# Utilization of Flue Gas Conditioned Fly Ashes in Cement and Construction Industries

*S. Shanthakumar*[1*], *D. N. Singh*[2] & *R. C. Phadke*[3]
[1]Associate Professor, School of Mechanical and Building Sciences, VIT University, Vellore-632014, Tamil Nadu
[2]Professor, Department of Civil Engineering, IIT Bombay, Mumbai-400076, Maharashtra
[3]General Manager, CHEMITHON Engineers Pvt. Ltd., Mumbai-400104, Maharashtra

**ABSTRACT**

*Fly ash is a waste generated from coal based boilers and has been used in various civil engineering applications. The pozzolanic activity of the fly ash plays a major role in its utilization. The ageing of the electrostatic precipitators (ESPs), variation in coal and ash properties results in higher suspended particulate matter (SPM) emissions. Globally the SPM limits are being reduced, flue gas conditioning (FGC), i.e. dosing of ammonia and sulphur trioxide to the flue gas alters the fly ash properties and increases the collection efficiency of ESPs. There is a concern that due to chemicals dosed in the flue gases, there could be an adverse effect on fly ash and its utilization. This paper presents the investigations on pozzolanic activity (as per ASTM specification) of the conditioned fly ash samples collected from the coal based thermal power stations in India, to conform its suitability for utilization. The pozzolanic activity and strength activity index of ammonia dosed fly ash samples were compared with undosed fly ash samples and found no change in the pozzolanic characteristics. Hence, the conditioned fly ash is suitable for its utilization in cement and other civil engineering applications.*

***Keywords:*** *Suspended particulate matter, Flue gas conditioning, Fly ash characterization, Utilization*

[*]***Author for Correspondence*** Email: sskumariit@gmail.com

## INTRODUCTION

Any developmental activity needs electricity for its sustained growth and more than 70% of which is generated by thermal power stations that utilizes coal as the fuel. In the process, it generates a huge quantity of fly ash and emits very fine dust particles in to the atmosphere. In order to control the emission of suspended particulate matter (SPM) from coal based thermal power stations, flue gas conditioning (FGC), a practice which involves the injection of the chemical agents (viz., sulphur trioxide, sulphuric acid, ammonium sulphate, ammonium bisulphate, sulphamic acid and ammonia for conditioning of flue gas) and water into the flue gas to alter the properties of the fly ash, is employed [1]. This helps in reducing the emission of SPM released into the atmosphere from thermal power stations due to the substantial increase in the efficiency of electrostatic precipitators (ESPs) [2].

Ammonia and Sulphur trioxide are the commonly commercially used FGC agents. Sulphur trioxide helps in reducing the resistivity of the fly ash where as ammonia helps in improving the surface charge and cohesiveness and hence minimizes the re-entrainment of particles [3, 4].

Fly ash has appropriate utilization potential in various engineering applications such as cement, concrete, bricks, backfill/road embankments, wall tiles and glass-ceramic products. Since, fly ash is a cementitious material, its utilization in construction industries depends on its pozzolanic characteristics, which in turn depend on its overall characteristics [5–11].

There is a concern that the presence of dosed chemical additives in fly ash will have adverse effect in utilization and hence, it becomes essential to determine the residual ammonia present in the fly ash. Hence, a study on the influence of flue gas conditioning on pozzolanic activity of fly ashes becomes essential for utilizing it in construction industries. With this in view, fly ash samples from coal based power stations, where flue gas conditioning is being done, were collected and the pozzolanic activity was determined. Based on the investigation, efforts have been made to emphasize the utilization of flue gas conditioned fly ashes in cement and construction industries, by comparing it with ordinary (without conditioning) fly ashes.

## EXPERIMENTAL INVESTIGATIONS

### Materials

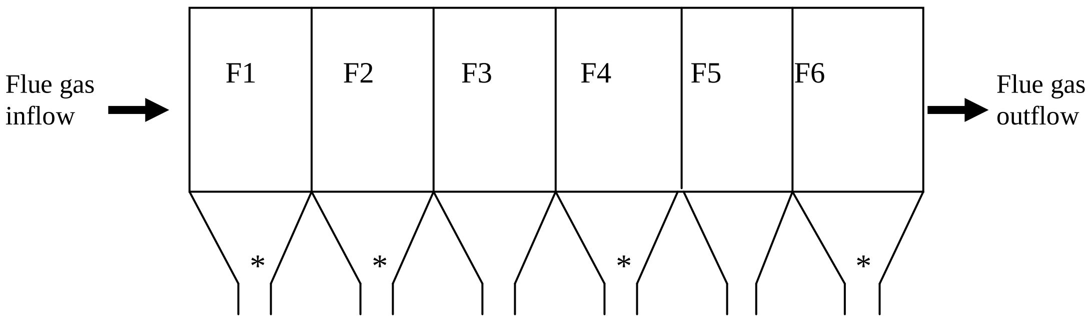
Fly ash samples from two coal based thermal power stations operating with ammonia flue gas conditioning, AFGC, (referred as Site-1 and Site-2, respectively) located at India, were collected for this study. These thermal power stations were operated with (different concentrations of Ammonia) or without flue gas conditioning system, respectively. The samples, depicted as * in Figure 1, correspond to different hoppers in ESP (field wise, depicted as F1 to F6). However, in Site-1, there is no accessibility for sampling in the Fields 3 and 5. In addition to this, samples of the fly ash being used by various construction industries (referred as Site-3), were also collected for this study. Details of the samples along with their designation are presented in Table I. Details of various tests conducted on the sample for its characterizations are presented in the following.

### Determination of Pozzolanic Activity

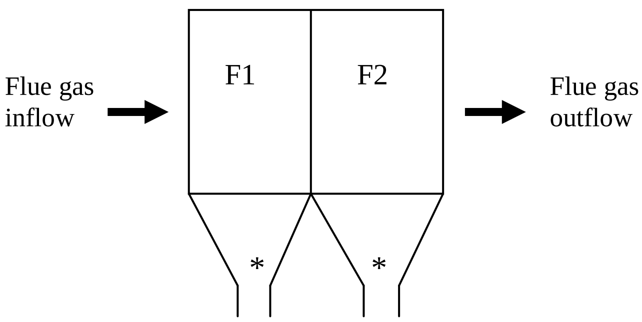
The lime reactivity, LR, of the material can also be determined by employing the concept of pozzolanic activity, PA, (as per ASTM C 311[12]). The fly ash samples (unconditioned and conditioned) from different thermal power stations were analyzed for their pozzolanic activity. The detailed test procedure is presented in the following.

Cubes were cast using the standard mortar (of pure ordinary Portland cement, OPC, 53 Grade), and mixtures of OPC and various conditioned and unconditioned fly ash samples in accordance with ASTM C 109 [13]. The proportions of the mixtures for standard mortar are: one part of cement to 2.75 parts of the standard graded sand. The water to cement ratio, W/C, was kept as 0.485 as per ASTM C 109 [13]. For the mixtures of the OPC and various fly ash samples, four parts of OPC, one part of fly ash and 13.75 parts of the standard graded sand were used. The ratio of water and the combined weight of cement and fly ash were fixed so as to achieve the flow value of 110±5 mm under 10 drops in 6s. These mortars were mixed with the help of a mechanical mixture and were cast to obtain the cubes of 50 mm. These molds were stored for 24 h and later, cubes were taken out of molds and were stored in the saturated lime solution for different curing periods, *T* (7, 28 and 90 days, respectively). These cubes were tested for their crushing strength, which is same as the PA of the material and the strength activity index, SAI,

was computed. The strength activity index is used to determine whether fly ash or natural pozzolan results in an acceptable level of strength development when used with hydraulic cement [12]. The average of these results obtained is reported in Table II. These parameters, for different samples, are plotted against the fields from which they were collected. However, for the sake of brevity, results of samples from Site-2, only, are being presented in Figure 2 and Figure 3, respectively.




Site 1




Site 2

**Fig. 1** Schematic of Sampling Locations in the ESP.

**Table I** Details and Designation of the Fly Ash Samples Used in the Study.

| Sampling station | Capacity (MW) | Dosing | Sample designation | No. of samples |
|---|---|---|---|---|
| Power station 1 (Site-1) | 210 | AFGC (15) | A15F1, F2, F4 & F6 | 4 |
| Power station 2 (Site-2) | 50 | AFGC (4) | A4F1-F2 | 2 |
| | | AFGC (6) | A6F1-F2 | 2 |
| | | AFGC (8) | A8F1-F2 | 2 |
| | | Nil | A0F1-F2 | 2 |
| Construction industry (Site-3) | - | Nil | 1-10 | 10 |

AFGC: Ammonia flue gas conditioning; figure in the parentheses indicates the rate of dosing (in kg/hr); A: Ammonia; F: Field.

**Physical Characterization**

The sample was analyzed for its specific gravity, G, by using an Ultra-Pycnometer (Quantachrome, USA), which employs Helium gas (as per ASTM D 5550-00 [14]) and the specific surface area, S, by using Blaine's air permeability apparatus (as per ASTM C 204-05 [15]). Portland cement was used as the standard reference material and results are presented in Table III.

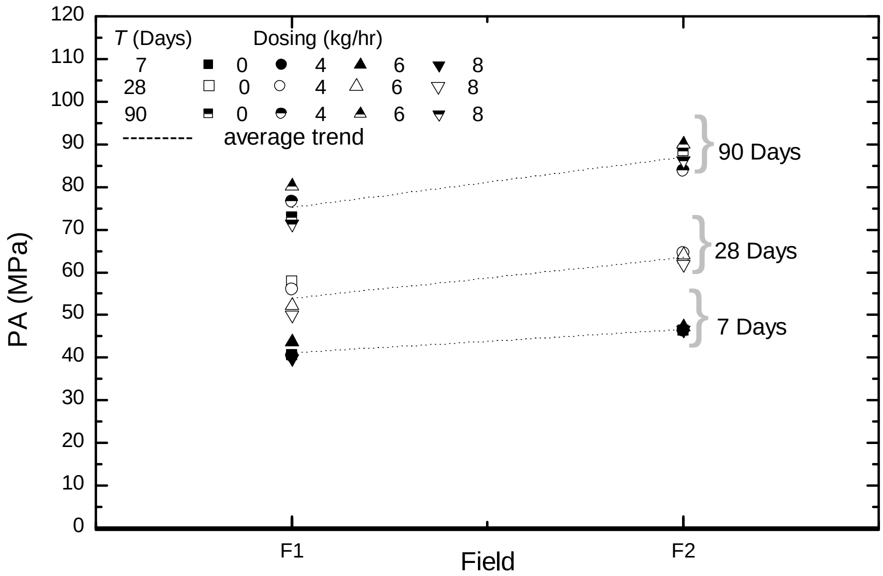



**Fig. 2** Pozzolanic Activity of Fly Ash Samples

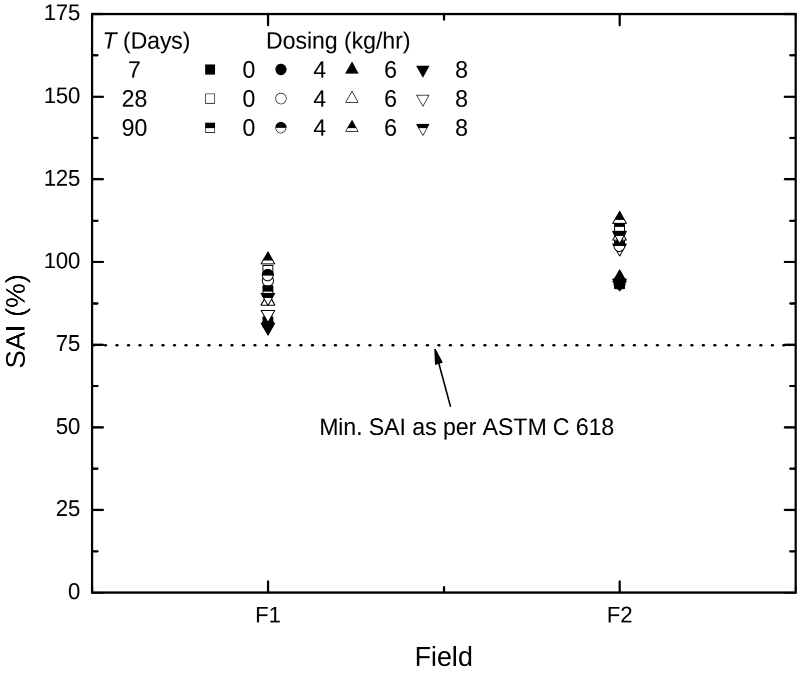



**Fig. 3** Strength Activity Index of Fly Ash Samples

Also, the percentage by weight of the fly ash retained on ASTM sieve No. 325 (45 μm), $R_{45}$, was determined by following the procedure presented by ASTM C 311-05 [12] and results are presented in Table III.

These parameters, for different samples, are plotted against each other. However, for the sake of brevity, results of samples from Site-2, only, are being presented in Figure 4 and Figure 5, respectively.

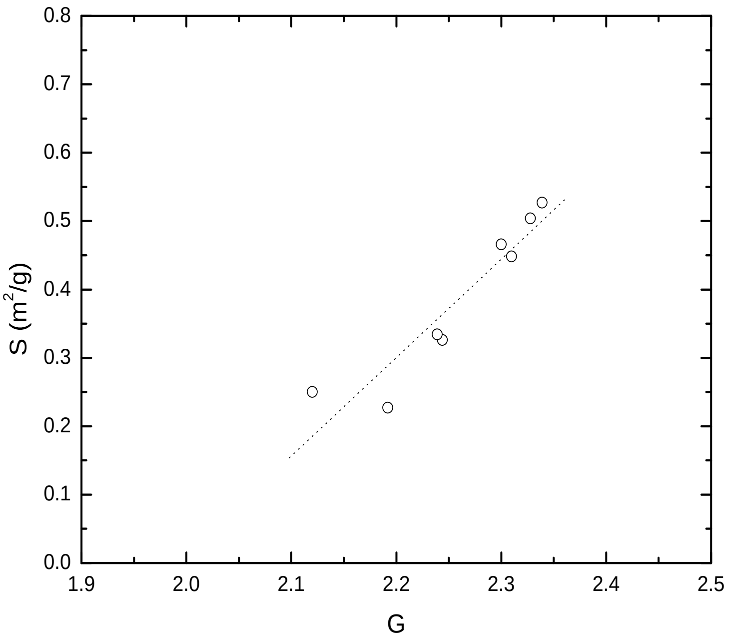



**Fig. 4** The relationship between Specific Gravity and Specific Surface Area of Fly Ashes

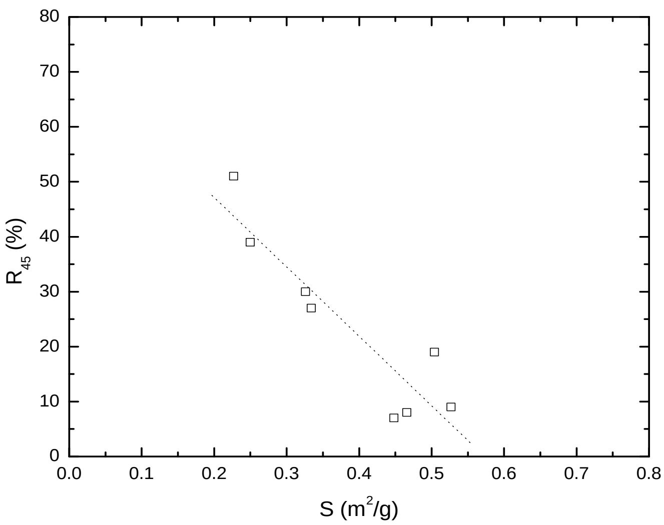



**Fig. 5** The Relationship Between Specific Surface Area and $R_{45}$ of Fly Ashes.

**Table II.** Results of Pozzolanic Activity of Different Fly Ash Samples

| **Sampling location** | **Sample designation** | **W/C** | ***F*** **(mm)** | ***T*** **(Days)** | **PA (MPa)** | **SAI (%)** |
|---|---|---|---|---|---|---|
| - | Standard Mortar | 0.485 | 115 | 7 | 49.7 | - |
| | | | | 28 | 59.8 | - |
| | | | | 90 | 79.7 | - |
| Site-1 | A15F1 | 0.48 | 112 | 7 | 41.5 | 83.4 |
| | | | | 28 | 50.8 | 84.9 |
| | | | | 90 | 75.3 | 94.5 |
| | A15F2 | 0.46 | 112 | 7 | 45.0 | 90.5 |
| | | | | 28 | 52.7 | 88.1 |
| | | | | 90 | 79.1 | 99.3 |
| | A15F4 | 0.42 | 116 | 7 | 47.2 | 95.0 |
| | | | | 28 | 56.9 | 95.1 |
| | | | | 90 | 89.6 | 112.4 |
| | A15F6 | 0.42 | 117 | 7 | 48.1 | 96.8 |
| | | | | 28 | 60.7 | 101.5 |
| | | | | 90 | 93.3 | 117.0 |
| Site-2 | A0F1 | 0.48 | 109 | 7 | 40.7 | 81.8 |
| | | | | 28 | 58.2 | 97.3 |
| | | | | 90 | 72.7 | 91.2 |
| | A0F2 | 0.42 | 113 | 7 | 46.4 | 93.4 |
| | | | | 28 | 63.7 | 106.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | 90 | 88.3 | 110.8 |
| | | | | 7 | 40.4 | 81.3 |
| | A4F1 | 0.48 | 112 | 28 | 56.4 | 94.3 |
| | | | | 90 | 76.5 | 96.0 |
| | | | | 7 | 46.4 | 93.4 |
| | A4F2 | 0.44 | 116 | 28 | 65.0 | 108.7 |
| | | | | 90 | 83.6 | 104.9 |
| | | | | 7 | 43.8 | 88.2 |
| | A6F1 | 0.48 | 114 | 28 | 52.7 | 88.1 |
| | | | | 90 | 80.2 | 100.6 |
| | | | | 7 | 47.3 | 95.3 |
| | A6F2 | 0.42 | 116 | 28 | 64.5 | 107.8 |
| | | | | 90 | 90.0 | 112.9 |
| | | | | 7 | 39.9 | 80.3 |
| | A8F1 | 0.48 | 114 | 28 | 50.4 | 84.2 |
| | | | | 90 | 71.2 | 89.3 |
| | | | | 7 | 46.6 | 93.7 |
| | A8F2 | 0.46 | 111 | 28 | 62.4 | 104.3 |
| | | | | 90 | 86.1 | 108.0 |
| | | | | 7 | 43.9 | 88.4 |
| | 1 | 0.44 | 114 | 28 | 56.4 | 94.3 |
| | | | | 90 | 79.8 | 100.1 |
| | | | | 7 | 51.5 | 103.7 |
| | 2 | 0.43 | 116 | 28 | 60.6 | 101.3 |
| | | | | 90 | 81.8 | 102.6 |
| | | | | 7 | 48.0 | 96.6 |
| | 3 | 0.43 | 111 | 28 | 59.5 | 99.5 |
| Site-3 | | | | 90 | 77.6 | 97.3 |
| | | | | 7 | 44.7 | 90.0 |
| | 4 | 0.45 | 114 | 28 | 57.7 | 96.5 |
| | | | | 90 | 80.2 | 100.6 |
| | | | | 7 | 47.0 | 94.5 |
| | 5 | 0.43 | 112 | 28 | 60.3 | 100.8 |
| | | | | 90 | 81.9 | 102.7 |
| | | | | 7 | 52.1 | 104.7 |
| | 6 | 0.42 | 113 | 28 | 61.9 | 103.5 |

| | | | | | |
|---|---|---|---|---|---|
| | | | 90 | 84.1 | 105.5 |
| | | | 7 | 48.8 | 98.2 |
| 7 | 0.42 | 115 | 28 | 62.4 | 104.3 |
| | | | 90 | 90.6 | 113.7 |
| | | | 7 | 48.0 | 96.6 |
| 8 | 0.43 | 116 | 28 | 61.9 | 103.5 |
| | | | 90 | 89.3 | 112.1 |
| | | | 7 | 52.8 | 106.3 |
| 9 | 0.43 | 116 | 28 | 63.8 | 106.7 |
| | | | 90 | 90.8 | 113.9 |
| | | | 7 | 50.4 | 101.3 |
| 10 | 0.45 | 110 | 28 | 62.3 | 104.1 |
| | | | 90 | 84.0 | 105.4 |

**Mineralogical Characterization**

The sample was evaluated for its mineralogical characteristics by employing X-ray diffraction (XRD) spectrometer (Phillips 2404, Holland) studies, using a graphite monochromator and Cu-Kα radiation. The sample was scanned from 2θ ranging from 5º to 80º. The presence of minerals has been confirmed with the help of the data files presented by the Joint Committee on Powder Diffraction Standards [JCPDS, 1994 (16)]. However, for the sake of brevity, results for sample A15F1, only, is being presented in Figure 6. It can be noted from the figure that the various crystalline phases of minerals present in the fly ash are Quartz, mullite and hematite, among which, Quartz is the major phase. It has also been noticed that there is no difference between the mineralogy of the conditioned and unconditioned ash samples.

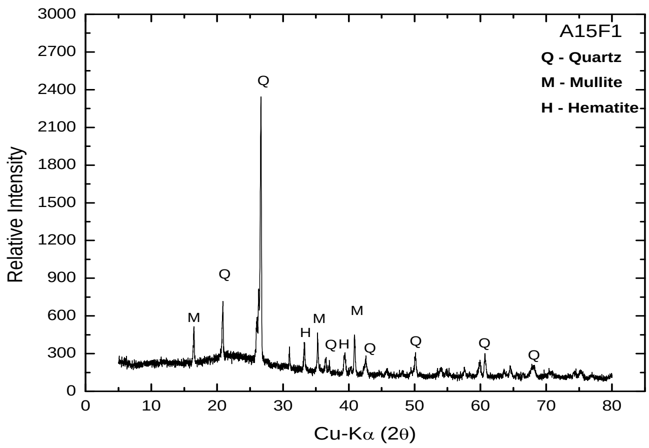



**Fig. 6** A typical X-ray Diffract gram of a Fly Ash Sample

### Chemical Characterization

pH and electrical conductivity (EC) of the sample was measured by using a water quality analyzer (Model PE 136, Elico Ltd., India). Liquid to solid (L/S) ratio of 10 and 20 were achieved by mixing 10 g and 5 g of the oven dried sample, respectively, with 100 ml of the distilled water. This mixture was stirred, continuously, for half an hour and later filtered. This filtrate was used to determine the pH and EC of the solution and the results are presented in Table III. It can be noted from the table that the pH value ranges from 4.9 to 7.0 for the samples collected from the thermal power stations and 5.7 to 10 for the samples collected from the construction industry.

Chemical composition of the sample, in the form of major oxides, was determined using an X-ray Fluorescence (XRF) setup, (Phillips 1410, Holland). Details of the sample preparation [2] are presented in the following.

4 g of fly ash sample, 1 g of microcrystalline cellulose and isopropyl alcohol were mixed thoroughly, and the mixture was kept below an infrared lamp for slow drying. A small aluminum dish (with inner diameter of 33 mm and height of 12 mm) was taken and one third of this dish was filled with methyl-cellulose, followed by filling up the container by the dried sample. The sample was compressed with the help of a hydraulic jack and the chemical composition of the sample was determined by mounting the compressed dish (pellet) in the sample holder of the XRF setup. The results of fly ash samples collected from Site-1 and Site-3 are presented in Table IV.

## RESULTS AND DISCUSSION

The PA versus different collection field was plotted for the conditioned and unconditioned fly ash samples, as depicted in Figure 2. It can be observed from the figure that the pozzolanic activity increases significantly as the curing time increases. However, there is no significant difference between the values of PA for conditioned and unconditioned fly ashes. In addition, the strength activity index, SAI, for different fly ashes were determined as per the guidelines provided in ASTM C 618 [17] and plotted against the collection field, as depicted in Figure 3. It can be noted from the figure that all the fly ashes have attained 75 percent of SAI, which is the minimum requirement as per ASTM C 618 [17]. As such, there is no significant difference between the conditioned and unconditioned fly ashes, as far as their utilization as pozzolanic material is concerned.

Since, there is no significant change in the values of pozzolanic activity of the conditioned and unconditioned fly ashes, the other characteristics such as physico-chemical and mineralogy were carried out for the fly ash samples and the results are discussed in the following.

The relationship between specific gravity and specific surface area was plotted for all the samples. However, for the sake of brevity, the results of the fly ash samples from Site-2 are presented in Figure 4. It can be observed from these figures that S increases as G increase. Incidentally, as depicted in Figure 5, the percent retained on 45μm size sieve (ASTM No. 325) is found to be much more for the samples with minimum S value.

**Table III** Physical and Chemical Characteristics of the Samples Used In the Study.

| Sample designation | G | S ($m^2/g$) | $R_{45}$ (%) | pH | | EC (μS/cm) | |
|---|---|---|---|---|---|---|---|
| | | | | L/S=10 | 20 | 10 | 20 |
| A15F1 | 2.084 | 0.207 | 40 | 5.7 | 5.7 | 118.7 | 71.2 |
| A15F2 | 2.110 | 0.205 | 39 | 6.0 | 6.2 | 123.4 | 72.6 |
| A15F4 | 2.429 | 0.575 | 3 | 5.2 | 5.3 | 615.8 | 329.8 |
| A15F6 | 2.419 | 0.585 | 3 | 4.9 | 5.1 | 677.3 | 353.9 |
| A0F1 | 2.192 | 0.227 | 51 | 7.0 | 7.0 | 106.7 | 62.7 |
| A0F2 | 2.310 | 0.448 | 7 | 6.1 | 6.1 | 253.9 | 145.2 |
| A4F1 | 2.244 | 0.326 | 30 | 5.6 | 5.7 | 146.2 | 79.9 |
| A4F2 | 2.339 | 0.527 | 9 | 5.2 | 5.5 | 459.7 | 234.5 |
| A6F1 | 2.239 | 0.334 | 27 | 6.1 | 6.2 | 164.4 | 95.1 |
| A6F2 | 2.300 | 0.466 | 8 | 5.7 | 5.7 | 481.2 | 251.8 |
| A8F1 | 2.120 | 0.250 | 39 | 5.9 | 6.1 | 139.2 | 79.6 |
| A8F2 | 2.328 | 0.504 | 19 | 5.9 | 5.9 | 348.5 | 193.1 |
| 1 | 2.201 | 0.266 | 14 | 5.7 | 5.9 | 225.3 | 142.7 |
| 2 | 2.336 | 0.348 | 6 | 6.0 | 6.2 | 402.4 | 260.2 |
| 3 | 2.169 | 0.236 | 15 | 10.0 | 9.7 | 320.5 | 212.4 |
| 4 | 2.208 | 0.262 | 20 | 8.2 | 7.5 | 348.2 | 232.1 |
| 5 | 2.175 | 0.267 | 12 | 6.7 | 6.5 | 229.7 | 156.9 |
| 6 | 2.333 | 0.365 | 4 | 7.5 | 7.5 | 305.2 | 182.8 |
| 7 | 2.302 | 0.356 | 2 | 6.5 | 6.7 | 527.7 | 305.8 |
| 8 | 2.264 | 0.365 | 3 | 6.6 | 6.6 | 312.4 | 178.3 |
| 9 | 2.358 | 0.355 | 2 | 7.2 | 7.3 | 430.7 | 249.4 |
| 10 | 2.183 | 0.278 | 8 | 10.0 | 9.6 | 311.9 | 205.6 |

**Table IV** Chemical Composition of the Samples Used in the Study.

| Sample designation | % by weight | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $Al_2O_3$ | CaO | $Fe_2O_3$ | $K_2O$ | MgO | $Na_2O$ | $P_2O_5$ | $SiO_2$ | $SO_3$ | $TiO_2$ |
| A15F1 | 27.37 | 0.48 | 4.57 | 0.93 | 0.33 | 0.01 | 0.31 | 64.14 | 0.03 | 1.67 |
| A15F2 | 27.45 | 0.49 | 4.70 | 0.88 | 0.32 | 0.01 | 0.32 | 64.01 | 0.03 | 1.64 |
| A15F4 | 32.84 | 0.49 | 5.53 | 0.92 | 0.47 | 0.05 | 0.71 | 57.18 | 0.02 | 1.64 |
| A15F6 | 33.70 | 0.45 | 5.07 | 0.93 | 0.46 | 0.05 | 0.72 | 56.77 | 0.03 | 1.66 |
| 1 | 26.34 | 0.81 | 3.49 | 0.83 | 0.34 | 0.07 | 0.53 | 65.63 | 0.01 | 1.73 |
| 2 | 27.86 | 1.54 | 5.34 | 1.18 | 0.81 | 0.11 | 0.27 | 61.05 | 0.11 | 1.53 |
| 3 | 23.56 | 2.40 | 4.41 | 0.97 | 0.68 | 0.14 | 0.23 | 65.80 | 0.03 | 1.52 |
| 4 | 25.31 | 2.08 | 4.41 | 0.74 | 0.60 | 0.09 | 0.27 | 64.78 | 0.01 | 1.48 |
| 5 | 26.80 | 0.97 | 3.65 | 0.86 | 0.46 | 0.03 | 0.51 | 64.87 | 0.01 | 1.65 |
| 6 | 28.88 | 1.75 | 4.38 | 0.87 | 0.60 | 0.14 | 0.42 | 61.24 | 0.05 | 1.46 |
| 7 | 30.10 | 1.24 | 6.04 | 0.94 | 0.64 | 0.04 | 0.46 | 58.64 | 0.06 | 1.63 |
| 8 | 30.11 | 1.14 | 5.92 | 0.88 | 0.61 | 0.03 | 0.51 | 58.93 | 0.03 | 1.65 |
| 9 | 23.70 | 1.79 | 6.71 | 1.00 | 0.79 | 0.07 | 0.31 | 63.68 | 0.07 | 1.68 |
| 10 | 23.03 | 1.83 | 5.96 | 0.95 | 0.56 | 0.03 | 0.30 | 65.48 | 0.04 | 1.62 |

## CONCLUDING REMARKS

This paper presents details of the investigations conducted for utilization of flue gas conditioned fly ashes in cement and construction industries. The pozzolanic activity was determined for the fly ash samples collected from coal based thermal power stations in India where flue gas conditioning is being done. Based on the analysis of the results obtained from the test, it has been demonstrated that there is no significant difference between the conditioned and unconditioned fly ashes, as far as their utilization as pozzolanic material is concerned. In addition, the dosed fly ash samples were analyzed for its physical, chemical and mineralogical characteristics to establish the variation, if any, in either of these properties. It has also been demonstrated that there is no significant change in these properties too.

## REFERENCES

1. Shanthakumar S. et al. *Progress in Energy and Combustion Science* 2008. 34. 685–95p.
2. Shanthakumar S. et al. *Fuel* 2008. 87. 3216–22p.
3. Dalmon J. & Tidy. D. *Atmospheric Environment* 1972. 6. 721–34p.

4. Parker K. R. *Applied electrostatic precipitation* London, UK. Blackie Academic & Professional. 1997.
5. Malhotra V. M. & Ramezanianpour A. A. *Fly ash in concrete* [Ed. 2] Canada Centre for Mineral and Energy Technology. Ontario. Canada. 1994.
6. Joshi R. C. & Lohtia R. P. *Fly ash in concrete: production, properties and uses* Amsterdam, The Netherlands. Gordon and Breach Science Publishers. 1997.
7. Pandian N. S. *Journal of Indian Institute of Science* 2004. 84. 189–216p.
8. Kim B. et al. *Journal of Geotechnical and Geoenvironmental Engineering* 2005. 131(7) 914–24p.
9. Yazici H. *Fuel* 2007. 86. 929–937p.
10. Zhang J. et al. *Journal of Hazardous Materials* 2007. 149. 523–26p.
11. Chandra N. et al. *Waste Management* 2008. 28. 1993–2002p.
12. ASTM C 311. *Standard test method for sampling and testing fly ash or natural pozzolans for use in Portland-cement concrete* Annual Book of ASTM standards, ASTM. West Conshohocken, PA, USA. 2005. 9p.
13. ASTM C 109. *Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens)* Annual Book of ASTM standards, ASTM. West Conshohocken, PA, USA. 2007. 9p.
14. ASTM D 5550. *Standard test method for specific gravity of soil solids by gas Pycnometer* Annual Book of ASTM standards, ASTM. West Conshohocken, PA, USA. 2000. 5p.
15. ASTM C 204. *Standard test method for fineness of Portland cement by air permeability apparatus.* Annual Book of ASTM standards, ASTM. West Conshohocken, PA, USA. 2005. 10p.
16. JCPDS. *Powder Diffraction File.* 7354-CD ROM (PDF 1- 44). International Centre for Diffraction Data, Pennsylvania, USA. 1994.
17. ASTM C 618. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.* Annual Book of ASTM standards, ASTM. West Conshohocken, PA, USA. 2005. 3p.