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PARTICLE SIZE ANALYSIS AS A MEANS TO BETTER UNDERSTAND THE INFLUENCE OF FLY ASH VARIABILITY IN CONCRETE

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ABSTRACT

Fly ash is generated from thermal power stations as an industrial by-product of coal combustion materials. Its particles are generally glassy, spherical in shape, and typically range in size from 0.5-300 µm. Coal fly ash is widely used as a partial cementitious material in concrete, which not only offers economic and environmental benefits but also improves concrete performance. However, variability of the physical description and chemical composition of fly ash has been considered to be a major barrier to its increased use in cement and concrete. In this study the variability and properties of fly ash are characterized with an emphasis on particle size analysis as a means for fly ash producers to better understand material properties in relation to the process of production, classification, and potential modes of utilization. Fly ash samples were collected from different coal-fired power plants from certain Indian and Canadian sources. The particle size analysis results using Laser Diffraction Technique showed a wide variation between the particle size distributions of the studied sources. However, no correlation between the varied size distributions and chemical compositions of fly ash samples was found. Laboratory experiments on the selected fly ash samples are being undertaken to correlate fly ash characteristics and their effects on the performance of concrete mixtures with cementitious replacement level up to 50%.

Keywords: fly ash, fineness, particle size distribution, median size, water requirement

1. INTRODUCTION

This study is part of a collaborative research programme focused on management and wider utilization of coal combustion by-products in India. The electric power industry has been under increasing pressure to reduce the environmental impacts of greenhouse gases (GHG) emissions. The burning of coal to produce electricity has environmental and human health impacts associated with disposal of coal fly ash to existing communities and future generations.

Over the last decade, important changes have occurred in the electricity generation sector in both Canada and India. In 2012, Canada became the first major coal user to ban construction of traditional coal-fired electricity units for clean energy generation. Currently, few coal-fired power stations have remained in operation in western Canada. By 2020, it is projected that 85% of the utility electricity will be generated from non-GHG-emitting resources (e.g., hydro, nuclear and renewables)[1]. In India, the total number of power stations has increased from 138 (2012- 2013) to 145 (2014-2015). Consequently, the fly ash generation has increased from 164.54 MT (2012- 2013) to 184.14 MT (2014-2015), of which 55.5% were utilized[2]. In 2009, the Indian Ministry of Environment and Forests (MoEF)[3] prescribed targets with an aim to achieve 100% utilization in a phased manner. According to the International

Energy Agency, India is expected to add between 600 GW to 1200 GW of new power generation capacity, most of it in the form of coal-fired plants, before 2050.

Fly ash has been used in a wide range of residential, commercial, industrial and infrastructure concrete applications. The typical use of fly ash in concrete is ranges from 10% to 35% by mass of the cementitious material. Engineers and scientists have made significant advancements over the past several decades in the utilization of fly ash with cement replacement levels of 50% or more in the manufacture of concrete. Optimized material mix designs are aimed at producing sustainable, high-performance concrete mixtures that show technical benefits including improved workability and consolidation, reduced heat of hydration, reduced unit cost of concrete, reduced water requirements, improved ultimate strength, decreased permeability, improved aesthetic finishes, and extended service life of concrete structures.

The variability of fly ash has the potential to adversely influence the variability of concrete, thus reducing marketability and limiting commercial viability of promoting increased fly ash utilization. The variations fly ash increase the operational complexity of concrete production and reduce its marketability. For instance, fineness, measured as a residue the 45-um sieve is highly regarded as a “useful key indicator” for assessing fly ash variability and current Canadian and Indian standards limit it to 34%. However, the 45-um sieve residue has been found to range from 5% to 34% between classified fly ashes. Moreover, Indian fly ash is of relatively coarse size and widely variable. The significant modification in latest revision of IS 3812 (Part 1)[5] in 2013 is that it provides a framework within which manufacturers can modify physical properties of noncompliant fly ash using suitable beneficiation technologies to meet material regulatory requirement. Presently, particle size is being improved by either fine grinding or high efficiency cyclone separation technologies. The latter technology has the shortcoming of resulting in disposal of large volumes of by-product coarse fly ash (Chatterjee 2010)[4]. The grinding action appears to breakdown agglomerates and porous particles with little influence on fine glassy spherical particle. All aforementioned parameters have direct impacts on accurate optimization of fly ash performance for use in concrete.

2. RESEARCH SIGNIFICANCE

A better understanding the physical properties of fly ash generated from Indian coal-fired power stations in relation to currently used Canadian sources should help producers and users to increase its utilization in concrete and substantially reduce GHG emissions. Fineness of coal fly ash is considered important as it affects both water requirement and reactivity of concrete mixtures[6]. In North America, fineness is characterized by the percentage of particles retained on a 45 micron sieve (No. 325) while the Indian standard specifies the Blaine air permeability method that estimates specific surface in m²/kg. The corresponding residue on 45 micron IS sieve is an optional test in IS 3812.1.13[5]. However, little effort has focused on investigating the relation between the standardized physical properties of fly ash and particle size distribution. Rather than using a single point, three or multiple points are typically reported by particle scientists to better describe particle size of a material particulate. A better understanding for particle size distribution can provide meaningful parameters for setting appropriate particle size specifications for fly ash to help fly ash producers improve consistency and performance of fly ash for use in cement and concrete. The primary objective of this study is to provide an outline for interpreting particle size distribution analysis of fly ashes having different physical properties.

3. EXPERIMENTAL PROCEDURE

3.1 MATERIALS

The purpose of this study is to evaluate if particle size distribution can be a meaningful mean for improving fly ash consistency and performance in concrete. The fly ash samples were selected broadly to represent the range of coal fly ash typically generated and utilized in Canada and India taking into account several attributes such as geographic locations of thermal power stations, fly ash generation volumes, utilization modes, and sources of variability between fly ashes (type of combustion materials, beneficiation technologies etc.). Thus, representative fly ash samples were collected from eight different power plants as shown in Table 1.

3.2 METHODS

Reported literature pertaining to coal fly ash characterization methods was the basis for the experimental design and testing protocols for this project. The North American and Indian testing protocols and standards including existing prescribed limits for fly ash for use in concrete were critically reviewed.

Table 1: Identification of fly ashes sources used

Fly Ash Code	Type	Thermal Power Station	Community	Origin
Ban.1-T	As collected	Guru Nanak Dev	Banga	India
Ban.2-T	As collected	Guru Gobind Singh	Banga	India
Roo.1-T	As collected	Badarpur	Roorkee	India
Roo.2-T	As collected	Chhotu Ram	Roorkee	India
Alb.1-R	Classified	Sundance	Alberta	Canada
Alb.2-R	Classified	Genesee	Alberta	Canada
Nag.2-R	Classified	Dahanu	Nagpur	India
Nag.3-R	Classified	Mundra	Nagpur	India

T: Target / R: Reference

The fineness by the 45-um (No. 325) sieve and specific surface by air permeability (Blaine), were tested in accordance with ASTM C430[7] and C204[8], respectively. The specific gravity was estimated using gas stereo-pycnometer. The particle size analysis was performed using Laser Scattering Particle Size Distribution Analyzer LA-950, Horiba Instruments[9]. As a complement to the laser technique, fly ash particle morphology and distribution were viewed by scanning electron microscope (SEM)[10]. The chemical compositions were determined using a X-Ray Fluorescence Spectrometer (XRF).

The water requirement and strength activity index of mortars containing 20% of fly ash by mass of cementitious materials were tested as prescribed by ASTM C311[11]. The amount of water required for obtaining constant flow within ±5 of a control mixture using general use portland cement, type GU, conforming to the chemical and physical requirement of CSA A3000[12]was determined.

4. RESULTS AND DISCUSSION

The chemical compositions of classified and as collected fly ash-samples were within the limits specified by their relevant standards. The class limits for the sum oxides (i.e., silicon, aluminium, and iron oxides) of ASTM C 618, IS 3812-Part 1, and calcium oxide of CSA3000-13 were in compliance as shown in Table 2.

The particle size analysis by Laser Scattering Analyser for all fly ashes is presented in Table 3 and Figure 1. The measured median particle sizes vary from 5 to 74 µm. A three-point specification including D10, D50, and D90 particle size values offer appropriate information for presenting the particle size span width of fly ashes. D50 is the diameter that splits the distribution with half above and half below this diameter. The D90 and D10 represent the coarsest and finest parts of the distribution, respectively.

Table 2: Summary of fly ash oxide analyses

ID	Class	Al_2O_3 (%wt)	SiO_2 (%wt)	Fe_2O_3 (%wt)	$SiO_2+Al_2O_3+Fe_2O_3$ (%wt)	CaO (%wt)
Ban.1-T	-	30.32	58.83	4.56	93.71	0.5
Ban.2-T	-	31.06	58.36	4.58	94	0.86
Roo.1-T	-	30.53	56.59	3.79	90.91	0.7
Roo.2-T	-	31.07	55.72	4.5	91.29	1.25
Alb.1-R	F	23.04	55.67	3.17	81.88	9.6
Alb.2-R	F	23.96	51.62	4.408	79.99	9.35
Nag.1-R	F	25.00	57.99	3.49	86.48	1.20
Nag.2-R	F	20.08	50.98	10.21	81.27	4.52
Standard mandatory requirements for fly ash chemical compositions						
CSA-A3001	Type F					15 max
ASTM C 618	Class F				70 min	
IS 3812	Grade I		35 min		70 min	

Table 3: Summary of particle size analysis results

	Minimum Diameter (μm)	Maximum Diameter (μm)	Under Passing Diameter 44.9 μm (%)	Median Size (D50 μm)	Diameter on Cumulative 10% (D10 μm)	Diameter on Cumulative 90% (D90 μm)
Ban.1-T	2.98	394	48	49	9	184
Ban.2-T	4.47	452	29	74	16	200
Roo.1-T	5.12	394	39	62	14	171
Roo.2-T	1.98	394	47	51	7	186
Alb.1-R	1.73	200	69	21	6	106
Alb.2-R	1.32	263	78	17	5	75
Nag.1-R	2.00	229	78	15	6	83
Nag.2-R	1.00	153	95	5	2	18

The results obtained by particle size analysis for all samples were examined under SEM. Figure 2 presents an example of fly ash particle range and the corresponding particle size distribution in Figure 1(a).

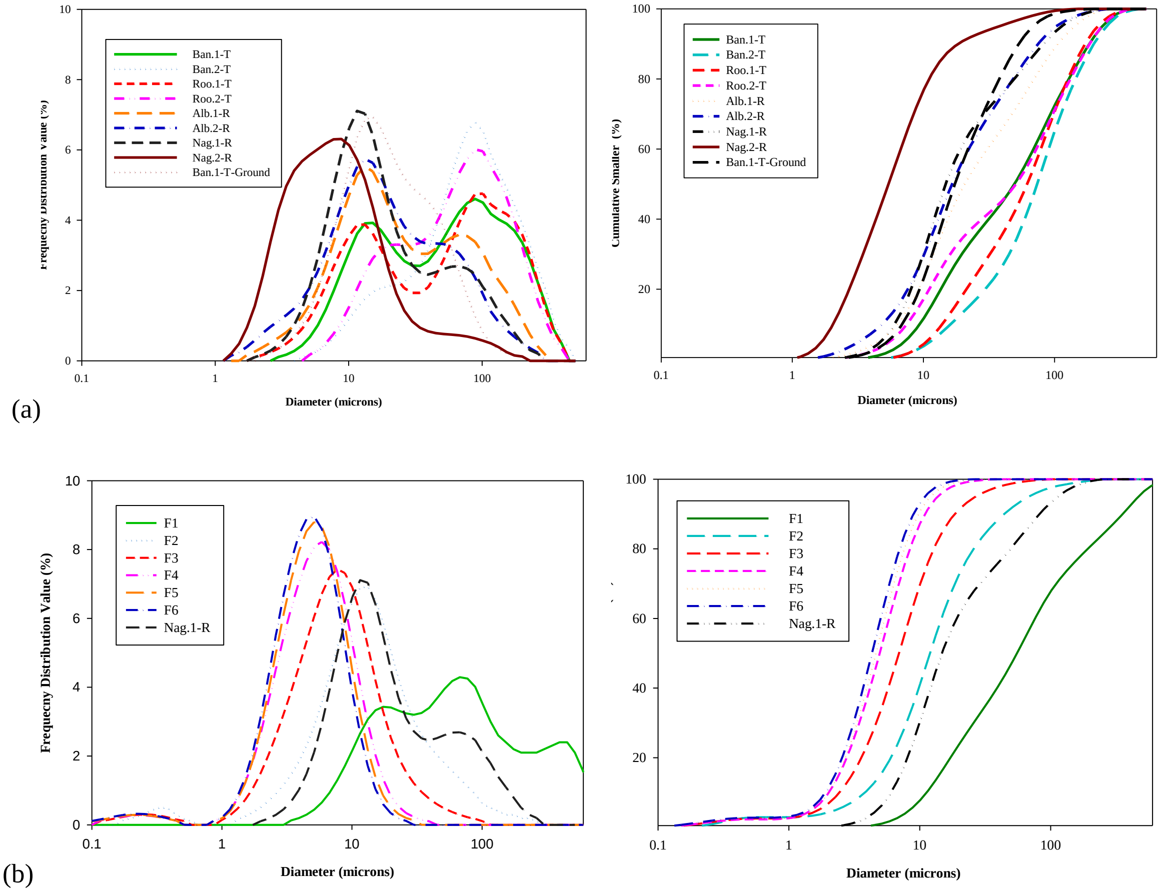


Figure 1: Graphical comparison of particle size distribution analyses (a) Measurements obtained for the studied fly ash sources (b) Measurements obtained for the fields of Nag.1-R coal power station

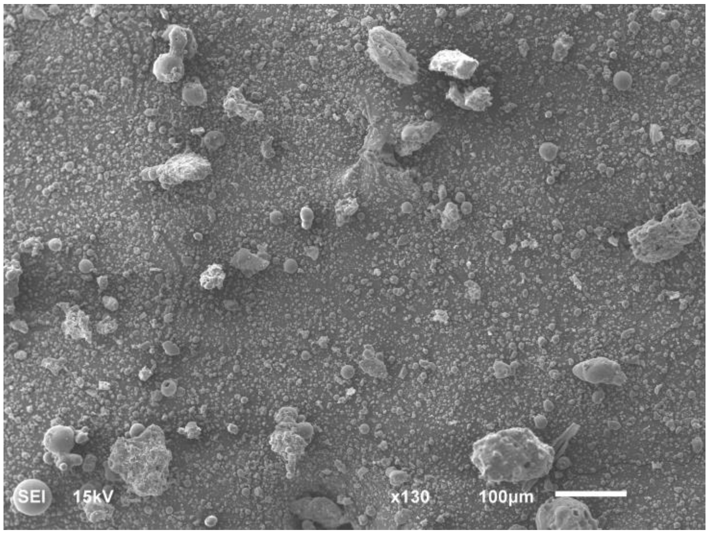


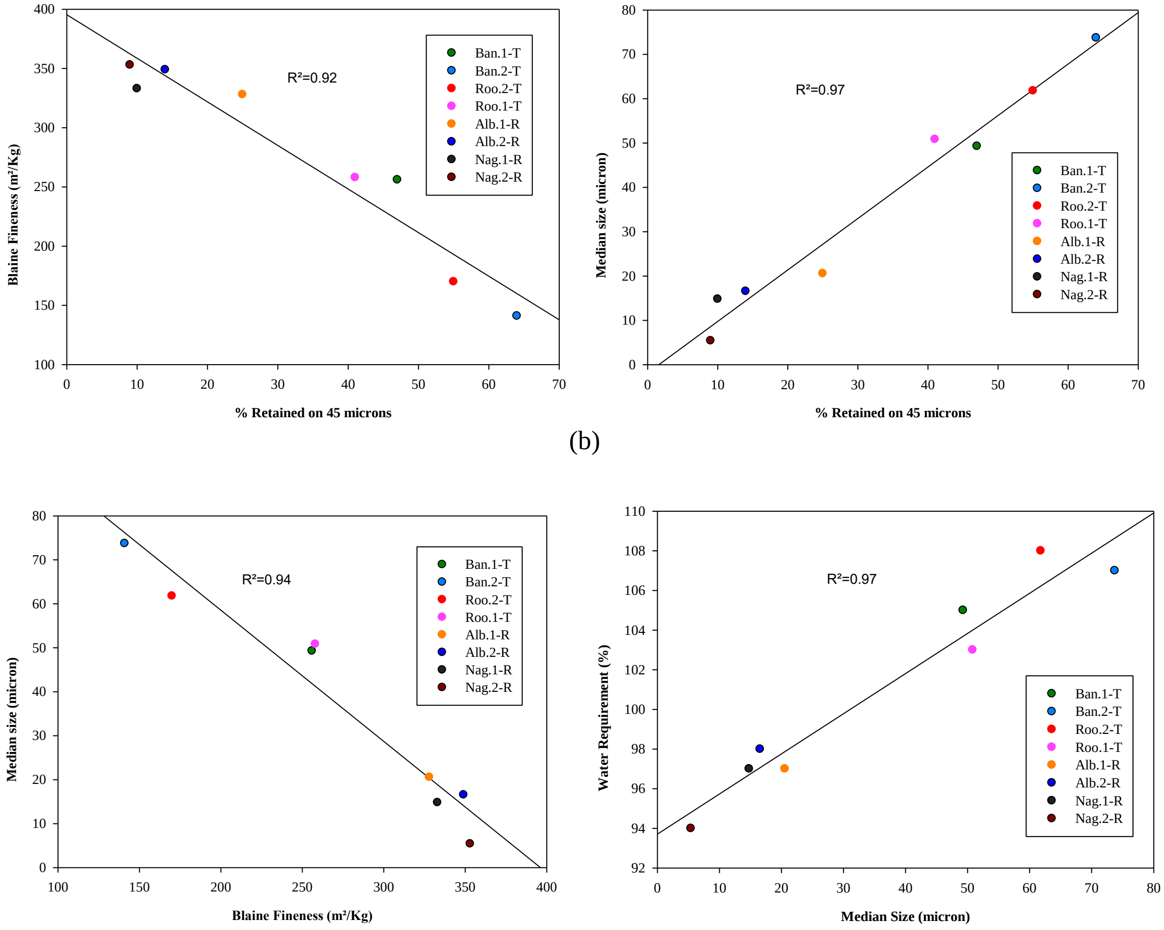
Figure 2: SEM micrograph of Roo.2-T fly ash particle shapes and sizes

The standard physical requirement for fly ash physical properties is presented in Table 4. Figure 3 (a, b, and c) illustrates that the median size D50 correlates well with fineness tests by the 45-um and air permeability (Blaine). The water requirement values to produce equivalent flow of control mixture for all mortars are shown in Figure 3 (d), which were clearly influenced the median size D50. All mortars made with classified fly ash required less water than that of the control mortar (94%-98%). In contrast, mortars with coarse fly ash required water higher than 100% including two samples above 105% which is the limitation specified by ASTM C 618. At the age of 7 days, as collected fly ash mortars had strength activity indices less than 75%, which in the min limit specified by ASTM C 618, while classified fly ash exceeded the limits. However, at the age of 28 days, the strength was improved significantly except for those where the water requirement was above 105%.

Table 4: Summary of standards requirement for fly ash physical properties

ID	Class	Specific surface by air permeability, m²/kg	Median Size by Laser Diffraction µm	Fineness: 45Micron Residue, %	Water requirement of control,%	Strength Activity Index, 7 days, %	Strength Activity Index, 28 days, %
CSA-A3001 Table A.3	Type F	-	-	34 max	-	-	75 min
ASTM C 618 - Table 2	Class F	-	-	34 max	105% max	75 min	75 min
IS 3812 - Table 2	Grade I	320 min	-	34 max ł		-	80 min

ł Optional requirement IS 3812 (Part 1): 2013



(a) (b)

(c) (d)

Figure 3: (a) Blaine fineness vs % Retained on 45 microns (b) Median size vs % Retained on 45 microns (c) Median size vs Blaine fineness (d) Water requirement vs median size

5. CONCLUSION

Using particle size distributions provides a better understanding of the sources of variability between fly ashes in relation to the pro cess of production, classification, and modes of utilization. It also creates a meaningful guideline for setting particle size specifications for fly ash.

In this study, physical properties as key indicators of fly ash performance are compared with the results of particle size distribution analysis using a Laser Scattering Analyzer. Key findings to date include:

1. The median size correlates well with the 45-um sieve residue and Blaine surface area, thus influencing the fly ash performance in hydraulic mortar and concrete (i.e. water requirement).
2. Use of a particle size distribution comprising of three point values D10, D50, and D90 provides a more meaningful characterization of particle size variability between fly ashes.
3. Microscopic examination of fly ash particles is a powerful approach to support the results obtained by particle size analysis.

This work is specifically targeting characterization of fly ash generated from coal-fired power station in the vicinity of specific Indian communities with the intent of promoting increased utilization.

6. ACKNOWLEDGMENT

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