Influence of Particle Size on Leaching characteristic of fly ash

Kumar S.[1*], Singh J.[2] and Mohapatra S.K.[3].

[1, 2, 3] Mechanical Engineering Department, Thapar University Patiala, 147004, India

*corresponding author:

e-mail: satish.kumar@thapar.edu

Abstract. The effect of particle size on the physical, chemical, mineral and rheological properties of coal ash has been studied. In this study, the leaching of heavy metals like, Fe, Ni, Cr, Cu, Pb and Cd from fly ash and its leaching behavior at different pH conditions were studied in order to predict potential environmental pollution. The leaching test of heavy metals from fly ash was investigated in order to predict the environmental effect from the ash disposal on the ground water quality.

Keywords: Physico-chemical properties, Mineral characterization, fly ash, Fly ash.

1. Introduction

Coal is used as a major source of energy from many years in the thermal power plant. About 70% of electricity in India is produced from coal-fired thermal power plants. However, the quality of coal used in Indian coal-fired thermal power plants are very poor contains low calorific value and large ash content (Mishra, 2004; Kumar *et al*. 2013, Kumar *et al*. 2016). The quality of coal ashes mainly depends upon combustion efficiency, coal properties, pulverized coal feed and particle size distribution maintained with suitable quality control etc. (Blissett and Rowson, 2012; Kumar *et al*. 2014). During the disposal of ash from thermal power plant, a large amount of toxic metal elements produces. These toxic elements pose hazardous to the environment as well as human health (Ugurlu, 2004; Ghosh *et al*. 2006; Baba *et al*. 2010). The environmental hazards can be reduces by proper utilization of ash. Presently, fly ash is utilizing in civil engineering applications like road construction, concrete, structural fill, embankment and geotechnical applications (Sharma *et al*. 2012; Nawaz, 2013). In the present work, extensive investigation has been carried out to study the influence of particle size distribution on physical, chemical, mineral, rheological and tracing element characterization of fly ash for their effective utilization.

2. Experimental investigations

Fly ash sample was collected from GGSS Thermal Power Plant, Ropar (India). A number of laboratory scale tests were conducted to analyze the physio-chemical characteristics of fly ash samples. Aimsize (AS-2011) particle size analyzer was used to determine the particle size distribution of fly ash. The specific gravity of ash samples were determined as per IS: 2386 (Part III) with the help of water pycnometer. ASTM D-2434 standard was used to find out the coefficient of permeability by constant head parameter. The water holding capacity of the ash samples were determined with the help of Keen's box method. The gravitational settling method was used to determine the static settled concentration of fly ash slurry that represents the maximum value of its solid concentration. A digital pH meter was used to determine pH value of the fly ash slurry suspension at any given solid concentration. Scanning Electron Microscope (Model: JSM-6510LV, JEOL, The Netherlands) was used to analyze the surface morphology and chemical composition of fly ash. Philips X'pert Diffractometer (Model: PW-1710) was used to analyze mineralogical composition using X-ray diffraction (XRD) technique. The rheological characteristic of fly ash slurry was determined with the help of Rheometer (Model: Rheolab Q-C, APC Ltd., Germany). During the rheology experimentation, the shear rate was varied from 50-300 s^{-1}. The solid concentration of the fly ash was taken in the range of 10 to 60% (by weight). The tracing metal analysis was performed to investigate the harmful environmental effect produced by the fly ash in the ash pond. ASTMD-3987 method was used to analyze the presence of tracing elements from collected fly ash samples. Before the tracing of heavy metal test, fly ash sample dried at 120ºC for 12 hours and then cooled. The liquid-to-solid ratio (L/S) was taken 20:1. The shaking operation was carried out at 100 rpm and 50ºC with Remi orbital shaking for 48 hours. An AAS-4129 (atomic absorption spectrophotometer) was used to analyze the tracing elements by following APHA-1995 standard methods.

3. Result and discussion

a. *Influence of particle size on Physical and chemical characterization*

A mechanical sieve shaker (Manufactured by: Superb Technologies, Ambala, Haryana, India) was used to separate the fly ash particles in the four different ranges namely below 53, 53- 75, 75-106 and 106–150 μm. The four different particle size range of fly ash samples are labeled as F_1, F_2, F_3 and F_4. The particle size distribution of fly ash samples was carried out on Aimsize (AS-2011) particle size analyzer with high accuracy (1 nm). Arithmetic mean diameters (AMD) namely d_{90}, d_{60}, d_{50}, d_{30} and d_{10} were evaluated for different particle size ranges. The values of d_{90}, d_{60}, d_{50}, d_{30} and d_{10} for sample F_1 were

Table 1. Physio-chemical and rheological properties of fly ash

S. No.	Properties	Sample F_1 (<53 μm)	Sample F_2 (53-75 μm)	Sample F_3 (75-106 μm)	Sample F_4 (106-150 μm)
i.	Uniformity coefficient ($C_u = \frac{d_{90}}{d_{10}}$)	1.60	1.22	1.40	1.37
ii.	Curvature coefficient ($C_c = \frac{(d_{30} \times d_{30})}{(d_{60} \times d_{10})}$)	0.91	0.90	1.02	1.05
iii.	Span ($S = \frac{d_{90}-d_{10}}{d_{50}}$)	0.47	0.18	0.34	0.32

found as 40.98, 37.95, 36.35, 28.69 and 23.8 µm respectively. The values of d_{90}, d_{60}, d_{50}, d_{30} and d_{10} for sample F_2 were found as 65.68, 63.04, 60.91, 56.82 and 54.61 µm respectively.The values of d_{90}, d_{60}, d_{50}, d_{30} and d_{10} for sample F_3 were found as 105.34, 91.46, 87.51, 83.96 and 75.24 µm respectively. The values of d_{90}, d_{60}, d_{50}, d_{30} and d_{10} for sample F_4 were found as 146.22, 129.35, 123.75, 120.49 and 106.94 µm respectively. The uniformity coefficient (C_u), curvature coefficient (C_c) and span (S) are calculated from the respective values of particle diameter which is mentioned in Table 1. The value of C_u was found in the range of 1.20- 1.72 (below 6) for samples F_1, F_2, F_3 and F_4. The value of Cc was found as 0.91 and 0.90 (C_u<1) for sample F_1 and F_2 whereas value of C_c for sample F_3 and F_4 was found as 1.02 and 1.05 respectively (C_u >1). The fly ash F_3 and F_4 was considered to be poor graded while value of C_u<6 and C_c>1 (According to ASTM D-2487). So, fly ash particle size range F_3 and F_4 are not suitable for utilization in cementing and stowing applications. The span of a particle size range determines its homogeneity. The value of span was found in between the range of 0.18–0.47 which indicates that all the samples of fly ash distribution are homogeneous. The specific gravity of the fly ash samples were found as 2.24, 2.21, 2.17 and 2.06 for sample F_1, F_2, F_3 and F_4 respectively whereas bulk density were determined as 1.17, 1.15, 1.10 and 1.02 gram/cm^3. The specific gravity and bulk density of fly ash decreases with increase in particle size range. As the particle size increases, gap between the particles gets increased moreover; particle weight per unit volume reduced which tends to decrease the specific gravity and bulk density of fly ash (Nikbin *et al*. 2016). The water holding capacity of the fly ash samples were found as 44.21, 45.67, 48.36 and 52.80% for sample F_1, F_2, F_3 and F_4 respectively whereas value of porosity were determined as 46.70, 47.96, 49.31 and 50.48% respectively. In the regular shaped finer fly ash, reduce the gap between particles and improve uniformity between the particles which control the interconnected pores hence porosity and water holding capacity of fly ash get reduced (Kim *et al*. 2005; Nikbin *et al*. 2016). The initial solid concentration of all ranges of fly ash was taken as 30% (by weight). The final value of settled concentration of fly ash sample F_1, F_2, F_3 and F_4 was found as 63.23, 59.55, 57.68 and 55.84% respectively. It seems that final settled concentration of was decreases with increase in the particle size because coarse irregular shape of fly ash particles settled more rapidly with time as compared to finer shape particles (Kumar *et al*. 2013). The pH value of four different particle size ranges of fly ash samples. The solid concentration of slurry suspension was varied from 10 to 60% (by weight). The pH value of fly ash sample F_1, F_2, F_3 and F_4 varies in the range of 6.10-5.95, 6.30-6.15, 6.55-6.10 and 6.75-6.38 respectively. From the pH value data, it is observed that pH of slurry suspension increases with the increase in particle size. The finer particle of fly ash found more reactive as compared the coarser particle. It can be also inferred that solid concentration of fly ash slurries has negligible effect on pH value (Chandel *et al*. 2009; Kumar *et al*. 2013).

b. Influence of particle size on cenospheres

The scanning electron micrograph (SEM) of different particle size ranges of fly ash sample of F_1, F_2, F_3 and F_4 at magnification of 1000× are shown in Figure 1(a-d). Micrographs data reveal that below 53 µm particle size of fly ash consist of mostly spherical particles. The brighter fly ash particles are identical to 'cenospheres'. As the particle size increased from 53 to 75 µm, the size of cenospheres increases. However, the quantity of cenospheres decreases for particle size above 75 µm. The irregular shaped particles can be seen in Figure 1(c-d). It seems that the large number of irregular shaped particles were present in the range of 106- 150 µm. The regular shaped fine spherical particle (cenospheres) of fly ash provides the low friction which helps improve the flowability and rheology of suspension (Kumar *et al*. 2013).

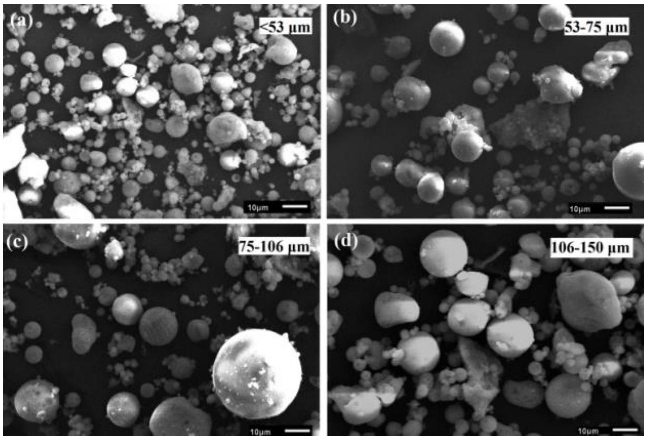

Figure 1. The scanning electron micrograph (SEM) of fly ash sample

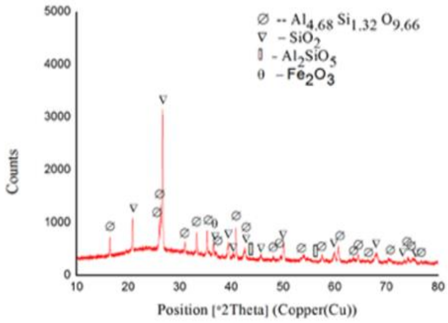

Figure 2. XRD result of fly ash

c. Mineral characterization of fly ash

From the chemical composition of fly ash sample result, it is found that, the proportion of aluminum oxide and silica oxide are more as compared to other elements like iron, potassium, calcium, copper, magnesium, zinc etc. The percentage of aluminum oxide and silica oxide in the fly ash sample was found as 36.73 and 53.63% respectively. It is observed that, the proportion of aluminum oxide and silica oxide are more as compared to other elements like iron, potassium, calcium, magnesium, zinc etc. The percentage of iron, potassium, calcium, magnesium, zinc was determined as 6.34, 0.20, 2.87, 2.02, and 1.05 respectively. This shows that these particles have a high surface enrichment of Al/Si. High surface enrichment of Al/Si indicates that these particles causing drag effects on the flow behavior of the fly ash slurry (Mosa *et al*. 2008). The Loss of ignition (LOI) was performed as per ASTM C-311 standards. The value of LOI in fly ash sample was found as 2.59%. The XRD result of fly ash is shown in Figure 2. It is seems that the major crystalline phases identified in collected fly ash sample are quartz, mullite, hematite and kyanite. The phases of the quartz, mullite, hematite and kyanite in the sample are found as 42.8 %, 51.4 %, 0.2% and 4.9% respectively. Quartz and Mullite are found most commonly phases in the fly sample. The chemical composition of quartz is SiO2 and composition of mullite is $Al_{(4+2x)}Si_{(2-2x)}O_{(10-x)}$ where the value of x varies between 0.17 to 0.59. The peaks in diffractions of fly ash sample indicate quartz as primary mineral. The strongest peak (2θ) of quartz (SiO_2) in the fly ash is found as 26.622°. Similar strongest peak of mullite found as 26.224°.

d. Influence of particle size on rheological characterization

The rheology experiments of fly ash slurry were measured in the solid concentration range of 10 to 50% (by weight). The shear stress - shear rate data for above range of solid concentration were obtained for each ash sample. Finer fly ash of F_1 and F_2 slurry suspension show Newtonian behavior at 30% solid concentration (by weight) beyond this it depicts non Newtonian flow characteristics. Whereas F_3 and F_4 slurry suspension show Newtonian behavior up to 40% solid concentration (by weight) beyond shows non Newtonian flow behavior. The variation of relative viscosity with solid concentration of different range of fly ash sample is shown in Figure 3(a).

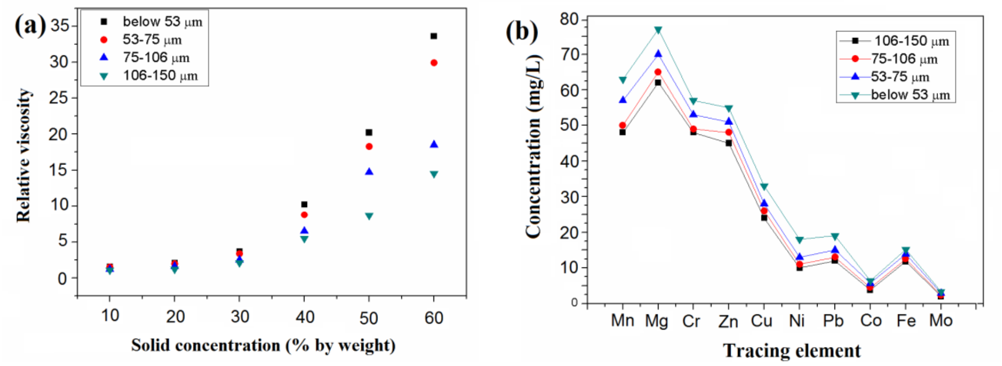

Figure 3. Fly ash **(a)** relative viscosity at different solid concentrations **(b)** Tracing element concentration for different particle size ranges

The rheology data indicated that slurry viscosity of the suspension is a function of solid concentration and particle size. It is seen that at any given solid concentration, the yield stress decreases with increase in particle size and similar trend is seen for relative Bingham viscosity also. The relative viscosity decreases from 10.27 to 2.52 (about 2 times) with increase of particle diameter (d_{50}) from 36.35 to 123.75 µm at solid concentration of 40% (by weight). Similar at solid concentration of 60%, the value of relative viscosity decreases from 33.64 to 14.52 (about 2.5 times) respectively. The increase can be explained on the basis of the fact that as the particle size decreases both the number of particles and their surface area per unit volume of slurry increase rapidly. It is found that surface area of the solids per unit volume of the slurry increases not only with the solid concentrations but also with the decrease in the top particle size (scalping) at a given concentration (Chandel *et al*. 2009; Kumar *et al*. 2013).

e. Influence of particle size on tracing element characterization

The tracing element concentration of different particle size range of fly ash sample F_1, F_2, F_3 and F_4 is shown in Figure 3(b). The tracing elements like Mg, Cr, Zn, Pb, Mn, Fe, Cu, Co, Mo and Ni were determined by ASTMD-3987 method. The (L/S) ratio was taken as 20:1. The heavy metal tracing element have been found as Mg> Mn > Cr > Zn > Cu > Pb > Ni > Fe > Co > Mo in the fly ash sample F_1, F_2, F_3 and F_4 respectively. It is also observed that the leachate concentration of tracing element is increases with decrease in particle size. As the pH value of fly ash decreases with the decrease in particle size The pH value of fly ash sample F_1, F_2, F_3 and F_4 varies in the range of 6.10-5.95, 6.30-6.15, 6.55-6.10 and 6.75-6.38 respectively. Finer particles of fly ash (F_1 and F_2) released more leachate concentration of tracing element due to comparatively lower pH value rather than coarser particles (Kumar *et al*. 2016). In other word, fine particles of fly ash produces more harmful effect as compared to coarser range of fly ash particle. From the leaching result data of fly ash, it seems that tracing element of Mn, Mg, Cr, Zn, Ni, Pb, Fe and Cu are most abundant while Co and Mo is the least abundant element. The tracing elements Co, Ni, Pb and Cu were found under the prescribed limits (IS 10500, 2009). Whereas elements Mn, Mg, Cr, Zn and Fe have crossed the standard limits. Present leaching result data shows good aggregation with the results claimed by researchers (Praharaj *et al*. 2002; Baba *et al*. 2010) on coal ash form power plants. These tracing elements raise serious health problems such as heart attack, liver failure, lung tumor and nervous system damage etc. The toxic metal element leaching concentration can be overwhelmed by adopting high concentration ash disposal system rather than conventional ash disposal system (Georgeakopoulos *et al*. 2002; Nawaz, 2013) and also by using coal of better quality and with control of temperature during combustion.

4. Potential of fly ash utilization

The above result data of physical, chemical, mineral and rheological characteristics of fly ash samples show that the fly as his potential material in various engineering applications. All the bottom ash samples shows the higher value of porosity (Table 1) which leads to more water holding capacity and it can also be used as substitute to soil and gravel for road embankments (Asokana *et al*. 2005; Yin *et al*. 2007). The sum of SiO_2, Al_2O_3 and Fe_2O_3 is more than the 96% of the total chemical composition in all fly ash samples. The loss of ignition (LOI) is less than 5%, confirm as F type of ash according to BS 3892-1(1997). F type fly ash upholds excellent self-hardening capacity (Kowapradit *et al*. 2007). Cement product formed by reaction of hydrate lime or moisture with silica and alumina, which are present in fly ash having fine particulates. Experimental investigations (Soong *et al*. 2002; Jaturapitakkul *et al*. 2003) reported that finer fly ash (F_1 and F_2) can be utilized as raw material for production of blended cement products. Due to higher strength and hydraulic conductivity with lower density than the natural soil, it is used for making light weight synthetic concrete block and artificial aggregates (Asokana *et al*. 2005; Yin *et al*. 2007). Light weight concrete shows high thermal and noise insulation (Asokana *et al*. 2005). Due to advantages of easily lugged, the light weight concrete members utilized as offshore structures (Kurama and Kaya, 2008). Both coarser as well finer fly ash is also suitable for backfilling of excavations, tunnels, sewers, and other underground facilities (Sharma *et al*. 2012; Nawaz, 2013). Cenospheres derived from finer fly ash can be considering as one of the best filler material for polymer matrix composites (Asokana*et al*. 2005). The strength of concrete enhanced with addition in the replacement ratio of fine aggregate fly ash. The fly ash with reasonable proportion of alumina and silica can be utilized as a raw material for synthetic alumino-silicate aggregates for refractory and ceramic applications (Nayak *et al*. 1999).

5. Conclusions

On the basis of present study, it can be concluded that specific gravity and bulk density of all sample increases whereas porosity, water holding capacity and loss of ignition (LOI) decreases after grounding the bottom ash. The presence of high proportion of silica and alumina improves the strength and CaO improves the strength and structural properties which tend the bottom ash bulk utilization in the field of geotechnical, civil engineering, cement materials and stowing etc. The disposal of the bottom ash on the grounded leads higher environmental risk. The tracing elements Mn, Mg, Zn, Cr, Ni, Pb, Fe and Cu are most abundant while Co is the least abundant element in both original and grounded bottom ash. The F type of bottom ash shows very good pozzolanic properties after grounding, which can be commercial utilized as raw material for blended cement products. Potential utilization of bottom ash helps to reduce the transportation cost as well as reduces environmental hazard.

References

Asokana P., Saxena M., Asolekar S.R. (2005), Coal combustion residues: Environmental implications and recycling potentials, *Resources, Conservation and Recycling*, **43**, 239–262.

Ahn J.W., Cho H.C., Han G.C., You G.S., Um N. (2006), Characteristic of Cu and Pb leaching behavior of municipal solid waste incineration bottom ash, *Geosystem Engineering*, **9**, 11-14.

Baba A., Gurdal G., Sengunalp F. (2010), Leaching characteristics of fly ash from fluidized bed combustion thermal power plant: Case study: Çan (Çanakkale-Turkey), *Fuel Processing Technology*, **91**, 1073-1080.

Blissett R., Rowson N. (2012), A review of the multi-component utilization of coal fly ash, *Fuel*, **97**, 1-23.

Chandel S., Singh S. N., Seshadri V. (2009), Deposition characteristics of coal ash slurries at higher concentrations, *Advanced Powder Technology*, **20**, 383-389.

Georgeakopoulos A., Filippidis A., Fournaraki A.K., Iordanidis A., Fernández-Turiel J.L., Liorens J.F., Gimeno, D. (2002), Environmentally important elements in fly ashes and their leachates of the power stations of Greece, *Energy Sources*, **24**, 83–91.

Ghosh C.N., Mondal P.K., Prashant A. (2006), Suitability of fly ash as a stowing material for underground coal mines-some studies, *Proceedings of 1st Asian Mining Congress,* Kolkata, January 16–18.

IS: 10500 (2009), Draft Indian standard drinking water: Specifications, *Bureau of Indian Standards*, New Delhi.

Jaturapitakkul C., Cheerarot R. (2003), Development of bottom ash as pozzolanic material. *Journal of Material and Civil Engineering*, **15**, 48-53.

Kim H.K., Lee H.K. (2011), Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete, *Construction and Building Materials*, **25(2)**, 1115-1122.

Kowapradit S., Pongnak W., Soytong K. (2007), Biological ash from bottom coal ash mixed with beneficial fungi on the growth of rice varpathumthani, *Indian Journal of Agriculture Technology*, **3**, 129−136.

Kurama, H., and Kaya, M. (2008), Usage of coal combustion bottom ash in concrete mixture. *Construction Building Materials*, **22**, 1922–1928.

Kumar S., Mohapatra S.K., Gandhi B.K. (2013), Effect of addition of fly ash and drag reducing on the rheological properties of bottom ash. *International Journal of Mechanical and Materials Engineering*, **8**, 1–8.

Kumar S., Gandhi B.K., Mohapatra S.K. (2014), Performance characteristics of centrifugal slurry pump with multi-sized particulate bottom and fly ash mixtures, *Particulate Science and Technology*, **32**, 466−476.

Kumar S., Singh G., Mohapatra S.K. (2016), An assessment of the physical, mineral, and rheological properties of fly ash for stowing in coal mines, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **38(20)**, 2955-2962.

Mishra U.C. (2004), Environmental impact of coal industry and thermal power plants in India, *Journal of Environmental Radioactive*, **72**, 35−40.

Nawaz I. (2013), Disposal and utilization of fly ash to protect the environment, *International Journal of Innovative Research Science, Engineering and Technology*, 2, 5259-5266.

Nikbin I.M., Rahimi S., Allahyari H. and Damadi M. (2016), A comprehensive analytical study on the mechanical properties of concrete containing waste bottom ash as natural aggregate replacement, *Construction and Building Materials*, **121**, 746-759.

Soong, Y., Schoffstall, M. R., Gray, M. L., Knoer, J. P., Champagne, K. J., Jones, R. J., and Fauth, D. J. 2002. Dry beneficiation of high loss-on-ignition fly ash. *Separation and Purification Technology*, **26**, 177-184.

Sharma A., Kabra S., Katara, S., Rani A. (2015), Variation of surface morphology and physic-chemical properties of the fly ashes through mechanical and thermal activations, *Journal of Advanced Chemical Science*, **2**, 70-74.

Ugurlu A. (2004), Leaching characteristics of fly ash. *Environment Geology*, **46**, 890-895.

Yin C.Y., Kadir S.A., Abdul-Malik A.S., Syed-Ariffin S.N., Mahazer S.Z., Zamzuri Z. (2007), Characterization of ash derived from combustion of paper mill waste sludge: Comparison with municipal solid waste incinerator ash, *Science Asia*, **33**, 473-477.