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Fly-Ash as Admixture in Manufacturing of Cement - A case study

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ABSTRACT An attempt has been taken to find out the sustainable use of fly ash which was used as an admixture with Shah Special Cement at 5%, 10% and 15% proportion. Laboratory test for the different parameters including the compressive strength, workability, flexural strength, splitting tensile strength of such mixtures were carried out to determine the optimum content. The obtained results show that almost no sacrifice for the strength of cement due to mixture of flyash with a proportion of 10%. Ten samples for compressive strength for each specified day, tensile strength for each specified day, flexural strength, splitting tensile strength were cast for 5%, 10%, 15% proportion of flyash. 5%-10% fly ash was successfully blended with ordinary cement and have positive impact on cement manufacturing.

(Flyash, admixture, compressive strength, workability, durability)

INTRODUCTION

In thermal power plant, coal is burnt at temperatures ranging around 1400 - 1500°C with about 20% excess air in the furnace. The utilization of flyash in the cement manufacturing is 20, 25 and 25% in the Australia, UK and France respectively [1]. Actually the flyash is extensively used in concrete as an admixture in order to reduce cost of cement. The industrial flyash was successfully blended up to 25% to 30% with ordinary Portland cement without sacrificing the strength and durability characteristics [2]. Moreover, chemical admixture is used to improve workability, increase strength and the manufacture of Portland cement is a significant contributor of the greenhouse gases [3]. With a view to reduction of green house gases, in this study flyash was colleted from Barapukaria Power Plant, for checking its feasibility to manufacturing of cement in Bangladesh. Coal from Barapukaria has been also collected and made to ash by burning at 1200-1500°C. The surface area of flyash 755 m^2/g was considered in this study. Table 1 shows the chemical characteristics of flyash.

Table 1. Characteristics of the flyash of Barapukaria Power Plant [3]

CONSTITUENTS	% OF WEIGHT
SiO_2	23.72
Al_2O_3	5.30
Fe_2O_3	2.8
CaO	65.80
MgO	1.26
K_2O	1.60

From Table 1, it clearly shows that percentage of reactive silica is 23.72, which is higher than that of flyash of Kalurghat Power Plant [2].

METHODOLOGY

A concrete mix with characteristic mean strength of 20MPa was designed with an aggregate cementatious ratio of 5.76 and water-cement ratio of 0.539. The total content of cementatious material was maintained at 337 kg/m^2. The

flyash/total cementatious ratios used for replacement were 0.05, 0.10 and 0.15 apart from the plain concrete without any flyash (by weight). The fineness of the flyash used was 16,000 cm^2/g on Blaine's apparatus as it was found that this fineness gave maximum strength.

For each of the flyash addition, concrete cubes were cast as per design mix and the specifications given by ASTM. For determination of the flexural strength; beam specimens of 100mm × 100mm × 500mm were cast for 5%, 10%, 15% proportion of flyash. For determination of splitting tensile strength, cylindrical specimens of 100mm diameter and 300mm long were cast for same proportions.

Prior to acid digestion, approximately 10g of dry fly ash was randomly selected from the composite samples. They were digested with 20ml nitric acid and 10ml perchloric acid. The digested material was filtered through a No. 42 filter paper and diluted to 100ml with distilled water. A liquost were taken for heavy metal determination.

The temperature and relative humidity of the concrete lab; during the period of the test were monitored respectively 23.13°C ± 1.58°C and 41.00% ± 4.50%. Ten specimens were tested for all types of concrete, i.e. concrete with no flyash, different percentages of flyash (by weight). All the tests such as compressive strengths, flexural strength and splitting tensile strength were conducted as per ASCE specification.

RESULTS AND DISCUSSION

The water content of the paste has marked effect upon the time of set as well as upon other properties. The paste at normal consistency is fairly stiff and is used only for determination of time of set and soundness. The effect of increase of flyash on water content is shown in Table 2. It is clear from the table that water content for 5% and 10% are near to that required for normal cement mixture. But 10% mixture is suitable for workability.

After proper mixing of cement and water at a specific proportion, when soft plastic paste becomes sufficiently stiff it is said to have set. The definition of the term stiffness of the paste, which is considered, set is somewhat arbitrary. Two terms, "initial" and "final" are used to distinguish between the beginning and ending of setting. The term hardening means a gain of strength of a cement paste follows the final setting. For practical reasons, it is essential that cement should set neither too rapidly nor too slowly. If a cement paste sets very rapidly there might be insufficient time to transport and place concrete before it becomes too stiff. This setting process is always accompanied by temperature changes in the paste, initial set corresponds to a rapid rise in temperature and final set to the peak temperature. Table 3 presented the effect on initial and final setting time by mixing of flyash with cement.

Table 2. Effect of increase of flyash on water content for Shah Special Cement with 5%, 10% and 15% fly ash

TYPE	SHAH SPECIAL CEMENT	SHAH SPECIAL CEMENT WITH 5% FLY ASH	SHAH SPECIAL CEMENT WITH 10% FLY ASH	SHAH SPECIAL CEMENT WITH 15% FLY ASH
Water content (%)	27.6	29.1	28.2	27.2
Water content (ml)	184.9	187.5	182.4	175.8

Table 3. Effect of flyash on Setting Time for Shah Special Cement

TYPE	SHAH SPECIAL CEMENT	SHAH SPECIAL CEMENT WITH 5% FLY ASH	SHAH SPECIAL CEMENT WITH 10% FLY ASH	SHAH SPECIAL CEMENT WITH 15% FLY ASH
Initial setting time (min.)	135.1	90.1	120.2	75.2
Final setting time (min.)	195.2	150.3	180.2	135.2

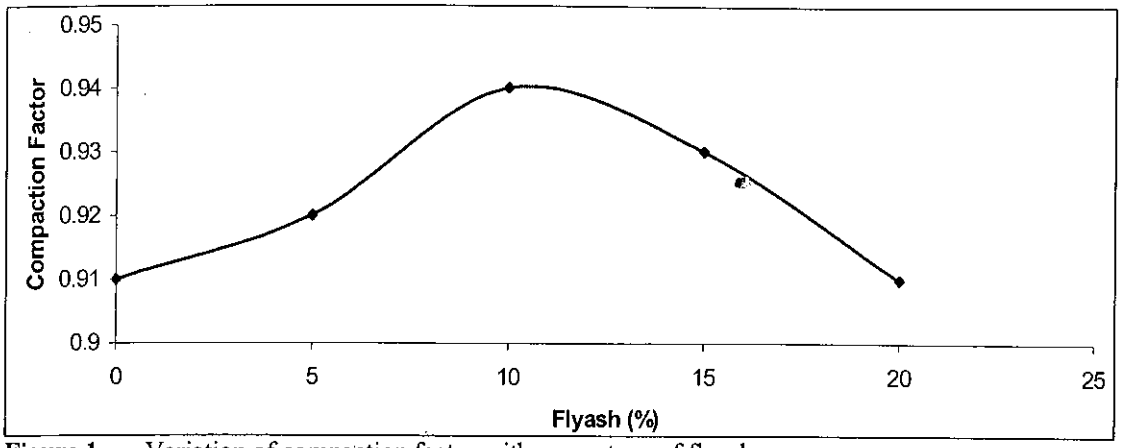

Figure 1. Variation of compaction factor with percentage of flyash

Compressive strength

The compressive strength of high flyash concrete for a given cement ratio decreases as the flyash content increases. Rao [8] reported that addition of 30% rich hush ash with flyash (30% to 60%) showed in improvements in 7-days strengths from 31% to 53%. Table 4 shows effect of flyash on compressive strength. The results clearly indicate that the presence of silica in flyash of Barapokoria Power Plant has a complex impact on compressive strength. Otherwise percentage of reduction of strength (compressive) would be more. Ten samples of each specification were tested for getting a clear idea about the effect of flyash. For 3-days compressive strength test, the result was 16.183 ± 0.88MPa, 15.183 ± 0.83MPa; 15.09 ± 0.74 MPa and 14.93 ± 0.58MPa for Shah Special Cement, Shah Special Cement with 5% fly ash, Shah Special Cement with 10% fly ash and Shah Special Cement with 15% fly ash respectively. For 7 days and 28 days, the compressive strength of the samples was within the ±0.56MPa. The presence of high reactive silica in significant amount in flyash leads to increase of compressive strength. Presence of silica leads to improved earlier hydration.

Table 4. Effect of fly ash on compressive strength of shah special cement with 5%, 10% and 15% fly ash

AGE (DAYS)	STRESS IN MPa			
	SHAH SPECIAL CEMENT	SHAH SPECIAL CEMENT WITH 5% FLY ASH	SHAH SPECIAL CEMENT WITH 10% FLY ASH	SHAH SPECIAL CEMENT WITH 15% FLY ASH
3	16.183	15.183	15.09	14.93
7	21.80	20.23	22.14	21.27
28	27.93	24.56	27.58	25.28

Tensile strength

The mechanical strength of hardened cement is the property of this material, which is the most important parameter for its structural use. The strength of cement is usually determined from the tests on mortars. Several tests were performed to determine the tensile, compressive and shear strength of cement for a certain proportion. Cement mortar of concrete gives a compressive strength of about 10 times its tensile strength [9, 10]. Table 5 shows the tensile strength of mortar with different percentage of flyash. It is clearly shown that the mixing within 5 to 10 percentages gives better and more satisfactory results. It is clearly observed from Table 5 that tensile strength of fly ash concrete decreases for 5% and 15% addition of flyash than the plain concrete after 3, 7 and 28days. But in the case of 105 fly ash, the addition has resulted in strengths almost equal to that of plain concrete both after 7 and 28 days.

Table 5. Effect of flyash on tensile strength of shah special cement with 5%, 10% and 15% fly ash

AGE (DAYS)	STRESS IN MPa			
	SHAH SPECIAL CEMENT	SHAH SPECIAL CEMENT WITH 5% FLY ASH	SHAH SPECIAL CEMENT WITH 10% FLY ASH	SHAH SPECIAL CEMENT WITH 15% FLY ASH
3	2.08	1.49	1.49	1.53
7	2.09	2.09	2.12	2.09
28	2.94	2.61	2.81	2.61

Using above values in computer program for development of relationship between tensile and compressive strength, the resulting equation is:

Compressive strength = 11.3971 × tensile strength $^{0.9775}$

Leachability and toxicity of heavy metals from fly ash

The sequential chemical extraction (SCE) was carried out at six fractions using multiple extractions of the fly ash [11, 12]. The following fractions are identified:

- Water-soluble metal ions.
- Exchangeable 1M $MgCl_2$ at pH 7.
- Carbonate bound (1M Na-OAC at PH 5)
- Fe- Mn bounded (0.04M NH_2OH, HCl in 25% acetic acid)
- Organically bounded (0.02 M nitric acid and 30% H_2O_2 at P^H 2 and 90°C followed by 1.2m ammonium acetate in 10% nitric acid)
- Residual metal ions (HNO_3 and $HClO_4$ acid digestion until dryness)

Table 6 shows the result of leaching test and it clearly shows that there is a possibility of contamination of ground water if it was used in foundation.

Table 6. Different Types of Heavy Metals in the Fly ash

	Zn	Ni	Cu	Fe	Mn	Pb
Water soluble %	0.16 ± 0.003	0.08 ± 0.005	0.07 ± 0.009	0.21 ± 0.007	0.01 ± 0.001	0.50 ± 0.1
Exchangeable	0.98 ± 0.005	0.91 ± 0.004	0.75 ± 0.008	1.52 ± 0.12	2.27 ± 0.11	0.77 ± 0.003
Carbonate bound	3.78 ± 0.21	4.28 ± 0.14	1.47 ± 0.08	0.35 ± 0.003	4.72 ± 0.31	11 ± 0.88
Fe-Mn bound	2.20 ± 0.009	3.59 ± 0.1	0.14 ± 0.001	41.44 ± 1.01	9.77 ± 0.98	4.43 ± 0.12
Organically bound	10 ± 0.16	2.72 ± 0.001	0.55 ± 0.007	40.08 ± 0.91	24.40 ± 0.98	5.60 ± 0.45
Residual	78.23 ± 1.12	90.28 ± 1.03	89.4 ± 0.65	16.80 ± 0.32	58.31 ± 0.12	

According to Ho and Lewis [13], concrete containing flyash showed slow rate of carbonation. Permeability is one of the most critical parameters, which is responsible for durability of concrete. Decrease in the permeability of the concrete results in increase of the resistance of chemical attack. The incorporation of flyash results in smaller crystalline products and finer pores in the hydrated paste interface that results in increase in permeability.

Splitting tensile strength

The effect of flyash content on splitting strength of mortar is listed in Table 7. It can be seen that the splitting tensile strength decreases with increases in flyash content. It is also observed that beyond 5% of flyash, the reduction in splitting tensile strengths is steeper. For splitting tensile strength, ten samples for each combination (0, 5, 10, 15 and 20) were tested. The results obtained were 3.82 ± 0.12MPa; 3.72 ± 0.19MPa; 3.54 ± 0.14MPa; 3.28 ± 0.22MPa and 3.11 ± 0.27MPa for 0, 5, 10, 15 and 20% addition of flyash (by weight) with cement.

Table 7. Effect of flyash content on splitting strength of mortar

FLYASH AMOUNT, % BY WEIGHT	SPLITTING STRENGTH, MPa
0	3.82
5	3.72
10	3.54
15	3.28
20	3.11

Flexural strength

The effect of flyash content on flexural strength of mortar is listed in Table 8. It is observed from Table 8 that flexural strength decreases with increases in the flyash content as in the case of compressive strength. It found that the increases of percentage of flyash have negative impact on the flexural strength. Similar result was reported by Rao [8]. For flexural strength, the average strength varies within ± 0.08MPa.

Table 8. Effect of flyash content on flexural strength of mortar

FLYASH AMOUNT (%)	FLEXURAL STRENGTH MPA
0	1.53
5	1.42
10	1.28
15	1.13
20	0.94

Durability

The durability of flyash based on concrete was determined in terms of loss of weight and strength due to exposure in acid and sulfate solutions in comparison with the control specimen. For durability test, the concrete cubes of 100mm * 100mm × 100 mm were prepared with 0 to 15% replacement of cement. The water/content ratio of 0.55 was considered in this analysis. All the samples were cured in normal water for 28 days and then three specimens of each type were placed in 5% HCl solution, 5% Na_2SO_4 solution and normal water. pH of 7 was maintained throughout the analysis. It is clear from the durability analysis that beyond 10% of flyash content, compressive strength are lower, the presence of silica in flyash of Barapokoria Power Plant may have a complex impact on compressive strength. It is interesting that compressive strength of cement having flyash 5% is more than cement having fly ash of 15%, after 80 days, it may be due to chemical reaction of different constituents within flyash.

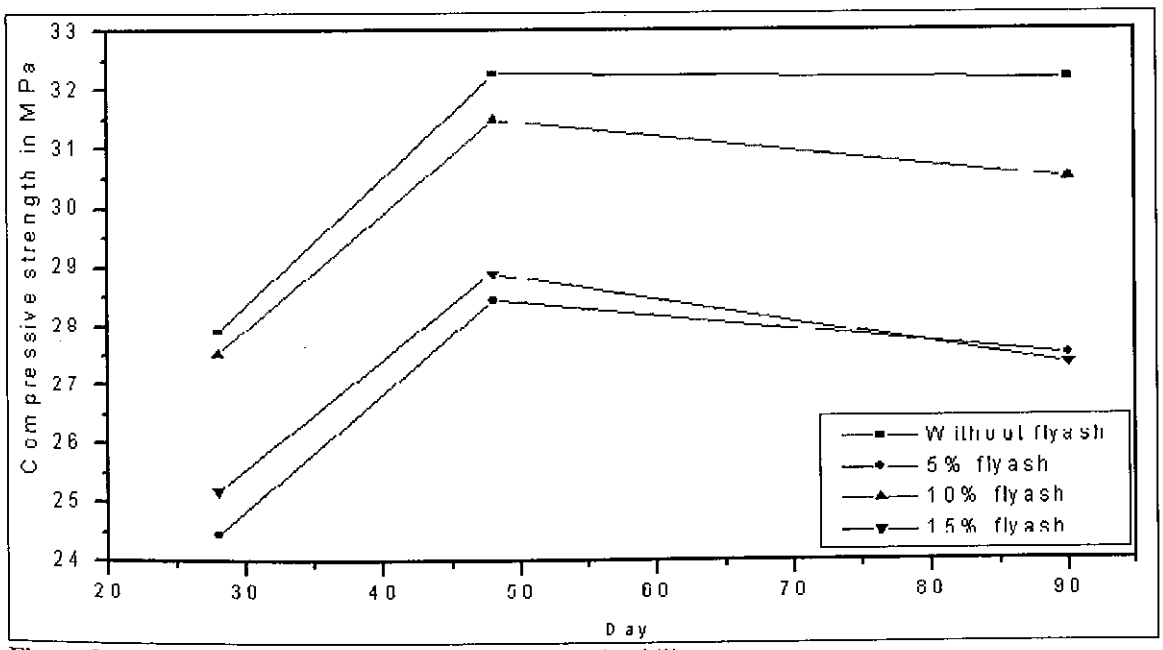

Figure 2. Variation of compressive strength during durability test

CONCLUSIONS

From the study, the following conclusions can be made:

- It can be concluded that power plant waste is suitable for materials in construction work.
- From test result it is observed that 5% - 6% fly ash was successfully blended with ordinary Portland cement without sacrificing strength and durability characteristics.
- Presence of some heavy metals such as (Pb, Ni, Cr etc) in fly ash, restricted it use in footing and under ground work.
- Fly ash is actually a solid waste. So, it has no monetary value. Use of this fly ash as a raw material in Portland cement is an effective means for its management. It can obviously reduce the production cost of cement manufacture.

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