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RELATIONSHIP BETWEEN 7 AND 28 DAYS CSS[1] FOR HSC[2] BY USE OF ANN[3] AND REGRESSION METHODS

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ABSTRACT

The use of high strength concrete (HSC) has been studied for many years in developed and developing countries. Although, HSC has a few disadvantages, it has many advantages. The concrete with compressive strength (CS) levels in the range of 50 to100 MPa, is called HSC. The most important property of HSC is 28-day CS as a criterion. Sometimes due to time limitations and construction project problems, estimation of 28- day CS based on 7-day CS can be useful. Based on many experimental tests and analysis of the results, three sets of equations are determined with ANN and Regression techniques are compared and the best is recommended.

Keywords: High strength concrete; compressive strength; mix design; artificial neural netowork; regression

1. INTRODUCTION

HSC has been widely used in recent years. This is because most of the rheological, mechanical and durability properties of these materials are better than those of conventional concretes. HSC is made possible by reducing porosity in homogeneity and micro cracks in concrete and the transition zone. This can be achieved by using SP and supplementary cementing materials such as SF and so on. Fortunately, most of these materials are industrial by-products and help in reducing the amount of cement required to make concrete less costly, more environment friendly, and less energy intensive [1].

A definition of HSC in quantitative terms which is acceptable to every one is not possible. In North American Practice, HSC is usually considered to be a concrete with a 28-day compressive strength of at least 42 MPa. In many developed countries, the concrete producers arbitrarily define the HSC as the concrete having the 28-day cube strength of above 45 MPa when the normal weight aggregates are used. Clearly then, the definition of HSC is relative; it depends upon both the period of time in question, and the location [2].

Although, use of HSC has a few disadvantages, such as relatively low shear strength

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and that with increasing its CS, it will be more brittle, it has many benefits. One such advantage is the reduction in beam and column sizes and increase in building height with many stories. In pre-stressed concrete construction, a great span-depth ratio, for beams may be achieved with the use of HSC. In marine structures, the low permeability characteristics of HSC reduce the risk of corrosion of steel reinforcement and improve the durability of concrete structures. In addition, HSC can perform much better in extreme and adverse climate conditions and can reduce maintenance and repair costs. Based on one view point, HSC can be divided into three groups: HSC, very HSC(VHSC) and ultra HSC (UHSC).

Usually, in this division, the concrete that has CS amount in limits of 50 to 100 MPa is called HSC. For developing

The use of HSC, it is necessary to recognize its mechanical properties. One of the most important properties is CS of concrete that uses the 28-day CS in structural designs as a criterion. Sometimes due to limitations of time of project performance, construction problems and rapid decisions for high performance, estimation of 28-day CS based on 7-day CS can be very useful. In this paper, the subject is studied by ANN and Regression methods.

1.1 ANN Method

1.1.1 Back-Propagation ANN

The primary characteristics of ANNs are their ability to learn, distributed memory and parallel operation eventually leading to fault tolerance. A typical three-layered network has an input layer (*I)*, a hidden layer (*H*) and an output layer (*O*) (Figure 1) is adopted in this study. Each layer consists of several neurons and the layers are interconnected by sets of correlation weights. The neurons receive inputs from the initial inputs or the interconnections and produce outputs by the transformation using an adequate nonlinear transfer function. A common transfer function is the sigmoid function expressed by $f(x) = \frac{1}{1+e^{-x}}$ that is used in this study. This transfer function is commonly used in back propagation networks. The training processing of neural network is essentially executed through a series of patterns. In the learning process, the interconnection weights are adjusted within input and output values.

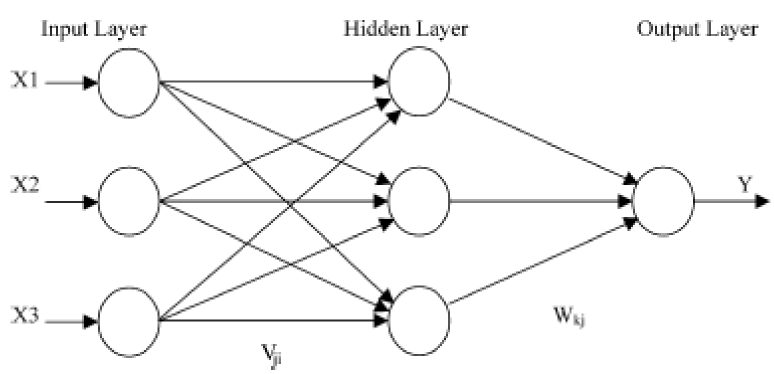


Figure 1. A typical three-layer network

Performance Evaluation Criteria: In order to estimate the accuracy of the proposed methodology, the root mean squared error (RMSE) and correlation coefficient (CC) were used as the agreement indexes:

$$RMSE = \sqrt{\Sigma_{k=1}^{n} \frac{(y_k - \hat{y}_k)^2}{n^2}} \tag{1}$$

$$CC = \frac{\Sigma_{k=1}^{n}(y_k - \bar{y}_k)(\hat{y}_k - \bar{\hat{y}}_k)}{\sqrt{\Sigma_{k=1}^{n}(y_k - \bar{y}_k)^2 \Sigma_{k=1}^{n}(\hat{y}_k - \bar{\hat{y}}_k)^2}} \tag{2}$$

where $\hat{y}_k$ is the observed value, y_k is the predicted value, $\bar{y}_k$ is the mean value of predictions, and $\bar{\hat{y}}_k$ is the mean value of observations.

1.1.2 Model Development

In order to develop a model and test its ability to determine 28- day CS of concrete samples, a back propagation ANN has been constructed using 198 set of data involving 7-day and 28-day CS. The basic structure of three-layered network has an input layer, one hidden layer consisting of 6 neurons, and an output layer as used in this model. There is one input factor, such as 7- day CS in the input layer and 28- day CS forecasting in the output layer. From the 198 available set of data, 170 data set were employed for training, and 28 data set were used for validation or testing the model.

2. ASSUMPTIONS AND LIMITATIONS

1. In all of mix designs, drinkable water was used.
2. Maximum size aggregates (MSA) was used in all mix designs is 10 to 20 mm.
3. In most of the mix designs, the Portland cement type I were used. Of course in some cases, Portland cement type III was utilized.
4. The limitation amount of cement used in the mix designs is 340 to 650 kg/ m^3.
5. Regression equations presented in the paper for estimating 28-day CS based on 7-day CS, in moist curing condition is applicable for three environments:
   A. Curing of specimens in pure water
   B. Curing of specimens in lime-saturated water
   C. Curing of specimens in fog room (with temperature 25±3 °C and RH= 95 to 100 %)
6. In most of mix designs, silica fume were used for increasing CS, also several kinds of super plasticizer were used for proper workability, but it is noted that for some mix designs especially for reference concretes super plasticizer and silica fume [3-6] have not been used.
7. It should be noted that presented regression equations in this paper are not applicable for HSCs that have slags (for example: FA, IA, GGBFS, RHA and so on)
8. In fact, the precision of regression equations for moist curing is higher than the

regression equation's precision for dry curing, the reason being that there is not sufficient data available for dry curing conditions. Therefore it is suggested that it is necessary to develop investigates for dry curing conditions. Developing of dry curing is necessary for countries that have water problems and especially for developing countries where the culture of concrete used is low and moist curing in performance works is a big problem.

9. It is noted that basically equations presented in this paper are based on cubic specimens with dimensions of 100*100*100 mm, but, they are also applicable for cylinder specimens with dimensions of 100*200 mm and 150*300 mm provided that below transformed relations are used in calculations:

$$F_{C,100*200} = 0.9 * F_{CU,100*100}, F_{C,150*300} = 0.9 * F_{C,100*200}$$
$$\Rightarrow F_{C150*300} = 0.81 * F_{CU,100*100}$$

In these relations, F_c and F_{cu} are 28-day CSs for cylinder and cube specimens in MPa, respectively. [7- 10]

10. In all mix designs were used for determination of 28-day CS for two types of curing, the limitation used for w/c (water cement ratio) is 0.22 to 0.50, of course in most mix designs; the amount of w/c was less than 0.40, Refs. [11-13].
11. The presented models for estimation of 28-day CS in moist curing condition, is valid for CSs in the limitations of 45 to 130 MPa. Actually, these models are applicable for high to VHSC.
12. From the 198 available set of data, 170 data set were employed for training, and 28 data set for validation or testing of models.

3. EXPERIMENTAL INVESTIGATION

Many experimental programs were designed to produce HSCs with and without use of SP and SF. Materials used and the experimental procedures are described as follows.

3.1 Materials

Cement

In most of mix designs, locally available OPC (ASTM Type I) in the range of 340 to 650kg/m^3 and sometimes high initial strength Portland cement (ASTM Type III) were used.

Aggregates

Many kinds of aggregates were used. For coarse aggregates, crushed granite, gravel, limestone, andesite, quartzite, basalt, diabase, gabbro, serpentine, steatite (high performance ceramics) with SPG in the limit of 2.13 to 3.06 and MSA in the limit of 10 to 20 mm and for fine aggregates, natural silica sand, mining or river sand, crushed granite sand, limestone, siliceous sand with specific gravity in the limit of 2.62 to 2.70 and fineness modulus (FM) in the limit of 1.95 to 2.80 [4-12] were used. The physical characteristics of some used aggregates can be seen in Table 1.

Water
In all mix designs, drinkable water was used.

Super Plasticizer (SP)
Different types of SP were used in casting of concretes. Some of them are as follows: naphthalene formaldehyde sulphunated with 41% solid content and a specific gravity=1.21, liquid polycarboxylic-ether-based with specific gravity=1.05 and 20% solid dosage, CERAPLAST 300 with SPG=1.24 and 40% solid content, sulphunated melamine formaldehyde according to ASTM C494-Type F, a commercially available modified polycarboxylate ether high-range water reducing admixture (HRWRA) with 44% solid particles, Rheobuild 1100 M with SPG=1.195 [13-19].

Silica Fume (SF)
In most of mix designs, silica fumes were used, having properties of SPG=2.10 to 2.22, SSA= 14000 to 20000 m^2/kg and average particle size equal to 0.1 microns. Percentages that were used are from 3 to 30% based on cementitious materials weight. It is noted that in all mix designs, w/c=0.22 to 0.50 and MSA were used, are in the limits of 10 mm to 20 mm and granular materials were used according to SSD case. Moreover, in some mix designs, super plasticizer and silica fume were not used and these concretes have been cast only with use of conventional materials. In Table 2, the chemical composition and physical properties of some cementitious materials are given.

Air
All mix designs were cast without use of any air entrainments.

Table 1. Physical characteristics of some used aggregates (coarse and fine)

	L	**A**	**Q**	**G**	**B**	**SS**	**LNS**	**RS**
SPG	2.65 ,2.69	2.48	2.85	2.68, 2.57	3.06	2.65	2.62	2.63
FM	---	---	---	---	---	1.91	1.95	2.42
PA	0.6 ,0.82	0.8	0.4	0.50 ,0.65	---	0.96	1.1	0.8

L=Lime stone, **A**=Andezite, **Q**=Quartzite, **G**=Granite,
B=Basalt, **SS**=Siliceous sand, **LNS**=Local natural sand, **RS**=River sand,
SPG=Specific gravity, **FM**=Fineness modulus, **PA**=% of absorption

3.2 Mix Proportions
More than 50 different mixes of HSCs were developed by trial

($50MPa \leq CS28D \leq 100MPa$) and VHSCs ($100MPa \leq CS28D \leq 150MPa$). In these mix designs, many kinds of aggregates were used. In all mix designs, aggregates were used in the SSD case. In mix designs, many types and several different dosages of silica fume and different levels of super plasticizer were used. However, there are some reference concretes that have not used SP and SF in them, Refs. [15- 20].

Table 2. Chemical composition and physical properties of some used cementitious materials

Chemical analysis	**% of cementitious materials**			
	OPC1	**OPC2**	**SF1**	**SF2**
SiO_2	20.32	22.1	93.5	90.22
Al_2O_3	4.94	4.86	0.06	1.7
Fe_2O_3	2.55	4.92	0.45	0.4
CaO	62.58	66.87	0.5	2.1
MgO	2.23	0.42	0.67	1.7
Cl	---	---		---
SO_3	3.46	4.03	0.10	0.5
K_2O	0.86	0.15	0.85	0.7
Na_2O	0.19	0.15	0.32	0.7
LoI	2.15	1.64	2.26	2.5
SSA, m^2/kg	351	350	---	2000 0
SPG, kg/m^3	3.17	3.15	---	2.21
Fineness	94.1	---	---	---
Setting time, h: min				
Initial:	---	2:10	---	---
Final:	---	3:40	---	---
1 day	---	15.8	---	---
3 days	25.2	34.2	---	---
7 days	30.3	44.3	---	---
28 days	38.2	55.2	---	---

3.3 Casting, Curing and Testing

Usually trial batches were used with pan mixtures. Coarse and fine aggregates were mixed first. Materials were used dry for a period of 2 to 3 minutes. Then after cement mixing, three quarter or sometimes all the water was added while the materials were being mixed, followed by SP and the remaining water and finally, SF. Cube specimens 100*100*100 mm or cylinder 100*200 mm (D*H) or 150*300 mm (D*H) steel moulds and compacted in three uniform or two layers by use of vibration table, respectively. After casting, specimens were covered with wet burlap to prevent moisture loss and were stored in the lab at temperature of about 28ºC and RH=70 to 90 %. After 24 hours, specimens were demoulded and cured in the cure environment with RH at least 95% under room temperature until 1 to 2 hours before testing. CS tests were performed on cube or cylinder specimens at ages 7 and 28 days, using appropriate machines, for example: 2000 kN with a digital load display with space rate 2.4 MPa/s. Testing were conducted about 1 hour after specimens were removed from the cure environment. At least three specimens were tested at each age to compute the average strength [18-20].

4. DATA ANALYSIS

Amounts of 28-day CS for high to VHSC for dry and moist curing were considered. In this consideration error amounts due to models (Power and Linear) were calculated, also. It can be seen that variations of this ratio is in limitations of 0.68 to 0.92 for moist cure and 0.84 to 0.94 for dry cure condition. It is noted that in ACI 363-R-92, for HSC, the amount of this ratio is given between 0.8 to 0.9 for moist cure condition that is not accordance completely with results of this study. It is noted that that for dry curing, ANN method is not applicable because data set available is limited.

5. DISCUSSION AND RESULTS

With performance of more than 50 mix designs and CS tests on about 650 specimens for ages 7 and 28 days, CS results are drawn in Figures 2 to 6. By use of regression relations on CS for moist and dry curing, two sets of equations were developed. It is noted that, since sufficient data for dry curing are not available, the precision of given equations for dry curing condition is less than equations of moist curing condition, and then conducting further investigations for dry curing is necessary. Among six regression relations studied here for estimating 28- day CS, power and linear relations are proposed. These two relations have higher precision compared to other relations and moreover use of them is very easy and also coefficient of determination (R^2) is bigger than other relations. For better identification of estimation proposed models, see Table 3. With comparison results of ANN and regression methods, it can be seen that power regression, ANN and linear regression have higher accuracy, respectively.

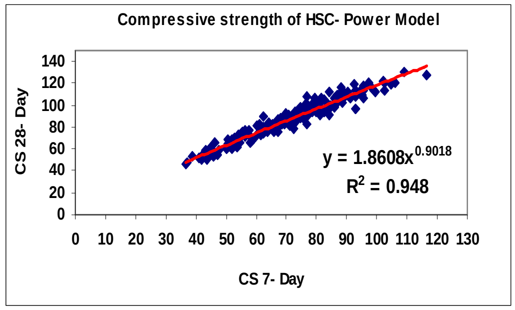
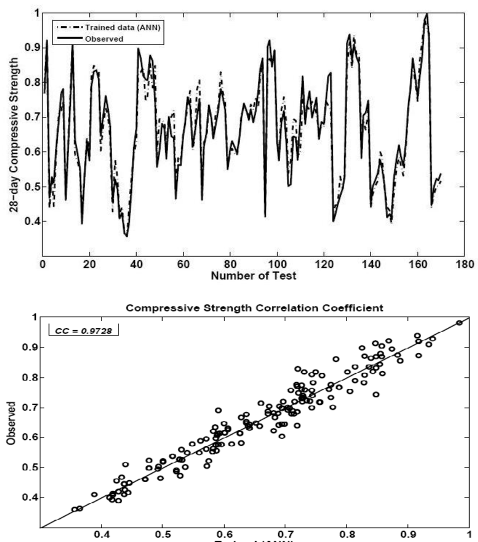
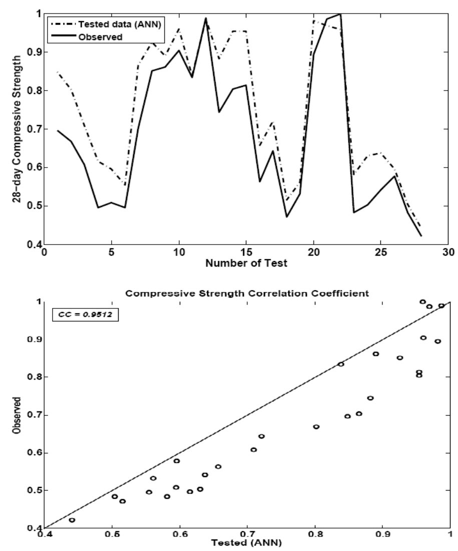


Figure 2. 28-day C S vs. 7- day C S for moist cured-power regression



A: trained data for ANN



B: tested data for ANN

Figure 3.

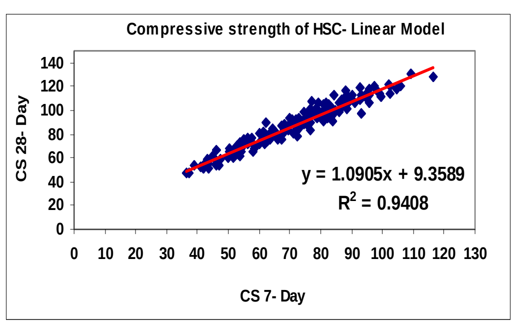


Figure 4. 28- day C S vs. 7- day C S for moist cured linear regression

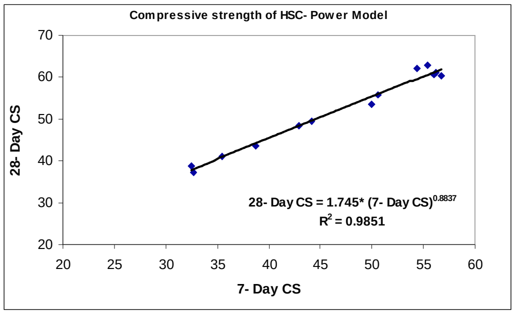


Figure 5. 28- day C S vs. 7-day C S for dry cured-power regression

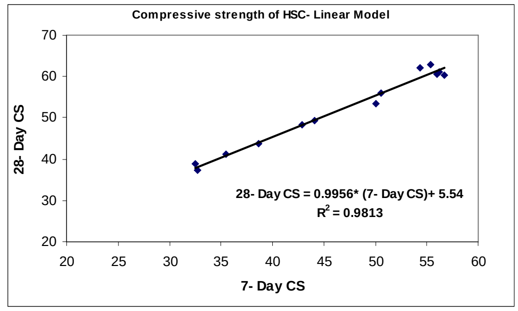


Figure 6. 28-day C S vs. 7- day C S for dry cured-linear regression

Table 3- Comparison of observed results of 28-day CS submitted in three papers (18-20) with estimated results by power and linear models

Data No.	CS7, Lab	CS28, Lab	CS28, power model	Error% of power model	CS28, linear model	Error% of linear model
1	53.5	63.4	67.63	6.7	67.75	6.9
2	58.3	67.8	73.02	7.7	73.01	7.7
3	60.5	70.3	75.48	7.4	75.42	7.3
4	57.5	69.2	72.12	4.2	72.14	4.2
5	68.3	79.8	84.11	5.4	83.97	5.2
6	76.7	90.5	93.29	3.1	93.17	2.9
7	72.1	85.7	88.28	3.0	88.13	3.0
8 [18]	68.8	81.9	84.66	3.4	84.52	3.2
9	78.3	100.9	95.03	-6.2	94.92	-6.3
10	86.9	108.9	104.29	-4.4	104.34	-4.4
11[19]	95.5	113.3	113.46	0.1	113.77	0.4
12	67.3	75.78	83.01	-9.5	82.87	-9.3
13	72.1	91.78	88.28	4.0	88.13	4.1
14	69.7	93.00	85.65	8.6	85.50	8.8
15	77.1	97.55	93.72	4.1	93.61	4.2
16 [20]	81.7	106.67	98.70	8.1	98.65	8.1

To the author's knowledge, actually it can be noted that, a model for estimation of 28-day CS for high to VHSC based on 7-day CS has not been proposed, yet. ACI 209`s. Formula is: $f_{cmt} = ((t/(a+b*t))*f_{cm28}$, Where f_{cm28} is the concrete mean C S at 28 days in MPa, *a* and *b* are constants, and t is age of concrete. The ratio of a/b is the age of concrete in days at which one half of the ultimate (in time) CS of concrete is reached. The constants *a* and *b* are functions of both the type of cement and the type of curing employed. The ranges of *a* and *b* for normal weight concrete, (using both moist and steam curing and cement types I and III) are: a= 0.05 to 9.25 and b= 0.67 to 0.97. Typical recommended values are given in Table 4.

Table 4. Values of constants a and b for use in equation of ACI 209R-92 model

Type of cement	**Moist-cured concrete**		**Steam-cured concrete**	
	a	***b***	***a***	***b***
I	4.0	0.85	1.0	0.95
III	2.3	0.92	0.70	0.98

It is noted that the accuracy of this formula is very low for HSC and usually is used for NSC. Moreover in ACI 363-R-92, reported by Parrott that typical ratio of 7- day to 28- day strengths is 0.8 to 0.9 for HSC [20]. It is noted that this ratio is not in accordance with some data in this paper.

6. CONCLUSIONS

Based on results of current and previous studies and according to tests done on more than 650 cylinders and cubes specimens and use of more than 50 mix designs, the following conclusions can be drawn for 28- day CS of high to VHSCs:

1. For dry cure condition, there is insufficient data in investigations and therefore it can be said that the precision of submitted formulas for dry cure condition is less than moist cure condition and so it is necessary that more investigations be carried out for dry cure condition.
2. In this paper, for estimation of 28-day CS based on 7-day CS for high to VHSC (45 to 130MPa), the best curves recognized were power regression, ANN and linear regression methods, respectively. Use of these curves is very simple and also they have the biggest R^2.
3. Submitted formulas for estimation of 28-day CS of high to VHSCs, are applicable for moist cure condition in cases of pure water, lime-saturated water and fog-room with at least RH=95% and temperature of 25±3°*C* and also are applicable for dry cure conditions with temperature 31±3°*C*.
4. Submitted formulas in this paper are valid only for HSCs without use of any slag.

5. Based on results of this study, the ratio of 7- day CS to 28- day CS for high to VHSC for moist and dry cure conditions are in the limitations of 0.68 to 0.92 and 0.84 to 0.94, respectively that it can be seen these amounts are not in accordance completely with ACI 363R-92.

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