Study on Suitability of Fly Ash To Be Used as pozzolana in Concrete.

[1]Sameer Vyas,[2]S.N. Sharma, [3]Beena Anand, [4]Rajeev Kumar

[1]Scientist B,[2]Scientist C,[3]Scientist C, [4]Scientist E
[1]Concrete Chemistry Division,
[1]Central Soil and Materials Research Station, New Delhi, India.

Abstract : Fly ash is most commonly used in the manufacturing of Portland Pozzolana Cement (PPC) in concrete applications. Fly ash utilization, especially in concrete, has significant environmental benefits. The use of fly ash in partial replacement of Ordinary Portland Cement (OPC) has many benefits and improves concrete performance in both the fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. The reduction in heat of hydration, reduce permeability, resistance against aggressive environment are few added advantages with fly ash application in concrete. Due to its abundance availability and associated disposal problem, the researcher tried to characterized fly ash for different application in green concreting.

The physical and chemical characteristics of fly ash vary among combustion methods, coal source, and particle shape. Currently, over 20 million metric tons (22 million tons) of fly ash are used annually in a variety of engineering applications. Typical highway engineering applications include: portland cement concrete (PCC), soil and road base stabilization, flowable fills, grouts, structural fill and asphalt filler.

Quality requirements for fly ash vary depending on the intended use. Fly ash quality is affected by fuel characteristics (coal), coal firing of fuels (bituminous and sub-bituminous coals), and various aspects of the combustion and flue gas cleaning/collection processes. The four most relevant characteristics of fly ash for use in concrete are loss on ignition (LOI), fineness, chemical composition and uniformity.

In the present paper , the fly ash from NTPC power plant of India is tested for its suitability to be use as **pozzolana** in concrete applications.

***IndexTerms* – Fly ash, Portland Pozzolana Cement (PPC), Ordinary Portland Cement (OPC), Portland Cement Concrete (PCC), Physical and Chemical characteristics.**

I. INTRODUCTION

Fly ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. The Indian coal is low grade and has high ash content (30-45%) as compared to imported coals (10-15%), so large quantities of fly ash are generated, 217.04 Million tons in 2018-19. The utilization of 78 percent fly ash means nearly 48 million tonnes of the ash had to be dumped.

The large areas are required for their disposal as well as remains a source of environmental pollution . In India an area of 65000 acres of land is being occupied by ash ponds and is its generation is expected to cross 225 million tones by the year 2021 . FA disposal in an unscientific way affects the local ecosystems due to the heavy metal pollution through erosion and leachate generation. Apart from occupying large areas, fly ash, if not managed well, by virtue of its weightlessness can become airborne. Dumped FA contaminates surface and groundwater, soils and vegetation by mobilization of its hazardous metals . In order to reduce the impact of fly ash on the environment and to lower the requirement of land for its disposal, various notifications have been issued by Ministry of Environment and Forest to achieve 100% utilization of fly ash . As far as the mode of utilization was concerned, the CEA’s report indicates that the utilization of fly ash is the highest in the cement sector with 24.04% of the total fly ash used, followed by bricks and tiles at 7.37 per cent. The concrete industry segment has the lowest level of utilization at 0.6 %

Different technologies have been adapted for safe and productive utilization of fly ash and this increased the utilization of fly ash For various reasons including, prevention of environmental pollution, reduction in disposal cost as well as dumping area, replacement of other costly resources and to gain financial returns, fly ash has been used in the form of an alternative to another industrial resource, process, or application [9]. Coal fly ash can be used in the construction industry, structural fill and pavement utilization, soil reclamation, soil ameliorant, an additive in anaerobic digestion and composting, zeolite synthesis, metal recovery, low-cost adsorbent for various gaseous and aqueous applications [10]. Fly ash is most commonly used as a pozzolan in PCC applications. Pozzolans are siliceous or siliceous and aluminous materials, which in a finely divided form and in the presence of water, react with calcium hydroxide at ordinary temperatures to produce cementitious compounds. When portland cement reacts with water, it produces a hydrated calcium silicate (CSH) and lime. The hydrated silicate develops strength and the lime fills the voids. Properly selected fly ash reacts with the lime to form CSH–the same cementing product as in portland cement. This reaction of fly ash with lime in concrete improves strength. Typically, fly ash is added to structural concrete at 15-35 percent by weight of the cement, but up to 70 percent is added for mass concrete used in dams, roller-compacted concrete pavements, and parking areas. Special care must be taken in selecting fly ash to ensure improved properties in concrete. Fly ash is typically finer than portland cement and lime. Fly ash consists of silt-sized particles which are generally spherical, typically ranging in size between 10 and 100 micron . These small glass spheres improve the fluidity and workability of fresh concrete. Fineness is one of the important properties contributing to the pozzolanic reactivity of fly ash.

Environmental benefits. Fly ash utilization, especially in concrete, has significant environmental benefits including:

- Increasing the life of concrete roads and structures by improving concrete durability.

- Net reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to Replace or displace manufactured cement.
- Reduction in amount of coal combustion products that must be disposed in landfills.
- Conservation of other natural resources and materials.

Benefits to Fresh Concrete. Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior. The resulting benefits are as follows:

- **Improved workability.** The spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix, thus providing a lubricant effect. This same effect also improves concrete pumpability by reducing frictional losses during the pumping process and flat work finishability.

- **Decreased water demand.** The replacement of cement by fly ash reduces the water demand for a given slump. When fly ash is used at about 20 percent of the total cementitious, water demand is reduced by approximately 10 percent. Higher fly ash contents will yield higher water reductions. The decreased water demand has little or no effect on drying shrinkage/cracking. Some fly ash is known to reduce drying shrinkage in certain situations.

- **Reduced heat of hydration.** Replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete. This reduction in the heat of hydration does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements.

Benefits to Hardened Concrete. One of the primary benefits of fly ash is its reaction with available lime and alkali in concrete, producing additional cementitious compounds. The following equations illustrate the pozzolanic reaction of fly ash with lime to produce additional calcium silicate hydrate (C-S-H) binder:

(hydration)

Cement Reaction: $C_3S + H \rightarrow C\text{-}S\text{-}H + Ca(OH)_2$

Pozzolanic Reaction: $Ca(OH)_2 + S \rightarrow C\text{-}S\text{-}H$

silica from ash constituents

- **Increased ultimate strength.** The additional binder produced by the fly ash reaction with available lime allows fly ash concrete to continue to gain strength over time. Mixtures designed to produce equivalent strength at early ages (less than 90 days) will ultimately exceed the strength of straight cement concrete mixes (Figure A).

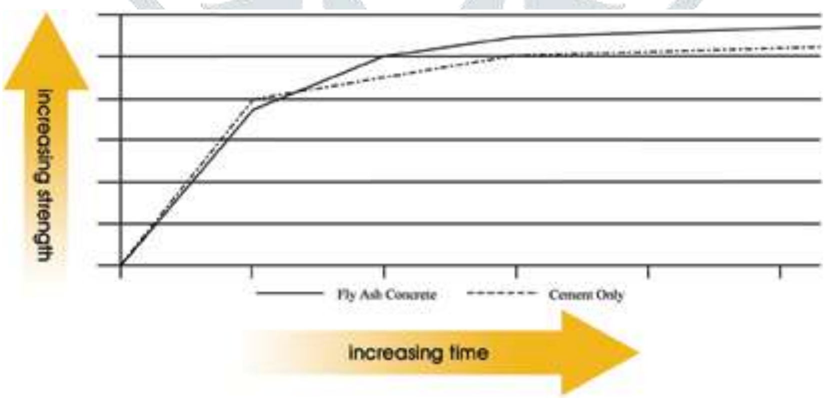

Fig.A. Strength gain with time

- **Reduced permeability.** The decrease in water content combined with the production of additional cementitious compounds reduces the pore interconnectivity of concrete, thus decreasing permeability. The reduced permeability results in improved long-term durability and resistance to various forms of deterioration (Figure B)

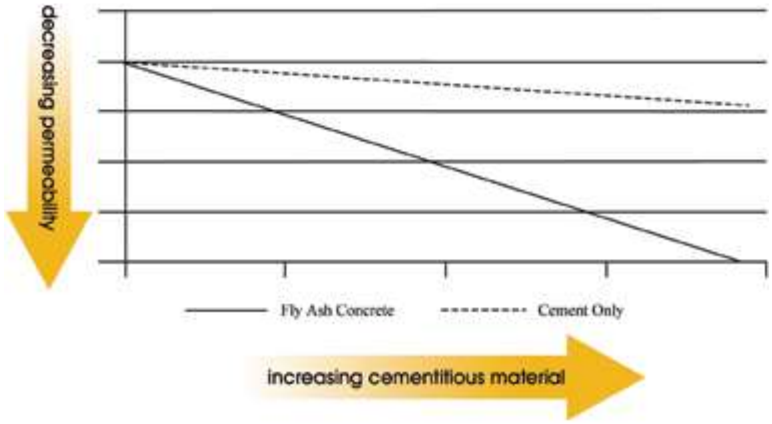

Fig. B. Permeability of fly ash concrete.

- **Improved durability.** The decrease in free lime and the resulting increase in cementitious compounds, combined with the reduction in permeability enhance concrete durability. This affords several benefits:
  - Improved resistance to ASR. Fly ash reacts with available alkali in the concrete, which makes them less available to react with certain silica minerals contained in the aggregates.
  - Improved resistance to sulfate attack. Fly ash induces three phenomena that improve sulfate resistance:
    - Fly ash consumes the free lime making it unavailable to react with sulfate
    - The reduced permeability prevents sulfate penetration into the concrete
    - Replacement of cement reduces the amount of reactive aluminates available
  - Improved resistance to corrosion. The reduction in permeability increases the resistance to corrosion.

Fly ash is used to lower the cost and to improve the performance of PCC. Typically, 15 percent to 30 percent of the portland cement is replaced with fly ash, with even higher percentages used for mass concrete placements. An equivalent or greater weight of fly ash is substituted for the cement removed. The substitution ratio for fly ash to portland cement is typically 1:1 to 1.5:1.

Fly Ash Properties

Fineness. The fineness of fly ash is important because it affects the rate of pozzolanic activity and the workability of the concrete. Specifications require a minimum of 66 percent passing the 0.044 mm (No. 325) sieve.

Specific gravity. Although specific gravity does not directly affect concrete quality, it has value in identifying changes in other fly ash characteristics. It should be checked regularly as a quality control measure, and correlated to other characteristics of fly ash that may be fluctuating.

Chemical composition. The reactive aluminosilicate and calcium aluminosilicate components of fly ash are routinely represented in their oxide nomenclatures such as silicon dioxide, aluminum oxide and calcium oxide. The variability of the chemical composition is checked regularly as a quality control measure. The aluminosilicate components react with calcium hydroxide to produce additional cementitious materials. Fly ashes tend to contribute to concrete strength at a faster rate when these components are present in finer fractions of the fly ash.

Sulfur trioxide content is limited to five percent, as greater amounts have been shown to increase mortar bar expansion.

Available alkalis in most ashes are less than the specification limit of 1.5 percent. Contents greater than this may contribute to alkali-aggregate expansion problems.

Carbon content. LOI is a measurement of unburned carbon remaining in the ash. It can range up to five percent per AASHTO and six percent per ASTM. The unburned carbon can absorb air entraining admixtures (AEAs) and increase water requirements. Also, some of the carbon in fly ash may be encapsulated in glass or otherwise be less active and, therefore, not affect the mix. Conversely, some fly ash with low LOI values may have a type of carbon with a very high surface area, which will increase the AEA dosages. Variations in LOI can contribute to fluctuations in air content and call for more careful field monitoring of entrained air in the concrete. Further, if the fly ash has a very high carbon content, the carbon particles may float to the top during the concrete finishing process and may produce dark-colored surface streaks.

II. EXPERIMENTATION

Materials and Methods

Research has shown that the quality of fly ash produced at NTPC's power stations is extremely good with respect to fineness, low unburnt carbon and has high pozzolanic activity and conforms to the requirements of IS 3812 - 2003-Pulverized Fuel Ash for use as Pozzolana in cement, cement mortar and concrete. The fly ash generated at NTPC stations is ideal for use in the manufacture of cement, concrete, concrete products, cellular concrete products, bricks/blocks/ tiles etc.

In the year 2017-18, NTPC produced 60.31 million tonne of ash from its own operating coal based power stations, out of which 32.24 million tonne (which is about 53.45%) ash was utilized in various areas and the unutilized quantity is being stored in ash ponds in environmentally safe manner.

The present study envisages use of fly ash as pozzolana with ordinary Portland cement for RCC work. The ideas behind such envision earmark dual benefits associated with the use of fly ash viz. (1) technical benefits as well as (2) financial benefits; being fly ash a cost-effective construction material.

Accordingly, the 10 nos. of fly ash samples in two separate lots of 5 nos. each were collected from NTPC, Kahalgaon (Bihar) and from NTPC, Bongaigaon (Assam). The decription of samples are presented in table 1.

Table-1 Details of Samples collected

Sample No.	Sample collected from designated Silo from Thermal Power Plant
1.	Silo No.1 (ESP-1&2)
2.	Silo No.1 (ESP-3&4)
3.	Silo No.5 (ESP-5)
4.	Silo No.6 (ESP-6)
5.	Silo No.7 (ESP-7)
6.	Silo No.6(ESP-6)
7.	Silo No.6 (ESP-6)
8.	Silo No.7 (ESP-7)
9.	Silo No.7 (ESP-7)
10.	Silo No.1 (ESP-1&2)

Fly ash, when tested in accordance with the methods of test specified in IS 1727 & IS 4032, shall conform to the Chemical & Physical requirements given in Table 2 & 3.

Table-2 Chemical Requirements

Sl. No.	Characteristic	Requirements		Method of Test
		Siliceous Fly Ash	Calcareous Fly Ash	
1.	Silicon dioxide (SiO_2) plus Aluminium oxide (Al_2O_3) plus Ironoxide (Fe_2O_3) in percent by mass, Min.	70	50	IS 1727
2.	Silicon dioxide (SiO_2) in percent by mass, Min	35	25	IS 1727
3	Reactive silica in percent by mass, *Min*	20	20	-
4	Magnesium oxide (MgO) in percent by mass, Max	5.0	5.0	IS 1727
5	Total sulphur as sulphur trioxide (SO_3) in percent by mass, Max	3.0	3.0	IS 1727
6	Available alkalis as equivalent sodium oxide (Na_2O) in Percent by mass, Max	1.5	1.5	IS 4032
7.	Total chlorides in percent by mass, Max	0.05	0.05	IS 4032
8.	Loss on ignition in percent by mass, Max	5.0	5.0	IS 1727

Table 3 Physical Requirements

S.No.	Characteristic	Requirements
1.	Fineness — Specific surface in m^2/kg by Blaine's permeability method, *Min*	320
2.	Particles retained on 45 micron IS sieve (wet sieving) in percent[1)], *Max*	34
3.	Lime reactivity — Average compressive strength in N/mm^2, *Min*	4.5
4.	Compressive strength at 28 days in N/mm^2, *Min*	Not less than 80 percent of the strength of corresponding plain cement mortar cubes
5.	Soundness by autoclave test — Expansion of specimen in percent, *Max*	0.8

III. RESULTS AND DISCUSSION

The chemical and physical test results of 10 nos. of fly ash samples of NTPC, Kahalgaon are summarized and tabulated in (Table 4,5 and 6) .

Table: 4- Physical Test Results of fly ash samples of NTPC,Kahalgaon

Sl No	Sample designation	Physical Test Results (As per IS:269:2015)			
		Sp. Gr	**Blaine's Permeability**	**45µ wet Sieve % retained.**	**Lime Reactivity LR Avg. Compressive Strength. N/mm2**
	Limit →		$320 cm^2/gm$	34%	**4.5**
1	Silo No.1 (ESP-1&2)	2.51	3275	31.30	5.85
2	Silo No.1 (ESP-3&4)	2.41	4035	25.97	5.47
3	Silo No.5 (ESP-5)	2.40	3546	32.15	7.17
4	Silo No.6 (ESP-6)	2.49	3596	25.30	5.75
5	Silo No.7 (ESP-7)	2.40	3814	26.60	5.59
6	Silo No.6(ESP-6)	2.08	4132	28.53	4.70
7	Silo No.6 (ESP-6)	2.13	4180	27.53	4.53
8	Silo No.7 (ESP-7)	2.11	3598	33.00	4.65
9	Silo No.7 (ESP-7)	2.15	4188	30.30	4.73
10	Silo No.1 (ESP-1&2)	2.25	3979	26.63	4.82

Table-5 Physical Test Results of fly ash samples of NTPC,Kahalgaon

Sample No	Data from Table 4			% variation from avg. value		
	45µm	BP	LR	45µm	BP	LR
1	31.30	3275	5.85	8.94	-14.59	9.84
2	25.97	4035	5.47	-9.61	5.23	2.70
3	32.15	3546	7.17	11.90	-7.52	34.62
4	25.30	3596	5.75	-11.94	-6.21	7.96
5	26.60	3814	5.59	-7.42	-0.53	4.96
6	28.53	4132	4.70	-0.70	7.76	-11.75
7	27.53	4180	4.53	-4.18	9.02	-14.95
8	33.00	3598	4.65	14.85	-6.16	-12.69
9	30.30	4188	4.73	5.46	9.22	-11.19
10	26.63	3979	4.82	-7.31	3.77	-9.50
Avg. value	**28.73**	**3834.3**	**5.33**	BP=Blaine's Permeability; LR=Lime Reactivity		
+15%	**33.04**	**4409.45**	**6.12**			
-15%	**24.42**	**3259.16**	**4.53**			

Table-6 : Chemical test results of 10 nos. of fly ash samples of NTPC, Kahalgaon

Parameters	**Sample No.**										**Limit as per IS: 3812 (I) 2013**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Loss on Ignition, % by wt.	0.34	0.27	0.22	0.33	0.31	0.31	0.24	0.19	0.26	0.16	5% Max
Silica, SiO_2% by wt.	59.61	60.27	58.57	59.88	60.10	58.45	59.72	60.18	59.41	61.10	35% Min
Reactive Silica, % by wt.	25.84	25.10	23.54	24.39	25.56	24.05	25.24	25.66	25.19	27.05	20% Min
Al as Al_2O_3, % by wt.	26.82	27.24	27.50	27.08	26.17	27.10	26.79	26.10	25.15	27.22	
Fe as Fe_2O_3, % by wt.	5.28	4.88	5.60	5.39	5.15	5.45	5.51	5.09	5.17	5.21	
Magnesium Oxide (as MgO), % by wt.	1.35	1.56	1.21	1.19	1.26	1.16	1.11	1.39	1.26	1.33	5% Max
Total (SO_3), % by wt.	0.35	0.27	0.56	0.17	0.44	0.22	0.19	0.37	0.29	0.23	3% Max
Total alkali (as Na_2O), % by wt.	0.19	0.16	0.12	0.10	0.15	0.13	0.12	0.17	0.15	0.18	1.5% Max
Chloride, % by wt.	0.015	0.012	0.011	0.009	0.010	0.007	0.009	0.013	0.010	0.014	0.05% Max
SiO_2+Al_2O_3+ Fe_2O_3	91.71	92.39	91.67	92.35	91.42	91.00	92.02	91.37	89.73	93.53	70% Min

Test Results and Discussion For The Fly Ash Smaples of NTPC, Kahalgaon (Table 4, 5 & 6)

The findings with respect to Chemical and Physical requirements as per IS: 3812 (Part 1): 2013 are as follows:-

- All 10 nos. of fly ash samples of NTPC, Kahalgaon meet the IS: 3812(Part 1): 2013 specification's provisions in terms of ***Table 2: Chemical Requirements*** and ***Table 3. Physical Requirements*** for the fly ash to be used as Pozzolana.
- All fly ash samples collectively and on individual basis both passed the physical tests and chemical tests criteria as specified in IS: 3812 (Part 1): 2013.

- All the fly ash samples are siliceous in nature possessing pozollanic properties and are derivative of burning of anthracite or bituminous coal.

The fly ash of NTPC, Kahalgaon based on the analysis of 10 numbers of fly ash samples has been found suitable to be used as Pozzolana

Discussion with respect to Uniformity Requirements as per Clause 7.2 of IS: 3812 (Part 1): 2013

For interpretation of test results as per uniformity requirement, a separate data Table 5 has been derived from Table 4 and values obtained in respect of variation in the 45µ (wet sieving), Lime Reactivity, Blaine's Permeability from the averaging of 10 individual results for respective parameters. The findings are as under:

- The 45µm (wet sieving analysis) data obtained in laboratory and % variation from the average of 10 fly ash samples have been recorded in Table 5. Accordingly variations for Blaine's permeability and Lime Reactivity values have been recorded in column 6th and 7th of the same Table.
- A pictorial presentation of variation in 45µm (wet sieving analysis), Lime Reactivity and Blaine's Permeability values is shown in Figure 1 K. It is seen in the figure that the lime reactivity values for sample No.3 is 34.62% which is higher than the prescribed limit of ± 15% needed under uniformity requirement. All other deviations in values in respect of parameters, 45µ (wet sieving), Lime Reactivity, Blaine's Permeability from average values of the 10 fly ash samples are well within the permissible limit of ± 15%.
- Variation in Lime Reactivity values for sample no.3 is at the higher side on individual basis but being actual data it has also been accounted for getting the average of all ten samples. All variation values for individual samples in respect of 45µm (wet sieving analysis); Lime Reactivity and Blaine's Permeability are well within the prescribed limit of ±15% except the Lime Reactivity values of sample No.3.

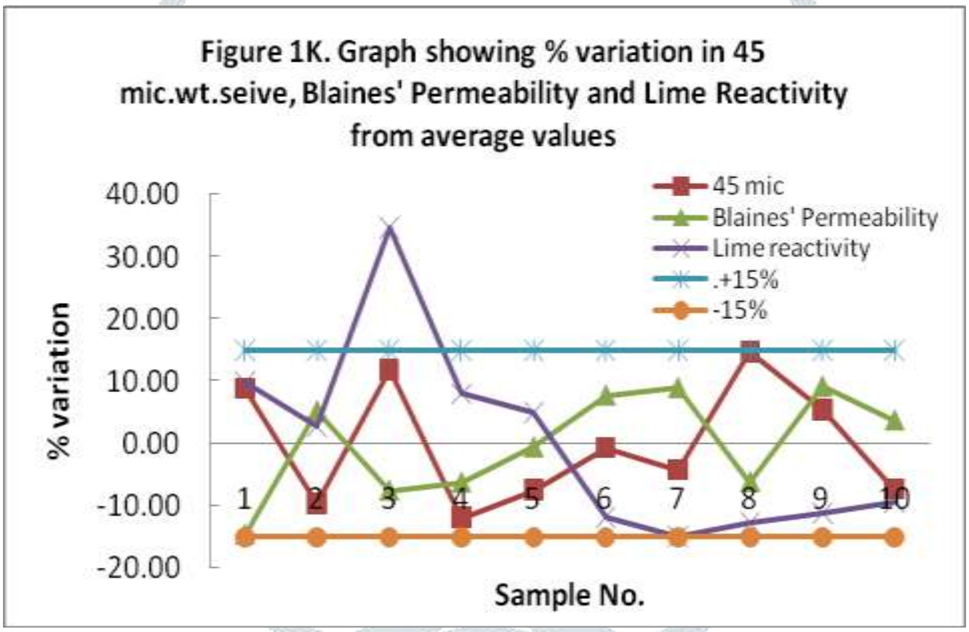

Fig. 1K- % variation in 45µm (wet sieving analysis), Lime Reactivity and Blaine's Permeability from average values.

Accordingly, a pictorial presentation for variation in 45µm (wet sieving analysis) and Lime Reactivity values are shown in Figure 2K. The variations observed are maintaining continuity and uniformity except one LR-value as per the uniformity requirements of IS: 3812 (Part 1):2013.

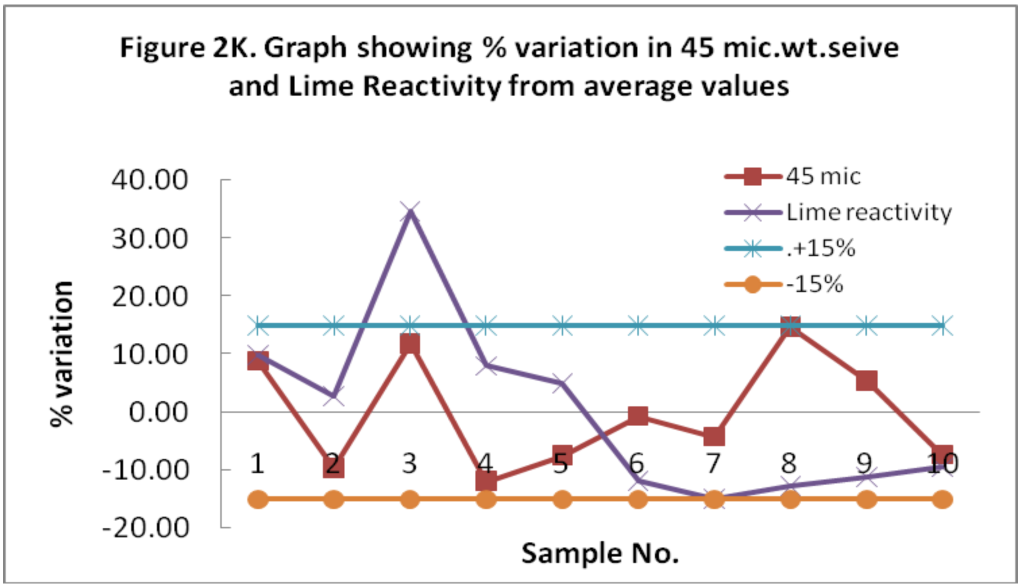

Fig. 2K- % variation in 45µm (wet sieving analysis) and Lime Reactivity values.

IV. CONCLUSIONS

- The test results of 10 nos. of fly ash samples of NTPC, Kahalgaon conform to the codal requirements of IS: 3812 (Part 1): 2013 for the fly ash to be used as pozzolana.
- The fly ash of NTPC, Kahalgaon is suitable for the RCC work.
- The values obtained from the analysis of 10 nos. of fly ash samples in respect of 45µm (wet sieving analysis) and Lime Reactivity establish following acceptable range to fulfil in order to comply with the Uniformity Requirements as presented in table 7.

Table-7 Uniformity Requirements

Determinants	**45µ (wet sieve) % retd.**	**Lime Reactivity Values (N/mm2)**
Avg. value	**28.73**	**5.33**
+15%	**33.04**	**6.12**
-15%	**24.42**	**4.53**
Uniformity Range	**24.42-33.04** (±15% of 28.73)	**4.53-6.12** (±15% of 5.33)

- The ranges arrived at for 45µm (wet sieving analysis) and Lime Reactivity in the above table meets all the requirements of IS: 3812 (Part 1): 2013 established for **chemical and physical test results** and **uniformity requirements**.

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