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Development of Strength Prediction Models of 28 days Fly Ash Concrete Strength by Accelerated Curing Method

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Abstract— As per IS : 456-2000 concrete should be accepted or rejected on the basis of 28 days normal cured strengths. If concrete fails to satisfy the criteria then consequent inspections such as core tests and/or load tests to be performed which are quite complicated, time consuming and results additional outlay. Assessement of 28 days strength from accelerated strength (1 day) can be extremely helpful. Through this concept designers can easily identify the uncalculated errors during mix design or variations in materials and exposure conditions etc and take necessary correction and modification measures to attain the desired strengths at 28 days. As per IS : 9013 methodology to prediction of 28 days strength from accelerated cured strength are indicated only for normal/control concrete. But recently fly ash concrete is frequently used in construction and there is no such guideline available by which assessment of 28 days strength of Indian fly ash concrete can be made from accelerated strength tests. In the present study is an attempt in this direction whereby some simple prediction models have been proposed to relate 28 days strengths with accelerated strengths. Total 55 concrete mixes consisting of 11 control mixes and 44 fly ash mixes have been taken into consideration to develop the strength models. Effect of other strength affecting parameters are also considered for the development of strength models

Index Terms— Accelerated curing, Compressive strength, Concrete, Control , Fly Ash, Normal curing, statistical modeling, Water-Cement ratio, Binder.

1 Introduction

According to Indian Standard acceptence and rejection of any type of concrete should be done by determining 28 days compressive strength[1]. It was observed that normal concrete achieve its potential strength within this time period. But for fly ash concrete 28 days strength does not yield its potential strength as its rate of strength development is significantly slower compare to normal concrete. Potential strength of fly ash concrete may develop at 90 days or even after 180 days. It is also known that strength of normally cured concrete at 28 days is considered for structural design. This time lag may lead to loss of valuable time and money. Accelerated curing of normal concrete by warm water method and boiling water method provided by IS:9013 are helpful to predict 28 days strength of control concrete with respect to accelerated cured strength by means of correlation between accelerated strength and normal curing strength[2]. For the prediction of 28 days strength of fly ash concretes no such correlation is available. The current paper some strength prediction models have been proposed.

These models can be considered as a primary guideline for strength estimation of fly ash concrete as this type of models are quite limited and lack of correlations available for later age strength prediction of fly ash concrete from accelerated strength for Indian fly ashes. Some of the important reporting in the field of accelerated cured strengths of fly ash concrete are reviewed which are as follows:

Bhanja and Pan proposed a relationship for fly ash concretes in which modified water-cement ratio law for fly ash concretes was generated through statistical analysis. 55 number of mixes was carried out to determine the influence of fly ash on 28 and 90 days over a wide range of water-cement ratio and fly ash percentage. Statistical models were proposed through the study and modified the Abrams water-cement ratio relationship was developed in which a second independent variable was introduced . Total six parameters were considered out of which fly-ash binder ratio, fly ash and cement contents were found to be significant strength affecting parameters along with the basic Abrams equation results in improving the strength prediction of concrete [3].

Chowdhury proposed a relationship to predict 28 days strength of fly ash concrete in terms of accelerated strength of fly ash concrete where regression analysis was performed on the test results of 55 mixes and an linear expression was proposed[4].

Jaydevan et al. investigated the reliability of accelerated curing techniques for speedy design of concrete mixes. A linear equation was proposed that correlates the accelerated strength and the 28 days strength [5].

Shelke and Gadve proposed that both normally and accelerated cured strengths of ordinary portland cement concrete achieved the target strength and it was also observed that predicted 7 and 28 days strength obtained by using accelerated strength was higher than normal compressive strength. A linear equation was obtained by performed regression anal-

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-ysis of test results [6].

Tokyay a relationship between standard compressive strength at 7, 28 and 90 days with the early strength attained by autogeneous, warm water and boiling water curing and developed a regression expression in the form of power equation, to predict the strength of concrete containing high –lime and low-lime fly ashes as partial cement replacement. All the concretes were proportioned to keep the slump value constant i.e., 80 – 100 mm [7].

Udoeyo et al. proposed a power equation for the early prediction of 28 days strength of laterized concrete where laterite is used as partial and full replacement of sand by using correlation between 28 days strength and autogeneous, warm water and boiling water cured accelerated strength. Investigation showed that early strength of concrete was between 72 and 82 % of its 28 days strength[8].

2 Experimental Programe

In the present investigastion to produce fifty five mixes three binder contents ranging from 337.5, 375 and 412.5 Kg/m3 with varying water-cementitious ratios 0.4, 0.45, 0.5, 0.55 and 0.6 is considered. Variation of fly ash percentages ranging from 0, 20, 30, 40 and 50 % is also considered. Fifty five mixes consists of 11 control mixes and 44 fly ash mixes. Each mix consists of six cube specimens and introduced to two different curing conditions. Out of which three specimens were introduced to accelerated curing condition at 550 C for a period of 20 hours and another three specimens were cured under water for a period of 28 days. Test results obtained from laboratory were analyzed and new expressions proposed. Expressions obtained from the study was not accurate with the expression existing in IS : 9013 [2].

2.1 Materials used

Cement : OPC 43 grade cement conforming 8112, having compressive strength 43 N/mm2 at 28 days normal curing. The cement had Blaine's fineness of 340 m2/kg. Specific gravity of cement is 2.13.

Fly Ash : Fly ash with Blaine's fineness of 342.08 m2/kg with specific gravity 2.108. Fly ash was collected from a thermal power plant in West Bengal.

Fine Aggregate : Natural river sand conforming to zone III of IS:383. Specific gravity and water absorption values of sand used were 2.59 and 0.20% respectively.

Coarse Aggregate : Angular, crushed, and graded coarse aggregate of 20 mm nominal maximum size was used having specific gravity and water absorption values of 2.88 and 0.81% respectively. Since graded aggregate are not readily available in the market thus two readily available aggregates namely 20 mm and 10 mm single sized are mixed with a proportion of 70% and 30% to achieve the desired grade of coarse aggregate. The proportion was determined by trial and error method.

Admixture : No admixture was introduced except fly ash which is a mineral admixture.

Water : Potable water was used for the mixing.

The constituent materials mentioned above were kept constant throughout the experimental process.

Fly ash used in this study had lower amount of reactive-silica content than any other fly ash samples. If it can be observed that incorporation of this poor quality of fly ash in concrete results good quality of concrete then consumption of poor quality of fly ash for fly ash concrete making can also be considered.

Mix proportions of coarse and fine aggregate was determined in the laboratory through a number of trials by which maximum packing density could be achieved and this proportion was kept constant for all 55 mixes.

For the binder content 337.5 kg/m3 water-cement ratios 0.5, 0.55 and 0.6 were taken for the preparation of concrete mixes. 0.4 and 0.45 were not considered as the mixes produced by lower water-cementitious ratio resulted unworkable mixes.

For the binder content of 375 kg/m3 all the five water cement ratios (0.4, 0.45, 0.5, 0.55 and 0.6) were considered.

In case of 412.5 kg/m3 binder content 0.4, 0.45 and 0.5 water cement ratios were considered. Higher water-cementitious ratios 0.55 and 0.6 were not taken into consideration as it resulted mixes with high amount of water that resulted in excessive segregation and bleeding.

From the experimental program it was inferred that total 55 cohesive and workable mixes were investigated in the study.

Preparation of test specimen

Cube specimens of dimension 150 × 150 × 150 mm were used for the determination of compressive strength. Test performed in accordance with Indian standards (IS : 516-1959) using digital compression testing machine with a capacity of 3,000 KN at a loading rate of 14N/mm2 [9].

2.2 Methods

For each mix 6 cubes were cast, in which 3 cubes were introduced to accelerated curing for a period of 20 hours at 550C and rest of the 3 cubes were cured under water for a period of 28 days. All the cube specimens were introduced to compression test at room temperature. Accelerated and normal strength of concrete was reported by taking the average values of 3 cube strengths.

3 Results and Discussion

It is well known that due to the presence of reactive pozzolan in fly ash concrete rate of strength gain is slower compared to normal concrete at the age of 28 days. Since IS:9013 had developed expression for the prediction of 28 days moist cured normal concrete strength with respect to accelerated cured strength by warm water method and boiling water method [2]. Thus strength results obtained from laboratory were analyzed by performing regression analysis to predict 28 days normal strength of fly ash concrete with respect to accelerated cured strength of fly ash concrete. Only accelerated strength is considered as the independent variable to predict the dependent variable which is 28 days strength in this present study.

Strength results of 11 control mixes, 44 fly ash mixes and all 55 mixes (11 + 44) were analyzed statistically by means of regression analysis. Efficiency of equations developed through modeling can be selected by comparing the values of R and S values. R representing multiple correlation coefficients and S representing standard estimated error. R measures the degree of association among the dependent variable and all the independent variables those were taken together for the purpose of modeling. S measures the prediction of accuracy. Equation with maximum R value with minimum S value was considered the best model or best equation. Significance of the equations which are obtained from the analysis and influence of the variables present in those equations are examined by performing 'F' and 't' test respectively. F and t value obtained from the regression analysis are compared to F critical and t critical value at 5 % level of significance to determine whether the null hypothesis is valid or rejected. If the F and t value obtained from analysis is greater than critical value then then null hypothesis is rejected and alternative hypothesis is valid. If alternative hypothesis is valid incase of 'F' test then it infers that at least one of the regression co-efficient among all the coefficients is non zero. For 't' test also if t calculated value is greater than t critical value at a given level of significance (i.e, 5%) the null hypothesis is rejected and alternative hypothesis is valid. It indicates that at least one of the independent variable is non zero. If null hypothesis exists in any model for a particular independent variables then the variable needed to be deleted from the model [10].

Since IS:9013 has developed a relationship between 28 days strength and accelerated strength for normal concrete shown in equation (1) . In this method that type of relationship is considered for the prediction of 28 days strength with respect to accelerated strength for fly ash concrete [2],[4],[5],[6].

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$$F_{28} = F_{acc} + 12.65 \qquad (1)$$

Where, F28 = 28 days normal cured strength of fly ash concrete

Facc = Accelerated cured strength of fly ash concrete

and 12.65 = Intercept

Similar type of expression was considered

$$R_{28} = R_{acc} + C \qquad (2)$$

Where, R_{28} = 28 days normal cured strength of fly ash concrete

R_{acc} = Accelerated cured strength of fly ash concrete

and C = Intercept

Total three equations were obtained where equation (3), (4) and (5) are obtained from the analysis of the strength results of 11 control mixes, 44 fly ash mixes and 55 all mixes respectively to predict 28 days compressive strength by performing linear regression analysis on the strength results of three mixes [3],[4],[10].

Table 1 Results of statistical analyses (ANOVA) for 28 days strength models (equations 3,4 and 5 for 11, 44 and 55 mixes respectively)

Eqn.	coefficient		t statistic		t_{cr}	F_{obs}	F_{cr}	R	S
	a		t						
	a_0	a_1	t_0	t_1					
3	5.809	1.527	0.992	6.050	2.262	36.607	5.12	0.895	4.872
4	9.330	1.322	4.877	10.210	2.018	104.255	4.072	0.884	4.772
5	8.604	1.383	5.233	14.134	2.008	199.770	3.182	0.889	4.801

Note:

t_0 and t_1 refer to the values of t statistics for the corresponding regression coefficients; tcr denotes critical values of t statistic; F_{obs} indicates values of F statistics calculated; F_{cr} indicates critical values of F statistics and a0 and a1 indicates coefficient values of independent variables.

R indicates the multiple regression coefficient and S indicates the standard estimated error.

't' test to check the significance of the individual independent variables

Among these three equations, in equation (3) t statistic value of intercept variable is smaller than t cr value at given level of significance. Thus null hypothesis is valid. That is why the equation can not be taken into consideration. In equation (4) and (5) t statistic is greater than tcr at given level of significance which indicating that alternative hypothesis is valid and independent variable present in those equations have significant influence.

F test to evaluate the significance of the statistical models

From the Table 1 it is observed that F values obtained from equation (3), (4) and (5) were higher than F critical value at given level of significance. So, all the models are significant as null hypothesis is rejected and alternative hypothesis is valid i.e. at least one of the values of the coefficients is non-zero.

Evaluation of the relationship using R and S

Selection of relationship can be done by comparing R and S values. Assessment of the quality of relationship between equation (4) and (5) was done by performing comparison of R and S values of equation (4) and (5) of Table 1.

Sample calculations for 'F' test and 't' test

At 28 day, equation (4) analyzed with strength results of 44 fly ash mixes, the value of calculated F from the present results is 104.255 shown in Table 1. F tests were performed at 5 % level of significance with [n-(m+1)] degree of freedom, Here m = number of independent variables on which strength depending on = 1 and n = number of observations = 44. Thus, number of degrees of freedom = [55 – (2+1)] = 52. For this value of degrees of freedom F critical value is 4.072.10 So, F calculated value is greater than F critical value, It indicates that null hypothesis is invalid and alternative hypothesis is valid.

Also for the independent variables that is accelerated cured strength in this case which is present in the models t tests were performed at the significance level of 5% with [n-(m+1)]

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degree of freedom, where n = number of observations = 44 and m = number of independent variables on which strength depending on = 1. The absolute value of t for the regression coefficients corresponding to accelerated cured strength was obtained as 10.210. The number of degrees of freedom for the present equation is equal to [55 – (2+1)] = 52. Corresponding to this degrees of freedom , the t critical value at 5% level of significance is 2.018.10 Since the absolute critical value for the parameter and a0 are greater than t critical value, the null hypothesis is invalid. This indicate that parameter can be considered to be statistically significant.

From equation (4) and (5) of Table 1 equation has higher R value compared to equation (4). Thus equation (5) can be considered the best equation. Equation correlating the accelerated strength and the 28 days strength is basically a linear fit which is shown below :

$$R_{28} = 1.383\times R_{acc} + 8.604 \qquad (6)$$

The equation developed through the present study is not accurate with the equation present in Indian Standards (IS:9013).2 Equation developed through the investigation is almost similar to the equation proposed by Jayadevan et al. and Shelke and Gadve. [5],[6].

4 Conclusion

A large-scale of investigation was performed to estimate the 28 day strength of fly ash conrete with respect to accelerated strength of fly ash concrete as a parameters. Based on the study it can be stated that :

As per Indian Standards the acceptance criteria for the quality of concrete is based on the compressive strength of cylinder or cube specimens cured in water at 28 day. But with the concept of accelerated curing strength of controlled concrete, 28 days strength can be estimated. That relationship in IS:9013. From the present study similar form of relationship is obtained shown below:

$$R_{28} = 1.383\times R_{acc} + 8.604$$

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