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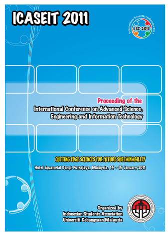

Compressive Strength of Fiber Reinforced Fly- Ash Concrete using Regression Model

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***Abstract*— In construction industry, strength is a primary criterion in selecting a concrete for a particular application. Concrete used for construction gains strength over a long period of time after pouring the concrete. The characteristic strength of concrete is defined as the compressive strength of a sample that has been aged for 28 days. Neither waiting 28 days for such a test would not serve the rapidity of construction, nor would neglecting it serve the quality control process on concrete in large construction sites. Therefore, rapid and reliable prediction of the strength of concrete would be of great significance. On this backdrop, the method is proposed to establish a predictive relationship between properties and proportions of ingredients of concrete, compaction factor, weight of concrete cubes and strength of concrete whereby the strength of concrete can be predicted at early age. A mathematical model for the prediction of compressive strength of fiber reinforced concrete containing fly ash was performed using statistical analysis for the concrete data obtained from the experimental work done in this study. The multiple linear regression model yielded fairly good correlation coefficient for the prediction of compressive strength for 3 days curing.**

***Keywords*— Concrete, Compressive Strength, Admixture, Regression Analysis, Predicted Strength, Predictive Tools**

I. INTRODUCTION

The concrete is a versatile construction material owing to the benefits it provides in terms of strength, durability, availability, adoptability and economy. It is a heterogeneous mix of cement, water and aggregates. Great efforts have been made to improve the quality of concrete by various means in order to raise and maximize its level of performance. Using same ingredients with little adjustments in the micro- structure (and probably adding specific materials), it is possible to obtain some of the special types of concrete such as high performance concrete (HPC), self compacting concrete (SCC) and roller compacted concrete, high volume fly ash concrete (HVFAC), etc. The development of these concretes has brought forth the need for admixtures, both- mineral and chemical, to improve the performance of concrete.

The admixtures may be added in concrete in order to enhance some of its properties desired specially. Very fine materials such as fly ash, a product of coal-burning power plant, render the fresh concrete more plastic. Other admixtures including various fats, sugars and minerals are used to increase or decrease the rate of hardening of concrete or to give it colour and increase durability and resistance to weathering. Contrary to the ordinary concrete, the concrete containing different admixtures has extra- ordinary rheological properties, especially its super workability and flow ability that make it superior as compared to other concrete mixes. There have been many studies (e.g. [1] -[13]) which reported the effect of different types of admixtures and in few cases, that of the inclusion of fibers on rheological behaviour as well as strength properties of the various types of the concrete.

In construction industry, strength is a primary criterion in selecting a concrete for a particular application. Concrete used for construction gains strength over a long period of time after pouring. The characteristic strength of concrete is defined as the compressive strength of a sample that has been aged for 28 days.

Neither waiting 28 days from such a test would not serve the rapidity of construction nor would neglecting it serve the quality control process on concrete in large construction sites. Therefore, rapid and reliable prediction of the strength of concrete would be of great significance. For example, it provides a chance to do the necessary adjustment on the mix proportion used to avoid the situation where concrete does not reach the required design strength or by avoiding concrete that is unnecessarily strong and also for more economic use of raw materials and fewer construction failures, hence reducing construction cost.

Prediction of the compressive strength of concrete, therefore, has been an active area of research and a considerable number of studies have been carried out. Many attempts have been made to obtain a suitable mathematical model which is capable of predicting strength of concrete at various ages with acceptable (high) accuracy.

II. Prediction Methods For Strength of Concrete

A number of improved prediction techniques have been proposed by including empirical or computational modelling, statistical techniques and artificial intelligence approach.

Many attempts have been made for modelling the aspect of the strength of concrete through the use of the computational techniques such as finite element analysis. These techniques are often based on the complex thermodynamic equations that underpin the aging of concrete and require non-proprietary mathematical tools.

A number of research efforts have concentrated on using multivariable regression models to improve the accuracy of the predictions. Statistical models have the attraction that once fitted, they can be used to perform predictions much more quickly than other modelling techniques and are correspondingly simpler to implement in software. Apart from its peed, statistical modelling has the advantage over other techniques that are mathematically rigorous and can be used to define confidence interval for the predictions. This is especially true when statistical modelling is compared the artificial intelligence based techniques. Statistical analysis can also provide insight into the key factors influencing the compressive strength through correlation analysis.

Some of the studies (e.g. [15],[17], [19], [22],[24] and [27]) used regression approach. As strengthening of the concrete is a complex non-linear process dependent on many variables, it is a problem well suited to the artificial intelligence concept known as Artificial Neural Network (ANN). Most of the research confined to the prediction of compressive strength recognizes that neural nets are appropriate for the problem.

In last few decades, Artificial Neural Networks (ANN) technology, a sub- field of the artificial intelligence have been used in evaluating and predicting different rheological and strength parameters of various types of concretes ([14], [16], [20]- [21], [23] and [25]).The most important property of ANN in the problems of concrete technology is its capability of leraning directly from the examples.

Few studies ([18] and [26]) used either approach for modelling the strength and flow behaviour of concrete. One of the studies [28] explored the potential use of the neuro-fuzzy (NF) approach, one of the soft computing tools, for modeling fresh and hardened properties of self consolidating concrete (SCC) containing pulverized fuel ash (PFA).

III. Objective of The Present Study

Based on the above review of literature, the present work is aimed at establishing a predictive relationship which can be complementary to the existing workability tests routinely carried out during concreting. It purports to recognise mathematically the heterogeneous nature of concrete using the properties of ingredients and the wet concrete. Predictive approach based on regression analysis is attempted.

The data required for this has been generated in the laboratory. In the trial mixes, Ordinary Portland Cement was used and plasticizer was added for the effect of workability. Polypropylene fibers were added. Fly ash was also used in the concrete mix. The formulae using three variables such as water cement ratio, cement contents and compaction factor; and six variables which included cement contents, fine aggregates, coarse aggregates, water cement ratio, compaction factor and weight of the cubes were proposed to be developed to predict the 3 days' strength.

IV. Experimental Programme

A. Materials

The materials used in the present investigation include cement, sand, aggregates, water and admixtures. The ACC Portland Pozzolana Cement (fly ash based) confirming to the requirements as stipulated in IS: 8112-1976 was used. The creek sand – Kolshet, Ghodbandar was brought into use. As regards the coarse aggregates Metal I, Metal II was used from Nerul quarry. The potable water was added for obtaining concrete mix. The physical properties of the constituents of concrete obtained through various laboratory tests are summarized in Table I.

TABLE I
PROPERTIES OF MATERIALS

Property	Value
Cement	
Consistancy	30%
Sp. Gravity	2.91
Fineness	3.0%.
Soundness	3 mm
Compressive Strength	(N/mm^2)
• 7 Days' Curing	31.69
• 28 Days' Curing	51.81
Sand	
Sp. Gravity	2.6.
Fineness Modulus (F.M.)	3.12.
Coarse Aggregates	
Sp. Gravity	2.86.
Fineness Modulus (F.M.)	
• Metal I	3.82
• Metal II	3.38

The admixture in the form of Plasticizer (trade name- Supercon® - 100) was also used in the present investigation. Supercon® - 100 is a pure melamine based superplasticizer which when added to concrete / mortar / plaster modifies the properties of concrete such as workability, strength, permeability, cohesion etc.

The plasticizer, Supercon® - 100, renders the mix very cohesive. It is capable of reducing the permeability by upto 94%. It enhances resistance against thermal stresses. It increases workability and reduces w/c ratio.

Though its application is normally found in case of generalized reinforced cement concrete construction, it is highly recommended water tanks, basements, foundations, floorings, bridge decks, etc. The technical specification of Supercon® - 100 are given in Table II.

The Supercon® - 100 is added to concrete / mortar / plaster between 0.5% to 2% by weight of cement, mix after stirring in little water and then the solution is added after adding other ingredients in the mixer. Supercon® - 100, when added in fresh concrete / mortar / plaster disperse cement uniformly in the mix. Due to deflocculation action on cement agglomerates the entrapped water is released and would be available for workability.

TABLE II
TECHNICAL SPECIFICATIONS FOR PLASTICIZER

Base	Sulphonated Melamine Formaldehyde resin
Dosage	0.5% upto 2% as per Workability requirements
Colour	Clear to Little Hazy
Water Reduction:	Between 15% to 20% (Conforms to IS 9103 – 1999 ASTM – C – 494 Type F)
pH	> 8.0
Stability	12 months in closes container
Packing	5 Kgs, 30 Kgs, 230 Kgs

The polypropylene fibers (trade name- Recron 3 S) were also used in the present investigation. Synthetic fibres have two effects on fresh concrete; they help reduce subsidence and cracking. They reduce bleeding so solids in the concrete don't settle as much, and they increase the tensile strength. The technical specifications of the fibers used in the study, i.e., Recron 3 S are given in Table III.

TABLE III
TECHNICAL SPECIFICATIONS OF RECRON 3S

Cut length	6 mm or 12 mm
Shape of fibre	special for improved holding of cement aggregates
Tensile strength	4000-6000 kg/cm2
Melting point	> 250ºC
Dosage rate	Concrete Use CT 2024 (12 mm) at 909 g/m3, Plaster Use CT 2012 (6 mm) at 125 g/cement bag 1:4 cement/sand ratio

Recron 3s fibres can be used in concrete elements such as RC and PC lintel, beam, column, flooring and wall plastering; foundations, tanks, manhole cover and tiles; plastering; roads and pavements; hollow blocks and precasts. Recron 3s is meant for improving the quality of construction, savings on wastage and for speeding up the work pace. Recron 3s is meant for secondary reinforcement only.

The fibres are sprinkled in the mixer with little water. The mixer is kept rotating and chips, sand, cement and water is added. It is allowed to mix for few minutes. In respect of hand mixing, half the fibers are mixed in a buket of water, stirred well and mixed in mortor. In the similar manner, remaining fibers are added.

Fly ash was also used in the present investigation. Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation. Fly ash material is solidified while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5micron to 100micron. They consist mostly of silicon (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). Fly ash is an inexpensive replacement for Portland Cement used in concrete, while it actually improves strength, segregation and ease of pumping of the concrete.

The chemical composition of the fly ash, as supplied by the supplier, is given in Table IV.

TABLE IV
CHEMICAL COMPOSITION OF FLY ASH

Constituent	%
Silica (SiO_2)	49-67
Alumia (Al_2O_3)	16-29
Iron Oxide (Fe_2O_3)	4-10
Calcium Oxide (CaO)	1-4
Magnesium Oxide (MgO)	0.2-2
Sulphur (SO_3)	0.1-2
Loss of Ignition	0.5-0.3

B. Testing of specimens

The experimental programme involved tests on 112 concrete cubical specimens of size 150×150×150mm.This is further divided into two groups. For first group 8 trials were carried out and in each trial 7 cubes were caste. Therefore, 56 concrete cubes were cast without adding plasticizer and in second group same procedure is followed by adding plasticizer and fibres; and replacing cement by fly ash. Cement, sand, coarse aggregate were thoroughly mixed in dry state so as to obtain uniform colour. The required percentages of admixture are added to the water calculated for the particular mix. This water is added to the dry mix with a view to obtain uniform mixture. The compaction factor test was carried out and the respective values were recorded for all mixes. The moulds with standard dimensions i.e. 150×150×150mm were poured with concrete in 3 layers by poking with tamping rod and vibrated by the table vibrator. The vibrator was used for 30 second and it was maintained constant for all specimens.

The samples were air dried for a period of 24 hours and then they were weighed to find out their weight before curing. Thereafter they were immersed in water. After curing for 3 days, they were weighed to find out their weight in saturated surface dry condition (SSD). The cubes were tested for compressive strength on the compression testing machine and results were recorded.

V. RESEARCH METHOD

Multiple Regression Analysis technique has been adopted to develop equations and predict the strength of concrete cube samples. The data generated in the laboratory is apportioned into two parts. One part is used for the analysis and remaining one is used for validation.

The data of 16 trials of mixes was used for the analysis. From the data of 8 trials without adding plasticizers 2 equations were developed and the data of other 8 trials done by adding plasticizers, fibres and fly ash was used for the validation of results and vice-versa. 'Multiple Regression and Correlation Analysis' was applied to derive the equations.

In Multiple Regression Analysis, various formulae *(1-4)* were developed, by varying the input parameters to predict the 3 days' strength of concrete cube. Selection of following equations with different inputs, which would help the user to predict the strength of concrete cube with available data / input parameters, is based on the results of analysis and the validation of formula.

Equations without plasticizer

3 Days' Strength Using Six Variables

$$=-514.536-31.908xfa-0.011xca-49.87xcem-354.86xwc+24.06xcomp-26.23xwt3 \quad .....(1)$$

3 Days' Strength Using Three Variables

$$= 251.20-12.68xcomp-191.07xwc-12.07xcem \quad ..... (2)$$

Equations with plasticizer, fibers and fly ash

3Days' Strength Using Six Variables

$$=-732.79+17.88xfa-0.94xca+42.45xcem+289.66xwc+20.45xcomp-21.10xwt3 \quad ......(3)$$

3 Days' Strength Using Three Variables

$$=260.41-20.30xcomp-184.34xwc-12.462xcem \quad ...... (4)$$

VI. Results and Discussion

The formulae derived by regression analysis were applied on 16 trial mixes, to predict the strength of concrete cubes after 3 days' curing. The compressive strength of the concrete observed experimentally and obtained using the regression models are shown in Table V and Table VI.

From Table V wherein the actual and predicted strength of the concrete without plasticizers and fibers are reported, it is observed that the either formulae give fairly satisfactory results. Though coefficient of correlation ranges between 0.9-1 which indicates good correlation, the coefficient in respect of the formula with three variables is 0.94 whereas it is 0.91 in respect of the formula with six variables. Formula with three variables is found to predict the 3 days' strength better as compared to the formula containing six variables.

TABLE V
SUMMARY OF ACTUAL STRENGTH AND PREDICTED STRENGTH WITHOUT PLASTICIZERS, FIBERS AND FIBERS

Trial	Actual Strength	Predicted Strength with various numbers of variables		Difference between the actual and predicted strength with various numbers of variables	
		Six (Eq.1)	Three (Eq.2)	Six	Three
1	28.86	27.90	28.64	0.96	0.22
2	22.44	24.45	26.30	-2.01	-3.86
3	20.98	19.31	23.36	1.67	-2.38
4	17.32	22.75	20.04	-5.43	-2.72
5	13.76	14.50	17.13	-0.74	-3.37
6	15.09	12.05	17.31	3.04	-2.22
7	12.43	15.43	13.93	-3.00	-1.50
8	10.21	6.43	14.37	3.78	-4.16

Further, when the compressive strength observed experimentally and predicted using the mathematical model developed based upon the properties of the ingredients as reported in Table VI are compared, it is seen that the formula with three variables does quite better prediction of 3 days' strength. The coefficient of correlation in respect of three variables is 0.91. However, the difference between the predicted strength in respect of the six variables and the actual strength is also slightly more. The coefficient of correlation in this case is observed to be 0.45.

TABLE VI
SUMMARY OF ACTUAL STRENGTH AND PREDICTED STRENGTH WITH PLASTICIZERS, FLY ASH AND FIBERS

Trial	Actual Strength	Predicted Strength with various numbers of variables		Difference between the actual and predicted strength with various numbers of variables	
		Six (Eq.1)	Three (Eq.2)	Six	Three
1	31.11	20.00	27.29	11.11	3.82
2	23.55	22.92	24.21	0.63	-0.66
3	22.20	18.21	19.30	3.99	2.90
4	17.33	24.85	16.82	-7.52	0.51
5	14.66	12.26	13.85	2.40	0.81
6	14.55	12.44	13.01	2.11	1.54
7	14.22	12.82	9.85	1.40	4.37
8	12.44	3.25	9.92	9.19	2.52

VI. Summary and Conclusion

The earlier and accurate estimation of the strength of the concrete are valuable to the construction industry. The presence of such a model as developed in the present study would possibly obtain the balance and equality between controlling the quality (quality control process) and economics (saving time and expenses). This model could be used in construction to make the necessary adjustments on mix proportion used, to avoid situations where concrete does not reach the required design strength or by avoiding concrete that is unnecessarily strong.

The Multiple regression analysis is effectively used as a predictive tool in the present study. Regression analysis as is well-known, gives explicit formula which can be directly used to predict the strength of concrete.

The prediction of the strength of concrete cube with the regression analysis is easy and handy tool. The formulae developed in the present study is capable of predicting only 3 days' strength of the fiber reinforced and plasticized concrete containing part of the fly ash and ordinary Portland cement. It may be noted that the formulae developed in this study are applicable in respect of the concrete mix containing melamine based chemical admixture

Furthermore, the existing variables in the model yielded reasonable results. Also, it is not preferred to load the prediction model with large numbers of variables because it is preferred to use a model with lesser numbers of variables with most higher possible accuracy to assure the rapid and easy use of the model.

NOMENCLATURES

cem	Cement contents
fa	Fine aggregates
ca	Course aggregates
wc	Water Cement Ratio
comp	Compaction factor
wt 3	Weight of the cubes after 3 days curing

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