or chemical attacks due to their external and internal causes. The total numbers of specimens for durability studies were 60 cubes and 15 cylinders. The specimen's size of 150 mm x 150 mm x 150 mm cubes, 100 mm x 200 mm cylinders were used. The cube specimens were used for finding mass loss in percentage of acid resistance test, salt resistance test, sulphate resistance test, water absorption and rapid chloride penetration test. The training procedure was carried out by presenting the network with the set of experimental data in a patterned format. Each training pattern includes an input set of two parameters representing the dry weight and wet weight in terms of kg and a corresponding output set representing the mass loss in terms of percentage.

Training of Acid Resistance Test for Binary and Ternary combination

The performance of CC, SFBAC, SFSSAC, BASSAC, and SFBASSAC of acid resistance test in terms of mass loss was examined. The comparison between experimental and predicted values of mass loss in percentageis shown in Figure 4. The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 5.

From the acid resistance results, it is seen that the values predicted by the proposed equation are in good agreement with the experimental values. The range of error obtained from the results was -1.68 to 5.17 in terms of percentage.

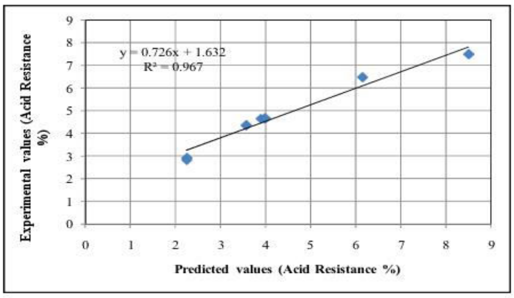

Fig. 4. Comparison of Predicted Vs Experimental Values of Acid Resistance

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4.5.2 Training of Salt Resistance Test for Binary and Ternary combination

The performance of CC, SFBAC, SFSSAC, BASSAC, SFBASSAC concrete of salt resistance test in terms of mass loss was examined. The comparison between experimental and predicted values of mass loss in percentage of salt resistance is shown in figure 5.

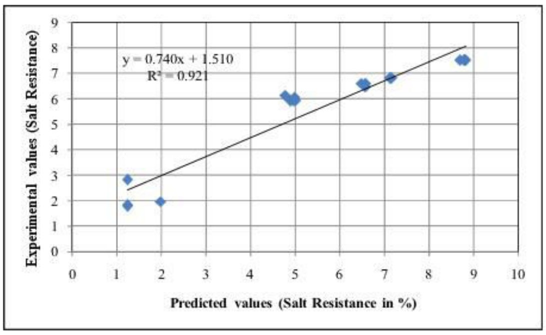

Fig. 5 Comparison of Predicted Vs Experimental Values of Salt Resistance

The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 6.

$$y = 0.740\,x + 1.510$$

From the salt resistance test results, it is seen that the values predicted by the proposed equation are in good agreement with the experimental values. The range of error obtained from the results was 2.26 to 8.94 in terms of percentage.

MODEL III: ANALYSIS AND TRAINING OF FLEXURAL BEHAVIOUR OF BEAMS

The training procedure was carried out by presenting the network with the set of experimental data in a patterned format. Each training pattern includes an input set of three parameters representing the moment of the beam, length of the beam and experimental ultimate load and a corresponding output set representing the ultimate load in kN. The specimen dimension of 250 mm (depth) x125 mm (width) with an effective span of 3000 mm was cast.

Totally Ten beams were cast for finding flexural behaviour in reinforced high-performance concrete. Two beams were reference beams (CC) and other eight beams were four mix ratios of combination of silica fume, bottom ash and steel slag aggregate of by-products were added (SF+BA, SF+SSA, BA+SSA, SF+BA+SSA).

The beams were designated as follows: specimens CB 1 & CB 2 were control beams, HPC 1 & HPC 2 were combination of silica fume and bottom ash (SF+BA), HPC 3 & HPC 4 were combination of silica fume and steel slag aggregate (SF+SSA), HPC 5 & HPC 6 were combination of bottom ash and steel slag aggregate (BA+SSA) and HPC 7 & HPC 8 were combination of silica fume, bottom ash and steel slag aggregate (SF+BA+SSA).

Ultimate load for CC and HPC Beams

The comparison between experimental and predicted values of load carrying capacity for beamsfound through ANN is shown in figure 6.

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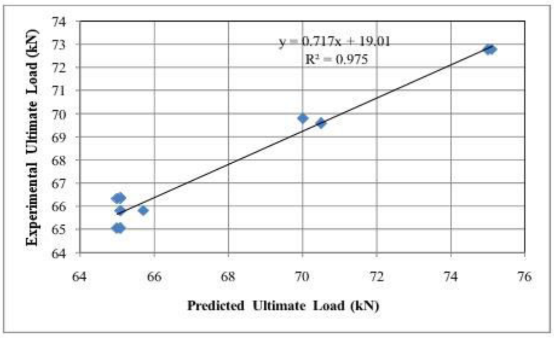

Fig. 6 Comparison of Predicted Ultimate Load Vs Experimental Ultimate Load of Beams

The input parameters are moment and length of beam as 3.0 m. The comparison of these values shows that the neural network modelling is supported better than the experimental results. From the results, it is seen that the values predicted by the proposed equation are in good agreement with the experimental results.

It is shown that although the use of the models is not as simple as that of the basic formula.They provide a more accurate tool for the prediction of the reinforced concrete ultimate load strength. The experimental and predicted values can be represented in terms of the empirical relationship is shown in regression equation 7.

$$y = 0.717x + 19.01$$

The ANN predicted results reveal that they are in good difference between experimental results, and the percentage of error is very minimum and negligible. The range of error obtained from the results was -0.06 to 1.14 in terms of percentage.

Overall Performance of Beam Specimens

The overall performance of CC, SFBAC, SFSSAC, BASSA and SFBASSAC for beams through ANN modelling is shown in figure 7. The graph between output and targets gives the values of R as 0.82956 and linear fit of output. To train the network, the weights of connections are modified according to the information.

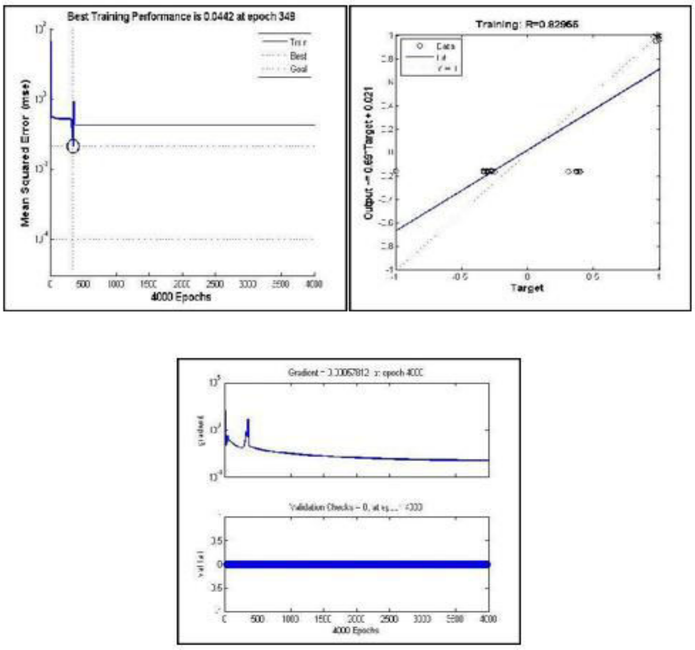

Fig. 7Overall Performances, Training Graph and Validation of Test Values of beams

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IV. CONCLUSION

This research aimed to formulate a methodology for using industrial by-products on the strength properties, durability characteristics and flexural behaviour of load carrying capacity of reinforced HPC beam elements and hence to enhance the strength when compared to the conventional concrete. The silica fume, bottom ash and steel slag aggregate are used to replace the cement, fine aggregate and coarse aggregate to produce high performance concrete. The summary of the works leading to such a formulation together with the conclusions are given in the subsequent section.

The following are the major findings derived from this study.

Concrete with 5 % silica fume replacement of cement had higher compressive strength on an average of 36.42 MPa at 28 curing days which was almost 4.46% higher with respect to CC. Concrete with 10 % bottom ash replacement of fine aggregate attained higher compressive strength on an average of 35.32 MPa at 28 curing days which was almost 1.486 % higher when compared with CC. Similarly, concrete with 10 % steel slag aggregate replacement of coarse aggregate obtained higher compressive strength value on an average of 39.55MPa at 28 curing days which was almost 12.02 % with respect to CC.

For SFC, it was observed that the three was maximum increase in the tensile strength and flexural strength of nearly 23.9 % and 21.43 % respectively. It was also understood that the split tensile strength increases in 5% SF content and beyond that the strength decreases. For BAC, there was a maximum increase in tensile strength and flexural strength of nearly 27.10 % and 20.46 % with respect to CC. For SSAC, it was observed that the maximum increase was in tensile strength and flexural strength of nearly 28.6 % and 17.99% with respect to CC.

For binary and ternary mixes, the optimum replacement percentage level was found from single combination results. The rate of increase in compressive strength at various curing periods of 28, 56, 90 and 180 days increased at the age of 180 days for all mixes of CC, SFBAC, SFSSAC, BASSAC, SFBASSAC on an average of 47.40 MPa, 62.30 MPa, 62.79 MPa, 56.52 MPa and 51 MPa which was almost 57.16 %, 94.74 %, 67.03 %, 54.08 % and 79.07 % withrespect to the age of 28 days. The increase in the strength was due to pozzolanic reaction of industrial by-products in concrete.

For split tensile strength, it was observed that the three were maximum percentage increases in the mix of SFSSAC on an average of 3.898 MPa which was almost 40.72 % increase with respect to CC. The rate of increase in flexural strength was observed that the maximum strength was attained in the mix of SFSSAC on an average of 8.15 MPa which was almost 14.62 % increased with respect to CC. The maximum modulus of elasticity was obtained in the mix of SFSSAC and it was 11.63 % higher with respect to CC.

The compressive strength of CC, SFBA, SFSSA, BASSA and SFBASSA was measured before and after immersion. The HPC mixes are found to have an excellent acid resistance in 1 % sulphuric acid solution. For acid resistance test for all mixes, it was observed that the superior performance towards mass loss in SFSSAC mix was 2.75 % and strength loss was also very less in SFBASSAC mix which was 5.53 % with respect to CC. For salt resistance test for all mixes, it was observed that the superior performance towards mass loss in BASSAC mix was 4.30 % and strength loss was also very less in mix which was 8.60 % with respect to CC.

The concrete BASSAC was found to have an excellent sulphate resistance in 5% sodium sulphate solution and it was the best of other types of concrete because the mass loss was 1.63 % and the strength loss in SFBAC mix was5.58 % with respect to CC. The water absorption was less in SFBAC, SFSSAC, BASSAC and SFBASSAC was 10.56 %, 9.12 %, 8.97 % and 3.58 % with respect to CC. For RCPT, it was observed that the rapid chloride penetration results were compared with CC the percentage level of SFBAC, SFSSAC, BASSAC and SFBASSAC 19.24%, 39.03%, 16.85%, 4.66% respectively.

V. FUTURE SCOPE OF THE STUDY

“The choice of the quantity and stage of use of industrial by-products are very important for enhancing the strength and durability of high-performance concrete. Silica fume has high early compressive strength and strengthens the interfacial transition zone and chemical admixture to reduce the water-binder ratio. Usage of industrial byproducts can help reduce the cost of waste treatment prior to disposal and eventually preserve natural resources and energy. Industrial by-products can improve compressive strength by refinement effect due to pozzolanic reaction which dominates over the

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increase of porosity. Steel slag aggregate plays a part to improve the performance of concrete and give good compressive, tensile strength. Also, the pore structure and interfacial transition zone of concrete can improve while adding steel slag aggregate." "The need for the present study arises from the requirements to improve the overall utilization of combination of industrial by-products in correct proportions in concrete particularly in aggressive environment depending upon the requirements. The effect of those industrial by-products towards the enhancement of the strength and durability of HPC needs to be researched. There are only few studies undertaken to investigate the effect of combination of industrial by-product on the behaviour of HPC beams. The present research aims to carry out the study of high-performance concrete beams."

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