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Original Research Paper

Performance Evaluation of Eco-friendly Green Concrete

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ABSTRACT

This study was aimed to minimize the use of natural river sand which is being used for several years in construction, and to utilize bottom ash from thermal power station as a partial replacement (30%, 60%, 100%) for fine aggregate. An experimental investigation has been carried out to find the compressive strength of the replaced eco-friendly green concrete with different curing methods. An equation recommended by ACI committee for conventional concrete was used to predict 56, 90 and 180 days compressive strength from 28 days compressive strength of the eco-friendly green (bottom ash) concrete that resulted with the difference between the experimental and predicted compressive strength to ± 12%. To minimize the percentage of difference, an empirical relationship was developed between the compressive strength of accelerated curing and normal curing (28, 56, 90, 180 days). It is concluded that empirical relationship predicts later age compressive strength with the minimum percentage of difference. This study of predicting later age compressive strength from empirical relationship will ultimately save time, material and most importantly assessing the quality of the design of construction.

INTRODUCTION

To create sustainability and to conserve the natural resources, scientists, researchers and engineers are engaged in bringing the "green concept" in the cement and concrete industry. The green technology was started in the early 19th century as a result of finding alternate energy system. Green concept in the cement and concrete industry can be applied to reduce CO_2 emission and conservation of natural resources such as limestone, clay, shale, natural rocks and other materials which are associated in the production of cement and concrete. The reduction of CO_2 from the cement industry is done by replacing the cement with admixtures like fly ash, silica fume and other pozzolan. River sand which is widely used as fine aggregate constitutes nearly 40% in concrete. About 12 billion tons of concrete is used every year in the world (Metha 1999). The use of river sand must be minimized and an alternate material which possesses the properties of river sand should be explored through research. This will result in the sustainability and can prevent the depletion of river sand which will result in the environmental problems such as loss of estuaries, loss of ground water, soil erosion in river bed and other associated problems. On the other hand coal combustion products such as fly ash, bottom ash and boiler slag are produced every year in thermal power stations. In India the total ash production is 170 million tons in 2012 (Vimal Kumar et al. 2005). This coal ash requires acres of land for storage and disposal which on the other hand results in air, land and water pollution. To save natural resources and to create sustainable development, the coal ash should be utilized to the maximum. Coal bottom ash is limited to be used as land fill and embankment. To utilize bottom ash as fine aggregate and thereby minimizing the use of river sand in concrete is of great importance.

In this study the bottom ash is replaced for fine aggregate in concrete as 30%, 60% and 100% and is tested for compressive strength. Two types of curing methods were followed, accelerated curing and normal curing. In accelerated curing, cubes were taken after 24 hours and cured in boiling water as per ASTM C 684 (2003) and tested for compressive strength. Normal curing was done in water tank for 1, 7, 28, 56, 90 and 180 days.

Materials and mix proportions: Cement used was ASTM C150 (2011) type I ordinary Portland cement of 53 grade and its physical properties are given in Table 1. Natural siliceous river sand, which was locally available for construction activities, conforming to ASTM C 33M-11 (2011) was used and its physical properties are given in Table 2. Particle size distribution of sand is given in Fig. 1. Coarse aggregate used was crushed granite stone with the size ranging between 12.5mm and 20mm. Water used for mixing and curing of concrete was ordinary potable water conforming to ASTM C 1602 (2012). Chemical admixture used was ASTM C 494 (2010) type F, high range water reducing admixture which is light brown in colour with the pH of 6 and relative density of 1.08 at 25 degree Celsius.

Bottom ash: Bottom ash (BA) used in the study was obtained from Neyveli Lignite Corporation of India Ltd. (NLC) thermal power plant which is located in southern India.

Bottom ash is lignite based with the calorific value of 2400 cal/kg. Particle size distribution of bottom ash is given in Fig. 1. The chemical composition, obtained by X-ray fluorescence spectroscopy, is given in Table 3.

The total carbon content was determined in accordance with ASTM D 7348-08 (2008) and loss on ignition was accepted as permissible limit in the concrete application.

Mix proportion: Fine aggregate is replaced by bottom ash as 30%, 60%, and 100% in concrete and titled as BA30, BA60 and BA100. The water binder ratio and slump range were kept constant for all the mixtures. In order to obtain desired workability and to maintain fixed slump range the dosage of superplasticizer was increased from 0.35% to 1.68%. The details of the mix proportions are listed in Table 4.

Preparation of the concrete mixture: Materials were mixed in a rotary concrete mixture machine; superplasticizer was mixed with water and added to cement and aggregates. The concrete was well mixed for homogeneity and cast in steel moulds of size 100mm ×100mm ×100 mm. The moulds with the concrete were placed on the compaction table for proper compaction. The compacted concrete mould was kept in room for 24 hours.

Compressive strength results: The compressive strength of the concrete mixtures is given in Table 5 along with the accelerated curing and normal curing. As the percentage of bottom ash increases the compressive strength decreases compared to the reference mix throughout the ages. Concrete containing 30% bottom ash shows compressive strength similar to the reference mixture.

Prediction of compressive strength from ACI Committee 209 recommendations: An equation recommended by ACI was used to predict later age compressive strength from 28 days compressive strength. Since this equation can be used for conventional concrete (cement, fine aggregate, coarse aggregate and water), the same equation was also used for the concrete containing bottom ash as fine aggregate replacement.

ACI committee 209 (1993) recommends the following relationship for the prediction of later age compressive strength from 28 days compressive strength.

$$F_{cm}(t) = F_{cm\,28}\left(\frac{t}{\alpha+\beta t}\right) \quad ...(1)$$

Where $F_{cm}(t)$ is the mean compressive strength at age *t* days; $F_{cm\,28}$ is the mean 28 days compressive strength; *t* is the age in days; α and β are the constants which are equal to 4 and 0.85 respectively. Table 6 and Fig. 2 predict the compressive strength of 56, 90 and 180 days.

Table 7 shows the percentage of difference between experimental value and predicted value. It is clearly observed that ACI recommended equation predicts the compressive strength with the maximum percentage of difference for 100%BA with 19.945 but for reference concrete mixture the maximum difference is -4.96%. To minimize the percentage of difference for ACI recommended equation with $\beta = 0.85$, the value of β is taken as 0.756 based on trial and error method. The percentage of difference between $\beta = 0.85$ and $\beta = 0.756$ for experimental value and predicted value is given in Table 7. This developed ACI equation with χ as 0.756 predicts the compressive strength of bottom ash replaced concrete with the percentage of difference of -10.27 for 100% BA which is lesser compared to ACI recommended equation with the $\beta = 0.85$.

It can also be noted that the percentage of difference decreases as the replacement level increases within the minimum range of lesser than ± 12% for the developed ACI equation. Thus, with the developed ACI recommended equation it is made easy for predicting the value of later age compressive strength of the concrete replaced with bottom ash with the available 28 days compressive strength.

But for assessing the quality, 28 days compressive strength is mostly considered as the evaluation process. To know the 28 days compressive strength the designer has to wait for 28 days which may also affect the duration of the construction. Advancement in the technology and rapid infrastructural development breaks the timeline of the construction practices. This urges the designer to obtain 28 days compressive strength at the earliest possible time through rapid and different curing methods. Moreover, the normally cured concrete may not always give reliable results because slight variation immediately after casting may affect compressive strength (Neville 1973).

Accelerated and normal curing: Accelerated curing method is to accelerate hydration process for attaining early age compressive strength. This method is widely accepted since it reduces number of experiments, materials and time. But 28 days of normal curing gives 100% of strength of concrete. In normal curing the rate of hydration takes place gradually, whereas in the accelerated curing the rate of hydration increases pozzolanic reaction i.e., formation of calcium silicate hydrate. The accelerated method of curing assures standard compressive strength which enables the quality with respect to the strength and also allows the engineer to redesign if the designed strength is not attained or any other issues in the quality of the concrete.

The following researchers clearly explained about the relationship between accelerated curing and normal curing and various statistical tools for prediction of compressive strength. Tokyay (1999) derived relationship between ac-

Table 1: Physical properties of cement.

Parameters	Values
Specific surface are (m^2/kg)	322
Specific gravity	3.1
Consistency %	31 ~
Soundness :	~
By Le-Chatelier method in mm	1
By Autoclave	0.01
Setting time :	~
Initial setting time(minutes)	90
Final setting time (minutes)	330
Loss on ignition (%)	1.9

Table 2: Physical properties of fine aggregate.

Type of aggregate	Fineness modulus	Specific gravity	Water absorption in (%)
River sand	2.9	2.64	-1.25
12mm	~	2.71	-0.54
20 mm	~	2.77	-0.18
Bottom ash	1.78	2.38	-6.54

Table 3: Chemical composition of bottom ash.

Chemical Compounds	Amount in percentage (%)
SiO_2	80.23
Al_2O_3	13.83
Fe_2O_3	2.91
CaO	1.24
MgO	1.03
Na_2O	0.14
SO_3	**0.26**
P_2O_5	0.28
TiO_2	0.08
LOI	1.68

celerated and standard curing method which depends upon the type of the materials used (admixtures such as fly ash for partial replacement of cement).

Resheidat et al. (1992) derived three types of relationships between accelerated compressive strength and 28 days compressive strength, such as linear function model, power function model and exponential model to predict 28 days compressive strength.

Tarun (1979) developed the relationship between accelerated compressive strength and 28 days compressive strength to predict the compressive strength of 28 days immediately after the day of casting using linear function.

Jui-Sheng Chou et al. (2012) developed combined classification and regression technique to predict compressive strength of high performance and novel technique which automates concrete mix design for civil infrastructure and building construction.

Behrouz Ahmadi-Nedushan (2012) developed two models, non-linear regression and adaptive network-based fuzzy inference system (ANFIS) for the estimation of elastic modulus from the compressive strength of the concrete.

Atici (2011) studied a non-linear functional relationship by multivariable regression analysis predicted compressive strength for later ages.

With this literature as the background, it clearly emphasizes the importance of prediction of compressive strength at the earliest possible time.

In this context and with the literature as the foundation, the following empirical relationship was developed between the compressive strength of the accelerated curing and 28, 56, 90 and 180 days of normally cured concrete. This will predict the later age compressive strength of 28, 56, 90 and 180 days without actually waiting for 180 days.

The generalised equation showing the relationship between the compressive strength of accelerated and normal curing method is given by

$$F_{cs} = A (F_{acc})^3 + B (F_{acc})^2 + C (F_{acc}) + D \qquad ...(2)$$

Where F_{cs} is the compressive strength by normal curing at *t* days (28, 56, 90 and 180 days in MPa); F_{acc} is the compressive strength by accelerated curing in MPa; A, B, C, D are constants depending on the percentage of bottom ash used (30%, 60% and 100%) and age of curing (28, 56, 90 and 180 days).

Percentage of difference between the compressive strength of experimental value and predicted values: The differences between the values of the compressive strength of the experimental values and predicted values are expressed in percentage as given in Table 9. The percentage of difference decreases as the curing age increases. The difference is maximum for 28 days (4.41%), and minimum for 180 days (-0.52%). This clearly shows the reliability of the empirical analysis for predicting later age compressive strength. With the above relationship, it is possible to predict the value of later age compressive strength just after 24 hours of casting with high precision for both conventional and bottom ash concrete.

CONCLUSION

This experimental investigation revealed the potential utilization of bottom ash as fine aggregate that can promote it as eco-friendly green concrete since the use of natural river sand is minimized. From the results, it is concluded that 30 % of bottom ash can be used as fine aggregate in concrete without affecting the compressive strength of the concrete. The importance of prediction of later age compressive strength was also made by ACI recommended equation and empirical relationship with following conclusion.

Table 4: Mix proportions.

BA in %	Cement in kg/m³	Fine aggregate in kg/m³	Coarse aggregate in kg/m³	Water in kg/m³	W/B Ratio	BA in kg/m³	SP in %	SP in kg/m³
0	333	754	1290	140	0.42	0	0.35	1.20
30	333	550	1290	140	0.42	204	0.50	1.65
60	333	346	1290	140	0.42	408	1.05	3.49
100	333	0	1290	140	0.42	680	1.68	5.59

Table 5: Compressive strength results.

Mix Id	Mix	Compressive strength in MPa						
		Accelerated curing	1 Day	7 Days	28 Days	56 Days	90 Days	180 Days
1	Conventional	26.00	20.13	37.83	46.53	50.65	51.80	56.13
2	30BA	29.93	22.30	36.97	42.10	47.03	51.06	53.13
3	60BA	24.93	19.70	27.50	36.77	42.83	46.36	48.86
4	100BA	22.50	13.03	23.03	32.70	36.10	42.56	48.63

Table 6: Comparison of compressive strength predicted by using 28 days from the recommended ACI equation with two different values of β.

Mix	β = 0.85 Predicted compressive strength in MPa			β = 0.756 Predicted compressive strength in MPa		
	56 days	90 days	180 days	56 days	90 days	180 days
Conventional	50.50	52.02	53.35	56.23	58.13	59.79
30% BA	45.69	47.07	48.27	50.88	52.60	54.10
60% BA	39.91	41.11	42.16	44.44	45.94	47.25
100% BA	35.49	36.56	37.49	39.52	40.85	42.02

Table 7: Comparison of percentage difference between ACI equation for conventional concrete and developed equation for bottom ash concrete.

Mix	β=0.85 % of difference between experimental and predicted value			β=0.756 % of difference between experimental and predicted value		
	56 days	90 days	180 days	56 days	90 days	180 days
Conventional	-0.30	0.43	-4.96	11.03	12.22	6.52
30%BA	-2.85	-7.82	-9.15	8.19	3.01	1.82
60%BA	-6.83	-11.33	-13.72	3.76	-0.91	-3.30
100%BA	-1.69	-14.10	-19.94	9.47	-4.01	-10.27

Table 8: Predicted compressive strength.

Mix Id	Mix	Compressive strength in MPa				
		Experimental Values	Predicted values			
		Accelerated curing	28 days	56 days	90 days	180 days
1	Conventional	26.00	47.88	49.69	51.49	55.74
2	30% BA	29.93	43.84	45.60	50.60	52.54
3	60% BA	24.93	38.03	41.98	46.08	48.52
4	100% BA	22.50	33.77	35.47	42.35	48.38

Table 9: Percentage of difference between the experimental compressive strength and predicted compressive strength in MPa.

Mix	Percentage of difference			
	28 Days	56 Days	90 days	180 days
Conventional	2.91	-1.89	-0.60	-0.69
30% BA	4.14	-3.04	-0.89	-1.11
60% BA	3.42	-1.98	-0.60	-0.69
100% BA	3.25	-1.75	-0.49	-0.52

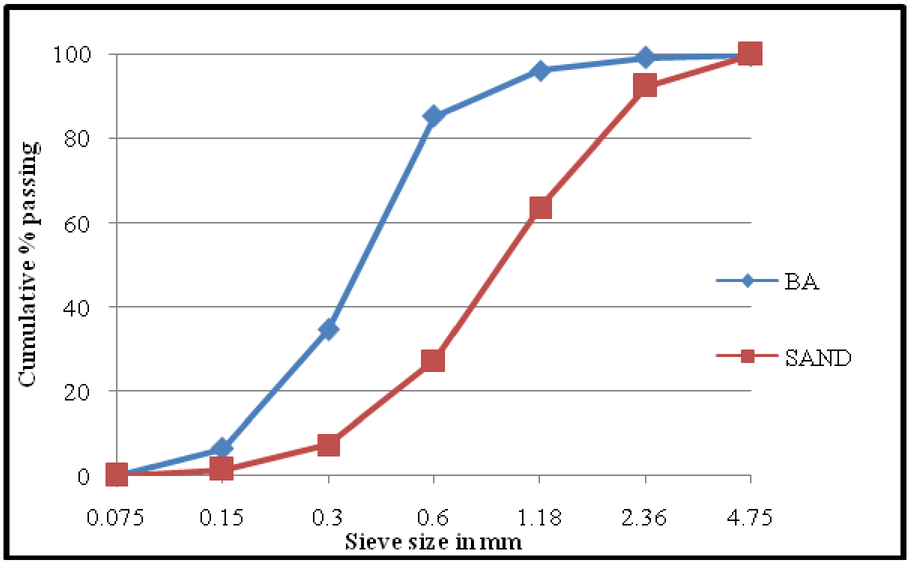

Fig. 1: Particle size distribution of sand and bottom ash.

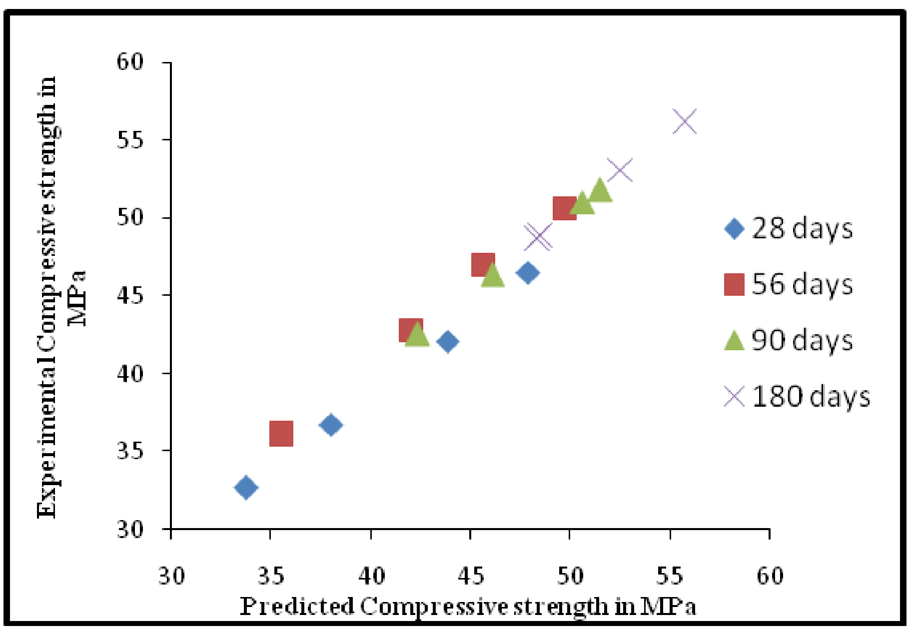

Fig. 2: Comparison between compressive strength of experimental value and predicted value for 28, 56, 90 and 180 days.

1. ACI recommended equation holds good for predicting later age compressive strength of conventional concrete and for bottom ash replaced concrete by modifying the constant $\beta = 0.756$ in ACI recommended equation to the minimum percentage of error difference to 12%.
2. The importance of curing method for quality assessment and predicting later age compressive strength is highlighted regardless of the material used in the concrete (bottom ash in this study) that will help the designer to improve the design of construction.
3. The empirical relationship predicts the 28, 56, 90 and 180 days compressive strength just after 28 hours from the accelerated cured compressive strength with the maximum error of 4%. This ultimately saves the time, material and also enhances rapid and quick quality assessment in the construction.
4. The percentage of difference decreases as the replacement level and the age of curing of bottom ash increases for both ACI recommended equation and empirical relationship which promises the reliability of the results.

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REFERENCES

ACI Committee 209, 1993. Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures (ACI 209R-92). ACI Manual of Concrete Practice, American Concrete Institute; Detroit, MI, Part 1, pp. 47.

ASTM C 1602/C 1602M-12, 2012. Standard Specification for Mixing Water Used in the Hydraulic Cement Concrete; Philadelphia.

ASTM C 33/C33M 11a, 2011. Standard Specification for Concrete Aggregates, Philadelphia.

ASTM C 494/C 494M-10, 2010. Standard Specification for Chemical Admixtures for Concrete; Philadelphia.

ASTM C 684-99, 2003. Standard Test Method for Making Accelerated Curing and Testing Concrete Compression Test Specimens; Philadelphia.

ASTM D 7348-08, 2008. Standard Test Methods for Loss on Ignition (LOI) of Solid Combustion Residues; Philadelphia.

ASTM, C. 150, 2011. Standard Specification of Portland Cement, Philadelphia.

Atici, U. 2011. Prediction of the strength of mineral admixture concrete using multivariable regression analysis and an artificial neural network, Expert Systems with Applications, 38: 9609-9618.

Behrouz Ahmadi-Nedushan, 2012. Prediction of elastic modulus of normal and high strength concrete using ANFIS and optimal nonlinear regression models. Construction and Building Materials, 36: 665-673.

Jui-Sheng Chou and Chih-Fong Tsai 2012. Concrete compressive strength analysis using a combined classification and regression technique. Automation in Construction, 24: 52-60.

Metha, P.K. 1999. A concrete technology for sustainable development: An overview of essential principles. CANMET/ACI International Symposium on Concrete Technology for Sustainable Development; Vancouver.

Neville, A.M. 1973. Properties of Concrete, Halstead Press. New York.

Resheidat, M.R. and Madanat, O.N. 1992. Accelerated strength and testing of concrete in Jordan. Material and Structures, 25: 79-83.

Tarun, R. and Naik, T.R. 1979. Utilization of accelerated strength testing methods. Cement and Concrete Research, 9: 7-18.

Tokyay, M. 1999. Strength prediction of fly ash concretes by accelerated testing. Cement and Concrete Research, 29: 1737-1741.

Vimal Kumar, Mukesh Mathur, Shaahank Shekhar Sinha and Sagar Dhatral 2005. Fly Ash: An Environment Savior, Fly Ash Utilization Program (FAUP); TIFAC.