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Research Article

PREDICTION OF THE COMBINED METHOD FOR EVALUATING COMPRESSIVE STRENGTH OF HPC BY USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT

High performance concrete (HPC) is developed gradually over the last 15 years with respect to production of concrete with higher and higher strength. The objective of the present study is to investigate the effect of mineral admixtures and by-products towards the performance of HPC. HPC with mineral admixture of silica fume at the replacement levels of 0%, 5%, 10%, 15% & 20% were studied at the age of 28 days and industrial by-products of bottom ash and steel slag aggregate at the replacement level of 10%, 20%, 30%, 40% & 50% were studied at the age of 28 days. 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. The use of industrial by-products in concrete is gaining popularity due to various advantages. An Artificial Neural Network technique for the prediction of compressive strength of concrete was performed for the concrete data obtained from laboratory experimental work done in this study. The variables used in the prediction models were the mix proportioning elements. The multiple nonlinear regression models yielded excellent correlation coefficients for the prediction of compressive strength at different curing ages as well as the other variations which includes use of silica fume as a partial replacement of cement, bottom ash and steel slag aggregate as a partial replacement of fine aggregate and coarse aggregate for the production of high performance concrete. Non destructive techniques are the one that can be used to predict the strength without damaging the structure. In the present study, the compressive strength of high performance concrete has been predicted using Artificial Neural Network (ANN). The predicted strength was compared with the experimentally obtained actual compressive strength of concrete and equations were developed for different models. Finally statistical analysis of RBH, UPV, and compressive strength relationship represents a good correlation between actual compressive strength and predicted compressive strength.

INTRODUCTION

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. Nowadays, most of the concrete mixture contains mineral admixtures and industrial by-product materials which form part of the concrete component. Engineers are continually pushing the limits to improve its performance of strength property and durability property with the help of innovative chemical admixtures and supplementary cementitious materials, mineral admixtures and industrial by-products [1].

The performance of a structure deteriorated with the passage of time for its whole duration. This deterioration is mainly because of damages due to environmental changes, lagging of material durability, change in nature of service load etc. This will cause structural failures which means loss of structure and economic disruption [2]. Industrial by-products such as silica

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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. With the progress of research on by-products in recent years, the use of materials as such as silica fume as binders has been increasing, along with bottom ash. By using these by-products, we can improve cost and environmental effects depending on the characteristics of the by-products. Now a day a new generation HPC require along with improved compressive strengths, high tensile strength, reduced porosity and very high durability. 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.

Non destructive testing (NDT) methods have a large potential to be part of current trend technology. A variety of advanced NDT methods have been developed and are available for investigating and evaluating the different parameters related to durability, strength etc. The investigation revealed that the combined use of silica fume, bottom ash and steel slag aggregate improved the mechanical properties and NDT properties of HPC and thus there 3 materials may use as a partial replacement material in making HPC. 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. In this present study, an attempt has been made to find the compressive strength of concrete with NDT techniques of rebound hammer, ultrasonic pulse velocity test method with experimental obtained actual strength has been predicted using Artificial Neural Network (ANN) modelling with regression analysis.

Evaluation of concrete structures by NDT

The non destructive testing of concrete has a great technical and useful concrete method for determining quality of concrete. These techniques have been grown during recent years especially in the case of construction field. The combination of several techniques of non-destructive testing is often used to enhance the reliability of the estimate compressive strength of concrete the principle is based on correlations between observed measurements and the desired property [3]. The compressive strength of concrete is usually the most sought after property. This will leads to develop the NDT method of rebound hammer test method and ultra sonic pulse velocity method.

Rebound Hammer Test

The rebound hammer is one of the oldest methods for finding surface hardness in concrete structure. It is usually used in comparing the concrete in various parts of a structure and indirectly assessing concrete strength. The rebound of an elastic mass depends on the hardness of the surface against which its mass strikes. The results of rebound hammer such as smoothness of test surface, size, shape and rigidity of the specimens, age of the specimens, surface and internal moisture conditions of the concrete etc.

Ultrasonic pulse velocity test

The ultrasonic pulse velocity test consists of measuring the pulse velocity through the concrete with a generator and a receiver. Many factors will affect the strength results such as surface of concrete, maturity of concrete, the travel distance of wave, the presence of reinforcement, mixture proportion, aggregate type and size, age of concrete, mixture content etc.

Experimental Methodology

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. 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. The pH value is not less than 8.0. 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. Bottom ash obtained from thermal power plant, Neyveli Lignite Corporation Ltd., Neyveli, Tamil Nadu, India was used in this investigation. The experimental study has been carried out on high performance concrete cubes of dimensions 150mmx150mmx150mm. The specimens were casted with different composition of cement, sand, coarse aggregate with replacement material of silica fume, bottom ash and steel slag aggregate material for replacement of all raw materials. Each cube was tested first by NDT techniques like rebound hammer test and ultra sonic pulse velocity test method and finally specimens were crushed under compression testing machine to have its actual compression strength. The experimental results were obtained in the form of rebound number, pulse velocity in km/sec and finally compressive strength in N/mm^2. The compressive strength results are given in Table 1.

Analytical Study using ANN

Regression analysis had been employed to several civil engineering problems in construction field. An artificial neural network (ANN) is a family of massively parallel architectures that can be used to solve difficult problems. In order to develop a system to predict the compressive strength and non destructive techniques in concrete, the Neural Network is trained with an input data pattern. ANN is based on the principle that a highly interconnected system of simple processing elements can learn the nature of complex interrelationships between independent and dependent variables. The various parameters like rebound hammer and ultrasonic pulse velocity and compressive strength in the input layer represent the factors which may affect the network output and having no computational activities.

In the present study the ANN toolbox of the program MATLAB was used to perform the necessary computations. All data from non-destructive tests are resumed in Table 2. The function of hidden layer neurons is to detect the relationship between network inputs and outputs. The various units or parameters like rebound number, penetration depth and ultrasonic pulse velocity, slump, weight of the cube in the input layer represent the factors which may affect the network output and having no computational activities.

Table 1 Test data for HPC mixes

Sl.No.	Mix Designation	Rebound Hammer Number	UPV value	Compressive strength N/mm^2
1	CC	22	3879	34.35
2	SF+BA	23	3970	40.07
3	SF+SSA	23	4248	42.76
4	BA+SSA	25	3979	42.84
5	SF+BA+SSA	24	3765	43.45

techniques as input for the statistical model and target was given as the actual value of compressive strength obtained from crushing of concrete cubes and rebound number and pulse velocity. The prediction of compressive strength has been made for individual NDT technique using statistical analysis. Similarly, the strength has also been predicted by combining the output of two NDT techniques as well as the target values were kept same as for individual techniques. The various curves and related equations have been developed to predict the strength by individual techniques and by combined techniques. From Table 1, it has been observed that value of rebound hammer, ultra sonic pulse velocity, observed compressive strength and predicted compressive strength has been entered.

Table 2 NDT and Strength Properties of control specimens and high performance concrete specimens

Sl. No.	CC				SF+BA				SF+SSA			
	RBH	UPV	f_{ck}	f_{ck}'	RBH	UPV	f_{ck}	f_{ck}'	RBH	UPV	f_{ck}	f_{ck}'
1	22	3660	34.5	34.10268	24	4190	40	40.15928	22	3190	35.8	34.93044
2	27	3990	33.9	35.26353	24	4270	41	40.44444	20	3440	38	37.42685
3	20	3300	32.2	32.49553	27	4260	41	40.78811	24	3410	36	36.85919
4	27	3930	34.2	34.96279	20	4180	40.8	39.61787	22	3480	36.9	37.66086
5	27	3990	34.8	35.26353	26	4290	41	40.76861	22	4190	43.6	44.34566
6	20	4170	37.1	36.85625	26	4290	41	40.76861	27	3950	38.2	41.72951
7	26	4110	37.2	35.96365	26	4360	41.4	41.01812	22	4170	42.1	44.15736
8	22	4210	38	36.85945	26	4300	41	40.80425	20	4180	44	44.39411
9	24	4140	37.8	36.3113	22	4250	40.8	40.12026	20	4030	43.8	42.98183
10	22	4190	38	36.75921	24	4290	40.9	40.51572	22	4310	46.8	45.47549
11	27	4180	33.9	36.21587	24	4340	41.4	40.69395	26	4160	43.1	43.77801
12	20	4040	36.2	36.20464	24	4170	40.7	40.08799	27	4130	43.3	43.42425
13	26	3890	33.5	34.86094	26	4140	40.2	40.23394	20	4250	44.3	45.05318
14	24	3860	35.1	34.90785	24	4310	41	40.58701	26	4320	44.7	45.28444
15	24	3650	36	33.85527	20	4230	40.8	39.79609	20	4170	43	44.29996
16	26	4100	36.2	35.91353	27	4240	40.9	40.71682	22	4180	44.9	44.25151
17	26	3860	34.4	34.71057	24	4170	40.7	40.08799	26	4080	43.7	43.02479
18	26	3100	31.8	30.9012	22	4040	40.2	39.37173	27	4080	43.8	42.95349
19	27	3790	33.1	34.26106	22	4060	40	39.44302	20	4140	44.2	44.0175
20	20	3660	33.2	34.29996	20	4050	40.3	39.15449	22	4000	42.5	42.55677
21	27	4160	36.7	36.11562	26	4040	40.1	39.87749	27	4090	43.6	43.04764
22	26	4170	37.1	36.26439	22	4100	40.2	39.5856	20	4040	43.1	43.07598
23	27	4110	36.1	35.86501	22	4180	38.7	39.87075	27	4050	43	42.67103
24	20	4660	38.2	39.31228	22	4210	35	39.97769	27	4160	44.1	43.70671
25	27	4270	37.8	36.66698	20	4140	40	39.47529	20	4190	44.6	44.48826
26	22	4180	36.6	36.70908	22	4010	39.8	39.2648	26	4000	42.5	42.27157
27	20	4190	36.8	36.95649	24	4140	39.9	39.98106	22	4040	44.1	42.93338
28	27	4070	36.2	35.66451	22	4070	37.8	39.47866	24	4080	44.8	43.16739
29	22	4100	36.4	36.3081	24	4130	40	39.94541	27	4260	45	44.64823
30	20	3860	34.1	35.30243	22	4260	37.5	40.15591	26	4080	43.8	43.02479
31	24	3650	33.6	33.85527	24	4070	39.8	39.73155	26	4150	44	43.68385
32	26	3900	34.2	34.91106	26	4040	38.5	39.87749	20	4040	43.1	43.07598

The output layer contains one or more processing units that compute the network output. In the present study, the ANN toolbox of the program MATLAB was used. A back propagation training algorithm was used in two layer feed forward network trained algorithm. At early compressive strength is predicted using ANN using different network models for each type of NDT techniques as well as in combination. In this study, relationships between the results of mechanical testing of specimens and those from NDT (RBH and UPV) are established, the values are plot in graphs, Matlab is used to extract the curves of regression plots and R^2 for determining coefficients are obtained for each regression line.

RESULTS AND DISCUSSIONS

The analysis of data obtained from experimental study has been analysed using statistical analysis. The various models has been developed by considering output data of both RBH and UPV

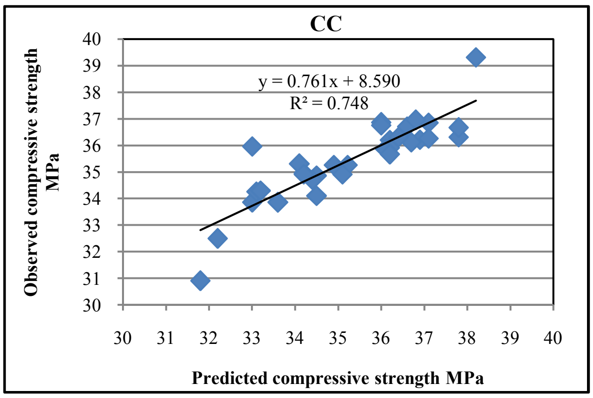

Figure 1 Comparison between predicted strength vs observed predicted strength on RBH & UPV

The comparison has also made between the predicted strength given by developed equations and actual compressive strength and is shown in figure 1-5. It shows the comparison between the compressive strength observed by crushing of cubes and the predicted strength by statistical analysis method for the various techniques used in the present study. It has been observed that the values of coefficient of determination for curve are 0.748 to 0.928 which shows the good correlation between the predicted strength as well as between actual strength of concrete cubes.

From the figure 1 the compressive strength values are mentioned in Table 1 indicating the actual and predicted strength of the trial mixes in respect of 28 days curing days, it is observed that the regression equations derived in this study give fairly better results.

The predicted strength is found to overestimate the actual strength in trial mixes. The predicted strength is found to overestimate the actual strength in 5 mixes by 0.8455 % on an average. However, in 5 mixes trials the predicted strength is seen to underestimate the actual strength by 0.7928 % on an average.

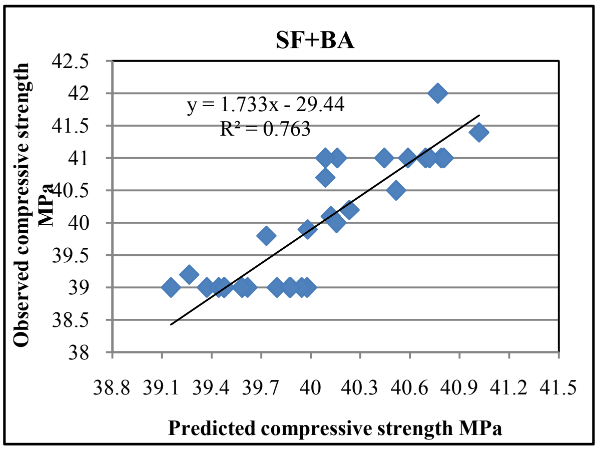

Figure 2 Comparison between predicted strength vs observed predicted strength on RBH & UPV

From figure 2 the predicted strength is found to overestimate the actual strength in trial mixes. The predicted strength is found to overestimate the actual strength in 5 mixes by 0.5048 % on an average. However, in 5 mixes trials the predicted strength is seen to underestimate the actual strength by 1.5163 % on an average.

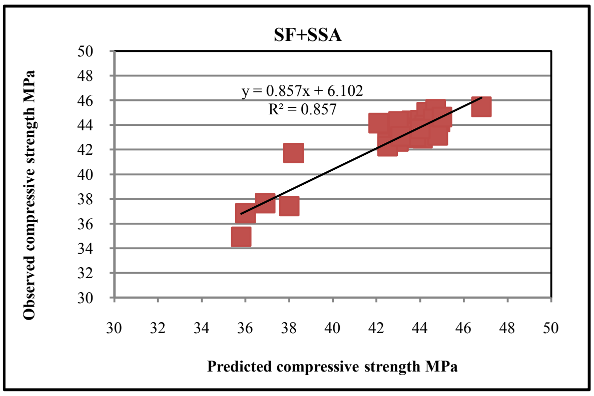

Figure 3 Comparison between predicted strength vs observed predicted strength on RBH & UPV

From figure 3 the predicted strength is found to overestimate the actual strength in trial mixes. The predicted strength is found to overestimate the actual strength in 5 mixes by 0.5921 % on an average.

However, in 5 mixes trials the predicted strength is seen to underestimate the actual strength by 0.9869 % on an average.

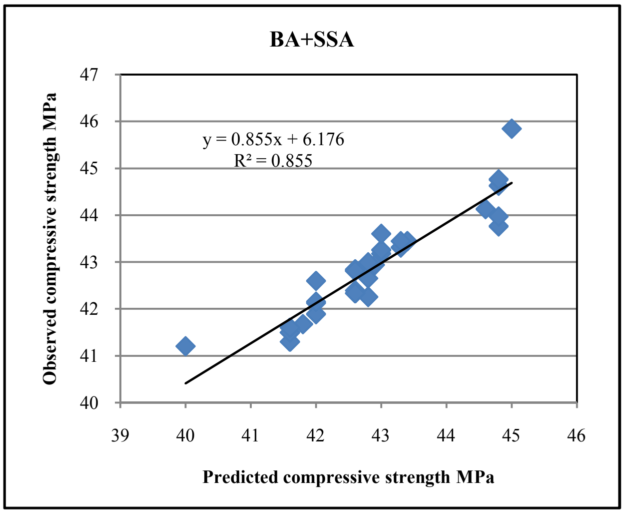

Figure 4 Comparison between predicted strength vs observed predicted strength on RBH & UPV

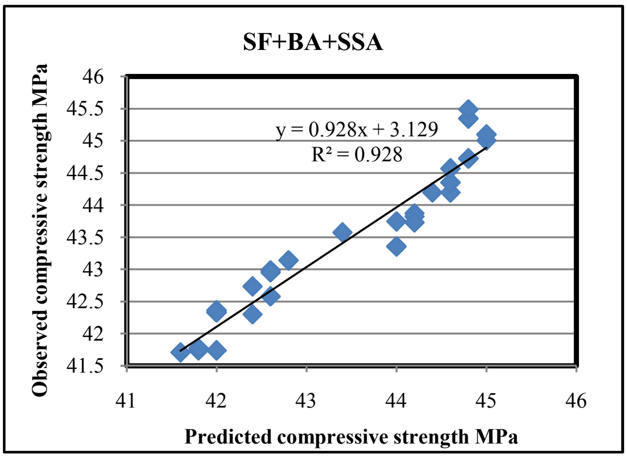

Figure 5 Comparison between predicted strength vs observed predicted strength on RBH & UPV

From figure 4 the predicted strength is found to overestimate the actual strength in trial mixes. The predicted strength is found to overestimate the actual strength in 5 mixes by 0.3143 % on an average. However, in 5 mixes trials the predicted strength is seen to underestimate the actual strength by 0.31430 % on an average.

From figure 5 the predicted strength is found to overestimate the actual strength in trial mixes. The predicted strength is found to overestimate the actual strength in 5 mixes by 0.2480 % on an average. However, in 5 mixes trials the predicted strength is seen to underestimate the actual strength by 0.2824 % on an average.

Table 3 NDT and Strength Properties of high performance concrete specimens

Sl. No.	BA+SSA				SF+BA+SSA			
	RBH	UPV	f_{ck}	f_{ck}’	RBH	UPV	f_{ck}	f_{ck}’
1	28	4210	44.8	43.76117	28	4080	42.4	42.29998
2	26	4170	43	43.17832	24	4050	41.8	41.74003
3	26	4110	42.6	42.38759	26	4190	43.4	43.57344
4	26	4090	42	42.12402	22	4060	41.8	41.77074
5	22	4160	42.9	42.93512	26	4110	42.6	42.57924
6	24	4060	41.8	41.67296	26	4240	44.6	44.19481
7	27	4040	41.6	41.49294	24	4150	42.6	42.98278
8	26	4190	43.4	43.44189	22	4320	45	45.00188
9	26	4100	42.8	42.25581	24	4320	45	45.09544
10	20	4040	41.6	41.29798	24	4290	44.8	44.72262
11	27	4370	45	45.84191	27	4210	44.2	43.86877
12	26	4100	42.8	42.25581	26	4240	44.4	44.19481
13	28	4140	42.6	42.83866	24	4340	44.8	45.34399
14	26	4180	43.3	43.3101	24	4100	42	42.3614
15	26	4190	43.3	43.44189	24	4180	44	43.3556
16	27	4140	42.6	42.81081	26	4040	41.6	41.70932
17	26	4230	44.8	43.96904	26	4040	41.6	41.70932
18	27	4040	41.6	41.49294	26	4210	44.2	43.82199
19	27	4240	44.6	44.12868	24	4290	44.8	44.72262
20	24	4180	43	43.2544	22	4170	42.8	43.13776
21	26	4130	42.8	42.65117	24	4320	45	45.09544
22	24	4110	42.6	42.33189	24	4260	44.6	44.3498
23	27	4070	42	41.8883	27	4340	44.8	45.48434
24	26	4020	40	41.20151	24	4180	44	43.3556
25	24	4130	42	42.59547	24	4050	42	41.74003
26	27	4140	42.6	42.81081	27	4200	44	43.74449
27	27	4090	42	42.15187	26	4270	44.6	44.56763
28	26	4280	44.8	44.62797	26	4090	42	42.33069
29	27	4200	43	43.60153	24	4130	42.4	42.73423
30	26	4290	44.8	44.75976	24	4210	44.2	43.72842
31	26	4050	41.6	41.59687	26	4140	42.6	42.95207
32	24	4160	42.8	42.99083	26	4090	42	42.33069

Table 4 Percentage error of high performance concrete specimens

Sl. No.	CC	SF+BA	SF+SSA	BA+SSA	SF+BA+SSA
1	0.39732	-0.15928	0.86956	1.03883	0.10002
2	-1.36353	0.55556	0.57315	-0.17832	0.05997
3	-0.29553	0.21189	-0.85919	0.21241	-0.17344
4	-0.76279	1.18213	-0.76086	-0.12402	0.02926
5	-0.46353	0.23139	-0.74566	-0.03512	0.02076
6	0.24375	0.23139	-3.52951	0.12704	0.40519
7	1.23635	0.38188	-2.05736	0.10706	-0.38278
8	1.14055	0.19575	-0.39411	-0.04189	-0.00188
9	1.4887	0.67974	0.81817	0.54419	-0.09544
10	1.24079	0.38428	1.32451	0.30202	0.07738
11	-2.31587	0.70605	-0.67801	-0.84191	0.33123
12	-0.00464	0.61201	-0.12425	0.54419	0.20519
13	-1.36094	-0.03394	-0.75318	-0.23866	-0.54399
14	0.19215	0.41299	-0.58444	-0.0101	-0.3614
15	2.14473	1.00391	-1.29996	-0.14189	0.6444
16	0.28647	0.18318	0.64849	-0.21081	-0.10932
17	-0.31057	0.61201	0.67521	0.83096	-0.10932
18	0.8988	0.82827	0.84651	0.10706	0.37801
19	-1.16106	0.55698	0.1825	0.47132	0.07738
20	-1.09996	1.14551	-0.05677	-0.2544	-0.33776
21	0.58438	0.22251	0.55236	0.14883	-0.09544
22	0.83561	0.6144	0.02402	0.26811	0.2502
23	0.23499	-1.17075	0.32897	0.1117	-0.68434
24	-1.11228	-4.97769	0.39329	-1.20151	0.6444
25	1.13302	0.52471	0.11174	-0.59547	0.25997
26	-0.10908	0.5352	0.22843	-0.21081	0.25551
27	-0.15649	-0.08106	1.16662	-0.15187	0.03237
28	0.53549	-1.67866	1.63261	0.17203	-0.33069
29	0.0919	0.05459	0.35177	-0.60153	-0.33423
30	-1.20243	-2.65591	0.77521	0.04024	0.47158
31	-0.25527	0.06845	0.31615	0.00313	-0.35207
32	-0.71106	-1.37749	0.02402	-0.19083	-0.33069

CONCLUSION

The present study shows that statistical analysis can predict the strength very close to actual strength of high performance concrete materials. The accuracy of the prediction also increased in manifolds and depends upon the learning of networks as well as the numbers of NDT techniques used. It has been concluded that

- With high correlation coefficient is found to work well for this matrix mixture for finding compressive strength. Finally the proposed statistical modelling method is capable of predict the effect of the mixture matrix to produce the required concrete compressive strength.
- The correlations were established between the compressive strength values derived from compressive strength, the prediction of concrete strength value appears more reliable.
- The statistical models based on the multiple linear regression analyzes were developed to predict the compressive strength for the various combinations of the materials considered in the present investigations.
- The value of coefficient of correlation for mix of CC is 0.748, mix SF+BA is 0.763, mix SF+SSA is 0.857, mix BA+SSA is 0.855 and mix SF+BA+SSA is 0.928.
- The values of actual strength are found in the increasing order in respect of Silica fume concrete, Bottom ash concrete and steel slag aggregate concrete for 28 days curing period considered in the present investigation.
- The utilization of silica fume for cement, bottom ash for fine aggregate, steel slag aggregate for coarse aggregate reveals higher strength than the conventional concrete.
- However, statistical analysis of RBH, UPV, and compressive strength relationship represents a good correlation between actual compressive strength and predicted compressive strength.

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