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SUSTAINABLE CONCRETE FOR THE CONSTRUCTION INDUSTRY

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ABSTRACT

The experimental investigation is mainly focused on the development of cost effective high strength concrete containing high volume fly ash. Fly ash is a byproduct of coal fired electric power station. The current annual worldwide production of coal ash is estimated about 700 million tonne. Fly ash is a beneficial mineral admixture for concrete. It influences many properties of concrete in both fresh and hardened state concrete. Utilization of waste materials in cement and concrete industry reduces the environmental problems; also utilization reduces the amount of solid waste, green house gas emissions associated with Portland clinker production and conserves existing natural resources. Due to increase in demand for cement, there is a need of alternate material. Since fly ash is pozzolanic in nature, it can act as partial replacement material for Portland cement. In this study, keeping the binder content as constant and replacing cement with fly ash upto 60%, the mechanical behaviors such as compressive strength, and split tensile strength were studied. Concrete with higher percentage of fly ash (60%) attained compressive strength of 47.08 N/mm^2 and 50.50 N/mm^2 at 28 and 90 days, respectively. Further the Cost analysis was done for all the mixtures. C60 mixture concrete gives 22% savings of cost than conventional concrete.

Keywords: concrete, high volume fly ash, economical, construction industry, waste utilization.

1. INTRODUCTION

Coal and Lignite based thermal power stations have been the major source of power generation in India. Fly ash is a byproduct material obtained after burning coal / lignite in these thermal power stations. Nearly 150 million tonnes of fly ash are being generated from the thermal power stations per annum in India and 700 million tonnes worldwide. Thermal power stations face major problems in dumping and disposal of fly ash [Dirk, 2011]. Fly ash is disposed of in either a wet or a dry state. Fly ash often contains heavy metals, namely Ni, Cd, Sb, As, Cr, Pb, etc. That may results in diseases such as respiratory problems, lung cancer, anaemia and skin cancer [Manas, 2011]. Fly ash consists of fine particles, the typical size of which is less than 90 micrometers. It is removed from the flowing gas using the force of an induced electrostatic charge inside the electrostatic precipitator. In the thermal power stations, dumping and disposal of fly ash require huge land spaces. If fly ash is disposed in the land, during the rainy season, it leaches out and contaminates the ground water, which leads to the pollution of the surrounding land [Dirk, 2011].

Since the chemical composition of fly ash is similar to that of cement, research has been carried out to use fly ash in various mass proportions to replace cement in concrete. At present, Portland Pozzolanic Cement (PPC) with fly ash is mainly used in the construction industry. The main disadvantage in using fly ash concrete is its lower early age strength. But, on the other hand, fly ash reduces the rise in temperature in the concrete and at the same time increases the compressive strength in the long term, thus improving the sulfate resistance and durability properties of concrete [Mehta, 2006; Neville, 2000; Mohan *et al*., 2012; Gjorv, 2011]. At the manufacturing level of Ordinary Portland cement, one tonne of cement emits 0.9 tonne of CO_2 to the atmosphere; it causes Global warming. Hence it is necessary to utilize a higher percentage of fly ash in the construction industries, thus minimizing the construction cost as well as green house gas effect. This study replaced cement with fly ash up to 60% by mass, and the mechanical behavior of high volume fly ash in concrete at the long term curing age is evaluated.

2. EXPERIMENTAL WORK

2.1. Materials

In this study, 53 grades Ordinary Portland Cement corresponding to Standard [BSI 12269-1987] and Class C fly ash confirming to ASTM C 618 were used as binder and mineral admixture, respectively. Specific gravity and consistency of cement were found by conducting lab experiments; the values are 3.12 and 32%, respectively. Fly ash was obtained from the Neyveli thermal power station, Tamil Nadu, India and having the specific gravity of 2.46. The chemical composition of the fly ash is shown in Table-1.

Natural river sand was used as fine aggregate; having the fineness modulus and the specific gravity as 2.55 and 2.4, respectively. Locally available crushed stone was used in the mass ratio of 60:40 in total coarse aggregate quantity size of passing through 12.5 mm and retained on 10 mm; and 20 mm, respectively.

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Table-1. Chemical compositions of fly ash.

Characteristics	From test in %	From IS 3812 Part I requirement in %
Silica (as $Si0_2$)	57.65	Min 25.0
Calcium oxide (Lime content) as CaO	11.64	-
Alumina (as Al_20_3)	15.29	-
Iron oxide (as Fe_2O_3)	6.10	-
Magnesia (as MgO)	0.37	Max 5.0
Sulphuric anhydride (as $S0_3$)	1.82	Max 3.0
Total loss on ignition	2.86	Max 5.0
Total chlorides (as Cl)	0.02	Max 0.05
Sodium oxide (as Na_2O)	0.44	Max 1.5
Potassium oxide (as K_2O)	0.04	-
Total alkalies (as Na_2O)	0.47	-
Silicon dioxide ($Si0_2$) + Aluminium oxide (Al_20_3) + Iron oxide (Fe_2O_3) in % by mass	79.04	Min 50.0

A polycarboxylate ether - based high range water reducing agent was used. Throughout the study, the binder content of 450 kg/m^3 was kept as constant as the cement was replaced by fly ash at various percentages.

2.2. Specimens preparation and curing

By keeping the binder content and water-cementitious materials ratio constant (450 kg/m^3 and 0.35 respectively), the cement content was replaced with 20% (C20), 40% (C40) and 60% (C60) by mass using fly ash. While increasing the volume of fly ash in the concrete, the water demand was high and the workability of concrete was affected. Hence, the high range water reducing chemical admixture was used in concrete to achieve higher workability and it was added to the concrete in % of total Binder (Cement + Fly ash) content. The mixture proportions of these concretes are shown in Table-2. The raw materials of concrete were mixed using a mixer for 5 min. The low slump values (25 mm to 75 mm) were maintained in all the four mixtures.

After mixing the concrete, test specimens were cast into their moulds using a vibrating table. Then, the specimens were de-moulded after 24 hours, and were cured in ordinary potable water until testing. For each mixture, 18 cube specimens (10 x 10 x 10 cm) and 12 cylinder specimens (5 cm radius, 20 cm length) were prepared. The setting time of concrete with high volume fly ash was less in this study due to presence of Class C (higher lime content) fly ash.

3. TESTING OF CONCRETE

3.1. Hardened concrete properties

At the ages of 1, 7, 28 and 90 days, compressive strength tests were carried out on the cube specimens and at 28 and 90 days. In the compressive testing machine, axial load was applied on the specimens up to the sample failure, the ultimate load was noted and the compressive strengths were calculated for cube specimens at the corresponding curing age. For finding the split tensile strength of concrete, 100 mm Ø cylinders were tested. Split tensile strength of concrete samples was calculated at 28 and 90 days. As per Indian standard [BSI 516-1959], tests were carried out on the specimens and the values are calculated and given in Table-3.

4. RESULT AND DISCUSSIONS

4.1. Compressive strength

The control concrete mixture was designed to achieve the target strength of 50N/mm^2. Based on the experimental results, the graphs were plotted at the various curing ages. From Figure-1 and Table-3, it is observed that the strength of concrete was decreased from 32.13 to 8.58 N/mm^2 at one day for mixtures containing 0% to 60% fly ash replacements. This shows the typically observed behavior that increasing the fly ash content in concrete, reduces the strength at the early ages [Duran-Herrera *et al*., 2011]. While comparing 1 day to 7 days compressive strength values, the control concrete gained less strength compared to the high volume fly ash concretes. After 28 days curing, concrete with 40% fly ash achieved a higher strength when compared to the control and that with 20% replacement.

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Table-2. Mixture proportioning (kg/m^3) of concrete.

Concrete mixture	Cement (kg/m^3)	Fly ash (kg/m^3)	% of replacement	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Admixture in % of binder
C0	450	0	0	157.5	717	1075.5	0.2
C 20	360	90	20	157.5	717	1075.5	0.4
C 40	270	180	40	157.5	717	1075.5	0.8
C 60	180	270	60	157.5	717	1075.5	0.9

Table-3. Mechanical properties of concrete.

Mixture ID	Compressive strength of cube in N/mm^2				Split tensile strength in N/mm^2	
	1 day	7 days	28 days	90 days	28 days	90 days
C 0	32.1	37.3	55.6	60.9	3.1	3.3
C 20	28.6	45.3	53.1	62.4	3.6	4.5
C 40	22.4	38.2	55.1	66.3	4.2	4.5
C 60	8.5	27.4	47.0	50.5	3.1	3.8

This enhanced strength may be due to the packing effect between the materials and ongoing pozzolanic reactions [Jatuphon *et al*., 2005]. High volume fly ash concrete (C60) strength increases linearly from 1 day to 90 days. C60 concrete attained 47 N/mm^2 at 28 days curing, and it achieved the target strength at the age of 90 days. The concrete with less than 60% fly ash achieved the target strength at 28 days itself, and the same mixtures attained more than 60 N/mm^2 at 90 days.

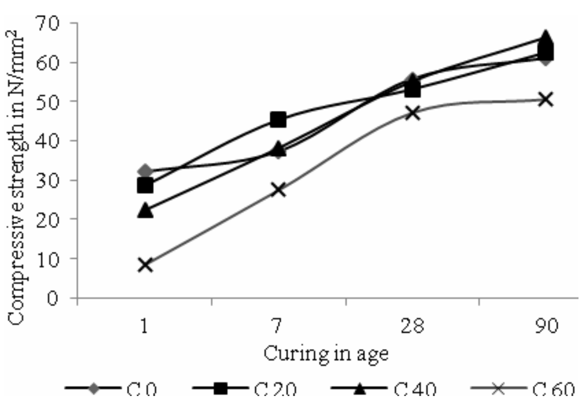

Figure-1. Compressive strength of different concrete mixtures at different curing ages.

4.2. Split tensile strength

Table-3 also gives the results of split tensile strength at 28 and 90 days, measured on standard cured specimens for the control (C0) and concrete containing fly ash upto 20%, 40% and 60%. At 28 days, the control concrete and the 60% replacement concrete achieved similar tensile strengths.

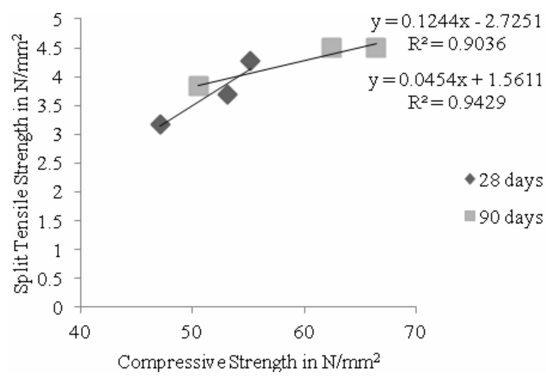

Figure-2. Regression plot for compressive strength versus splitting tensile strength of concrete samples at different curing age.

Replacement concretes (C 20 and C 40) have higher tensile strengths than that of the control at 28 days. The control concrete gained 5% in tensile strength between 28 to 90 days, whereas, the C 20 and C 60 mixtures gained 22% and 20% respectively. In Figure-2 a linear regression analysis was performed on the various mixtures with two different curing ages. Based on the analysis, equations are proposed to find out the split tensile strength of fly ash concrete mixtures based on their measured compressive strength at 28 and 90 days. The correlation coefficient of R^2 as 0.9 and 0.94 and the average error is 0.24 and 0.27, respectively.

5. COST ANALYSIS

Building Materials and Technology Promotion council (BMTPC), Government of India, published that, 60% of construction costs were spent for materials. In that, a major amount was spent for cement, namely around 10 -

14% of materials cost [BMTPC]. It is a high time to find the alternate (inexpensive) binder material to be used in construction industries. In this present study, fly ash, obtained from the thermal power plant, is used as a binder material in concrete. Various percentages of cement were replaced with fly ash, and strength behaviors like compressive and split tensile strength of concrete were studied at various curing ages. From Figure-3, it is observed that, concrete C60 attained strength of 47 N/mm^2 at 28 days and 50 N/mm^2 at 90 days, respectively. This clearly indicates that 60% replacement concrete achieves sufficiently higher strengths. A study on comparison of cost is made for the concrete with fly ash and the control concrete and results are furnished in Table-4. Utilization of fly ash reduces cost by 8.1%, 11.8% and 22.1% respectively at the 20 %, 40 % and 60 % replacement levels. Based on the results obtained from compressive strength tests and cost analysis, a graph was plotted between % of cement replacement with fly ash, Compressive strength and Cost per meter cube of concrete and is shown in Figure-3.

This graph shows that at 90 days, the cost of the concrete gets reduced linearly from Rs 3551.00 to Rs 2765.00. At the same time, 60% replacement of cement with fly ash concrete gained 50.50 N/mm^2 and 20% and 40% mixtures gained higher strength than the control concrete.

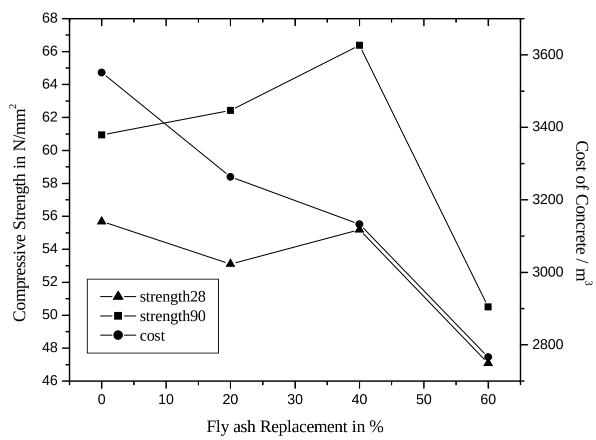

Figure-3. Relation between compressive strength, fly ash replacement and the cost of concrete.

Table-4. Cost comparison.

Mixture ID		**C0**		**C 20**		**C 40**		**C 60**	
Materials	**Cost / kg** (Rs)	**Materials and cost for per m^3**		**Materials and cost for per m^3**		**Materials and cost for per m^3**		**Materials and cost for per m^3**	
		Materials in kg	**Cost / m^3** (Rs)	**Materials in kg**	**Cost / m^3** (Rs)	**Materials in kg**	**Cost / m^3** (Rs)	**Materials in kg**	**Cost / m^3** (Rs)
Cement	6.2	450	2790	360	2232	270	1674	180	1116
Fly ash	1.25	0	0	90	112.5	180	225	270	337.5
Fine aggregate	0.25	717	179.25	717	179.25	717	179.25	717	179.25
Coarse aggregate	0.38	1075.5	408.69	1075.5	408.69	1075.5	408.69	1075.5	408.69
Chemical admixture	175	0.9	157.5	1.8	315	3.6	630	4.05	708.75
Water	0.10	157.5	15.75	157.5	15.75	157.5	15.75	157.5	15.75
Cost of concrete / m^3		(Rupees)	3551.19		3263.19		3132.69		2765.94

6. CONCLUSIONS

From the above discussions, the following conclusions are made.

- For this cement content, control concrete (C0) and replacement mixtures (C20, C40) attained more than 20 N/mm^2, except C60 at 1 day.
- The C60 mixture attains 8.58 N/mm^2 at one day and its strength drastically increased by 320% at 7 days. Compressive strength at 28 days is nearly equivalent to the design strength (50 N/mm^2).
- The concrete with 20% and 40% fly ash attains strength of more than 50 N/mm^2. Hence for M50 grade concrete, these mixture proportions are suitable.
- At 90 days, control concrete gained 107.44% strength, but C20 and C40 concrete gained 118 and 120% strength, respectively. The values represent the fact that the pozzolanic reaction contributes to strength development in the fly ash concrete, particularly at later age.
- The C40 concrete attained higher tensile strength when compared to other replacement concretes and the control concrete at 28 days. At 90 days, the C20 and C40 mixtures achieved the same strength, while the C60 concrete attained a higher tensile strength than the control concrete.
- From the cost and strength analysis, it is observed that 60% replacement of cement with fly ash attained

equal strength to the control concrete, and also it saves above 20% of the cost compared to the conventional concrete.

Hence utilizing 60% of fly ash in construction industries will reduce the Green house gas effect without compromising long term strength and reduces the Environmental impact of Land, Water and Air by reducing the cement usage.

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