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Research Paper

MORPHOLOGICAL AND GEOTECHNICAL PROPERTIES OF DADRI FLY ASH

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In a developing country like India, population growth demands expansion of metropolitan cities and urban areas. Thus, increasing infrastructural growth has forced the construction industry to look for cheap and suitable materials for construction. In any given area, it is difficult to obtain a pure and perfectly suitable material for construction purposes. It therefore becomes necessary to utilize the available materials either individually or as a mixture to enhance the geotechnical properties. The present study makes an attempt to find a viable solution to save soil and facilitate en masse use of fly ash in conformation with Fly Ash Mission (1994). Physical and chemical properties of Dadri fly ash were investigated in the laboratory. JEOL JSM-6510 Scanning Electron Microscope (SEM), and Energy Dispersive X-Ray Spectroscopy (EDS) were used for the study. The results show that fly ash particles are mostly spherical. Fly ash was classified as class F and almost cohesion-less material. Maximum dry density, optimum moisture content and shear strength parameters of fly ash exhibit that it can be used as an alternative to soil.

Keywords: Fly ash, SEM, Triaxial Shear Test, Proctor Compaction Test

INTRODUCTION

Coal-fired plants account for 57% of India's installed electricity capacity. The power generation in India has increased from 1,362 MW in 1947 to 2,32,164 MW in 2013, the world's fifth largest. Further, Government of India is planning to enhance the installed capacity to 3,00,000 MW by 2017. As per an estimate of Fly Ash Utilization Program (FAUP), the annual ash generation is expected to reach about 300-400 million tons by 2017 (Haque, 2013). It is estimated that about 1,000 million tons of ash is dumped in ash ponds in India and every year 100 million tons of ash is added to this quantity (Murthy, 1996). As a result of continuous disposal of ash, more than 65,000 hectares of precious land has already been used for storage that could have been used for agriculture or habitation (Das and Yudhbir, 2004). Besides the handling problems

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of huge quantity of ash, there are severe environmental concerns from rising dust from ash ponds to the nearby areas.

Large-scale utilization of fly ash in geotechnical construction like embankments, road sub-bases, and structural landfill, as a replacement to the conventional earth material solves two main problems: elimination of solid waste and provision for needed construction material by conserving the soil (Vittal, 2001). The utilization of fly ash has improved from a meager 3% (one million ton) in 1994 to 27% (22 million tons) in 2003-04. This utilization increased further to 60 million tons per year (46% utilization) in 2006-07 as against a generation of 130 million tons per year (CPCB Annual Report). India utilized 63% of fly-ash during 2009-10, the highest level, and 54.33% in 2011-12 (Central Electricity Authority, 2012). There are several studies that evaluated the geotechnical properties of fly ash (e.g., Raymond, 1961; Sherwood, 1975; Leonard and Bailey, 1982; Toth *et al.*, 1988; Indraratna *et al.*, 1991; Yudhbir and Honjo, 1991; Pandian *et al.*, 1998; Sridharan *et al.*, 1998; Lee *et al.*, 1999; Cocka, 2001; Kaniraj and Gayathri, 2004; Kim and Salgado, 2005; Das and Yudhbir, 2006; Moghal and Sivapullaiah, 2011; and Mir and Sridharan, 2013).

In this paper, the test program included determination of chemical properties, morphological properties (SEM, EDX), grain size distribution, unconfined compressive test, unconsolidated undrained triaxial compression test, falling head permeameter, etc.

MATERIAL CHARACTERISTICS

The fly ash used in the study was brought from National Thermal Power Station situated at Dadri (Ghaziabad), India and has an installed capacity of 800 MW of power generation. The plant produces nearly 39 MN (4,000 metric tons) of fly ash everyday. Fly ash was collected dry, sieved through IS sieve 425 micron and stored in airtight containers in the laboratory.

RESULTS AND DISCUSSION

Chemical Properties

The results of the experiments for the chemical composition are shown in Table 1. Fly ash has more than 70% of Silicon dioxide (SiO_2), Alumina (Al_2O_3) and Iron oxide (Fe_2O_3) and less than 10% of CaO. Therefore, as per ASTM C 618-89, it was classified as class F which is typically derived from bituminous and anthracite coals and consists primarily of an alumino-silicate glass, with quartz, mullite and magnetite.

Particle Morphology and Mineralogy

The morphological characteristics and particle chemistry were evaluated using Scanning Electron Microscope (SEM) attached with Energy Dispersive X-Ray (EDX). SEM ((JEOL Company, JSM-6510) was carried out at the University Sophisticated Instruments Facility (USIF). SEM produces high-resolution images of small particles which cannot be observed by conventional light microscopy. The morphological characteristics of the fly ash, as shown in Figure 1, were taken under the following conditions: accelerating voltage = 15 kV, magnification = 3000, spot size = 40, micron marker = 5, Tilt = 0. Figure 2 were taken at accelerating voltage = 15 kV, magnification = 700, spot size = 17, micron marker = 20, Tilt = 0. It is very clear from the figure that fly ash consists mostly of smoothly spherical particles with varying sizes. EDX of fly ash is shown in Figure 2.

Table 1: Chemical Properties of Dadri Fly Ash

S. No.	Chemical Composition (%)	Value
1.	Silicon dioxide (SiO_2)	59.00
2.	Alumina (Al_2O_3)	29.00
3.	Iron oxide (Fe_2O_3)	6.50
4.	Calcium oxide (CaO)	1.80
5.	Magnesium oxide (MgO)	1.44
6.	Sodium oxide (Na_2O)	0.80
7.	Sulphur trioxide (SO_3)	0.28
8.	Potassium oxide (K_2O)	0.10

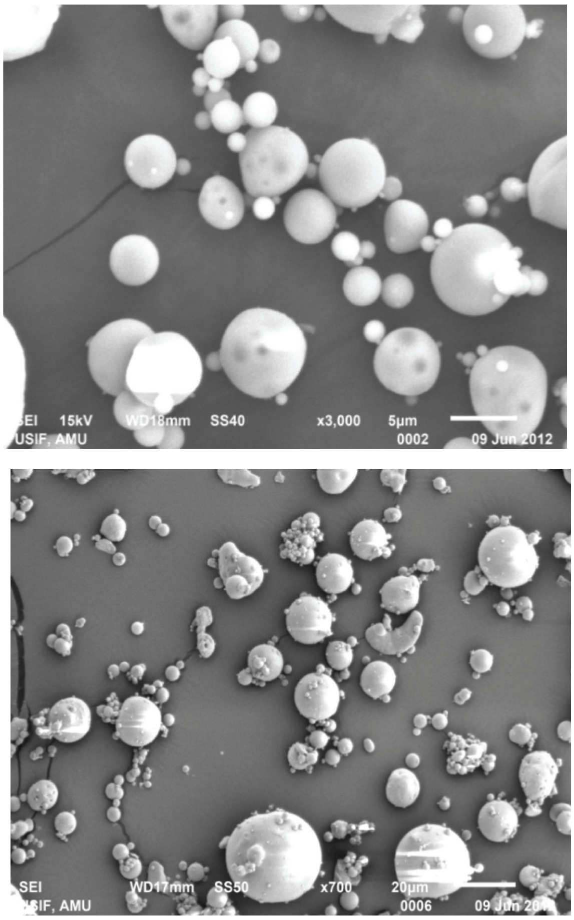


Figure 1: Scanning Electron Microscope (SEM): Fly Ash Particles (a) 3,000x Magnification (b) 700x Magnification

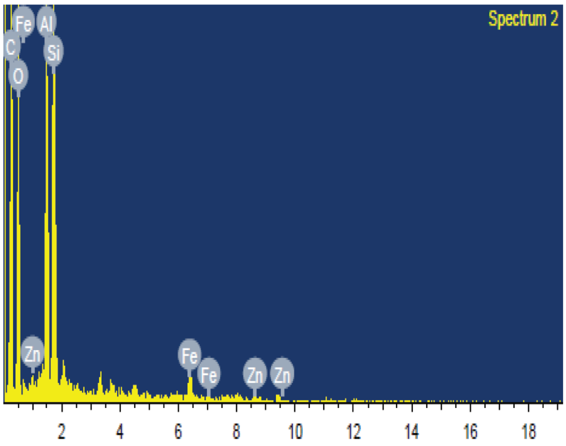


Figure 2: Energy-Dispersive X-Ray Spectroscopy (EDX) of Dadri Fly Ash

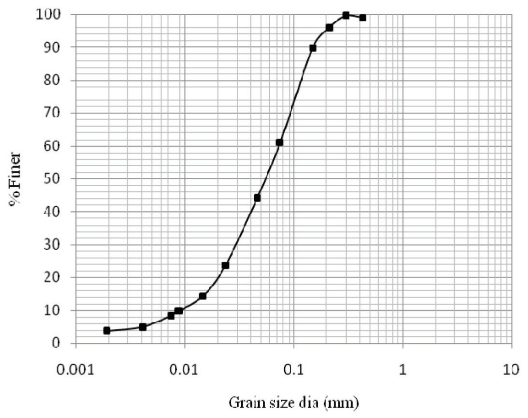
Specific Gravity

The specific gravity of fly ash was determined by density bottle method according to IS: 2720 (Part-III/sec-I) 1980 and the value was found to be 2.19. The specific gravity of Indian fly ash varies between 1.46 and 2.66 (Pandian *et al.*, 1998).

Particles Size Distribution

Sieve analysis (IS: 2720 Part IV 1985) was performed on the fly ash and bentonite having particle size higher than 0.075 mm. Rifling or quartering method took the required quantity of soil sample, dried in oven at 105 °C to 110 °C and was subjected to dry sieve analysis using a set of sieves with sieve openings 0.425, 0.300, 0.212, 0.150 and 0.075 mm and pan. The material retained on each sieve and on the pan were separately collected and weighed. Hydrometer analysis was carried out on the fly ash particles which passed through 0.075 mm IS sieve. 50 gm of the oven dried fly ash passing through 75 µm sieve was taken and placed in an evaporating dish and 100 ml of distilled water and 100 ml of deflocculating agent were added to it. The deflocculating agent was prepared by properly mixing 33 g of sodium hexametaphosphate and 7 g of sodium carbonate in 1000 ml of distilled water. Meniscus correction, temperature correction and deflocculating agent correction were also applied. Particle size distribution curve was plotted as shown in Figure 3. It was found that most of the particles are of silty size. The Uniformity coefficient, C_u and Coefficient of curvature, C_c were calculated as 5.60 and 0.72, respectively.

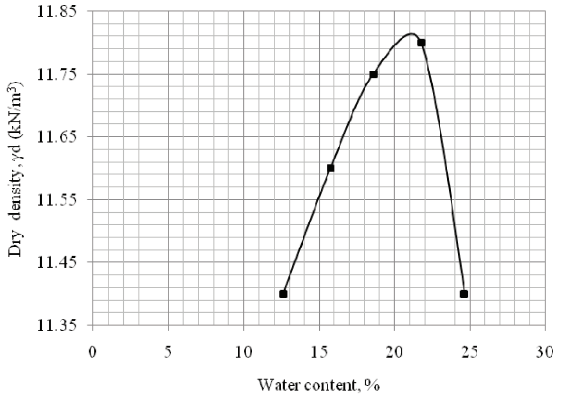
Figure 3: Particle Size Distribution Curve for Plain Fly Ash



Liquid Limit

The liquid limit was determined as per IS: 2720 (Part V)–1985 in the laboratory by the help of standard liquid limit apparatus. About 120 g of fly ash mass passes through 425 IS sieve. A groove was made by groove tool which IS: 9259-1979 designates. One brass cup was raised and allowed to fall on a rubber base. The water content corresponding to 25 blows was taken as liquid limit. Test with different moisture contents was repeated at least three more times for blows between 10 and 40. A semi-log curve was plotted between water content and number of blows as shown in Figure 4. The value of liquid limit was found to be 24%.

Figure 4: Proctor Compaction Curve For Fly Ash



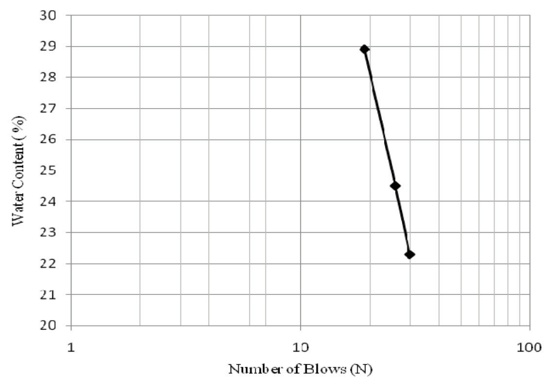
Plastic Limit

Plastic limit of fly ash and bentonite were determined as per IS: 2720 (Part V)–1985. To determine the plastic limit, the soil fly ash, passing through 425 micron sieve, is mixed thoroughly with distilled water until the fly ash mass becomes plastic enough to be easily moulded with fingers. Fly ash sample does not allow making threads of diameter of 3 mm because it is almost non-plastic material so plastic limit was zero.

Proctor Compaction Test

The optimum moisture content and maximum dry density of fly ash was determined by performing the “standard proctor test” as per IS: 2720 (Part VII) 1974. The test consists of compacting fly ash at various water contents in the mould in three equal layers, each being given 25 blows of 2.6 kg dropped rammer from a height of 30 cm. The collar is removed and the excess fly ash is trimmed of to make it level. The dry density γ_d, obtained in a series of determinations shall be plotted against the corresponding moisture content, *w*. A curve was drawn as shown in Figure 5 to find the maximum dry density and the corresponding

Figure 5: Liquid Limit Curve For Fly Ash

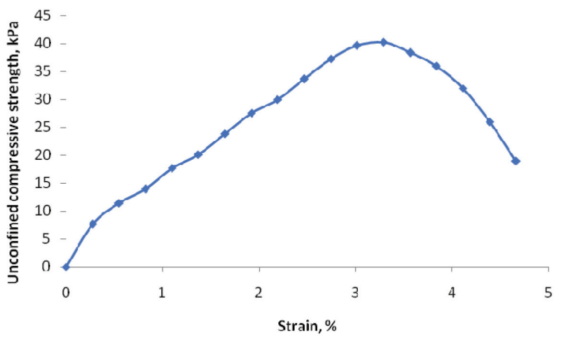


water content (OMC). The values of optimum moisture content, unit weight and maximum dry density of Dadri fly ash were found to be 22%, 14.39 kN/m^3 and 11.8 kN/m^3, respectively.

Unconfined Compressive Strength

A cylinder of fly ash sample without lateral support is tested to failure in simple compression. The compressive load per unit area required to fail the specimen is called unconfined compressive strength of the soil. Fly ash was compacted at optimum moisture content in proctor compaction apparatus. Three undisturbed samples were extruded through samplers and transferred into a split sampler of size 34 mm diameter and 74 mm length by mechanical system. Each sample was mounted on unconfined compression testing machine and the load was applied through proving ring at a constant rate of strain. A dial gauge was fixed to measure the vertical compression of the specimen. Average compressive strength and average strain were taken to plot graph as shown in Figure 6. The value of unconfined compressive strength was found to be 39.23 kPa.

Figure 6: Unconfined Compressive Strength Curve of Fly Ash



Triaxial Compression Test

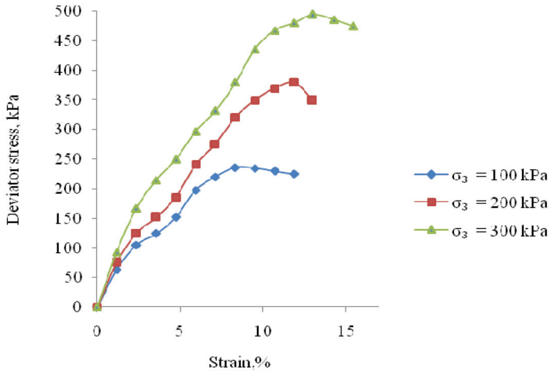
Unconsolidated-Undrained (UU) test was carried out on the fly ash sample in which initial water content of the test specimen was not permitted to change during shearing of the specimen. The shear strength of soil as determined in UU tests correspond to total stress, and is applicable only to situations where little consolidation or drainage can occur during shearing. A triaxial cell in which the sample can be subjected to an all round hydrostatic pressure, together with a vertical compression load acting through a piston was used for tests. The vertical load from the piston acts on a pressure cap. The cell is usually designed with a non-ferrous metal top and base connected by tension rods and with walls formed of Perspex. Air-dried fly ash was compacted on optimum moisture content (22% water content) in proctor compaction apparatus. Three undisturbed samples were extruded through samplers and transferred into a split sampler of size 39 mm diameter and 84 mm length by mechanical system and then were taken out from it carefully as shown in Figure 7. The sample was properly sealed with its end caps and rubber rings in position and

Figure 7: Triaxial Shear Test Specimen before Failure

the sealing rings for the cell were also correctly placed. The sample was placed in the compression machine and vertical load was applied to give a rate of strain of 2% per minute. The samples were subjected to the confining pressures of 100 kPa, 200 kPa and 300 kPa and were studied to obtain the deviator stress and axial strain. The graph, as shown in Figure 8, was plotted between deviator stress and axial strain to evaluate the shear strength parameters. It can be easily observed from the graphs that the samples subjected to 300 kPa sustained greater axial strains and higher deviator stresses than those confined to lower confining pressures of 100 kPa and 200 kPa.

Shear Strength Parameters

Figure 8: Deviator Stress V/S Strain Curves for Fly Ash



Shear strength parameters of Dadri fly ash were evaluated by both theoretical and graphical method. ‘c’ and ‘φ’ values were calculated by solving equations 1, 2 and 3.

$$\sigma_1 = \sigma_3 N^2 + 2cN \quad ...(1)$$

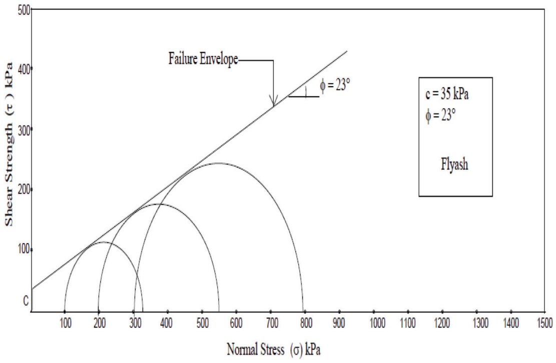
$$\sigma_1 = \sigma_3 N^2 + 2cN \quad ...(2)$$

$$\sigma_1 = \sigma_3 N^2 + 2cN \quad ...(3)$$

where N = tan (45+φ/2)

σ_1 = total stress, the sum of deviator stress and confining pressure. Equations 1, 2 and 3 were used for three different confining pressures. Mohr’s circle was also drawn as shown in Figure 9. ‘c’ and ‘φ’ values were evaluated by drawing failure envelope and

Figure 9: Mohr's Circle for Fly Ash



values were found to be 35 kPa and 23°, respectively by both the methods.

Coefficient of Permeability

The coefficient of permeability was determined by falling head permeameter (IS: 2720-Part 17, 1986). A specimen of length 10 cm and diameter 10 cm was tested to evaluate the coefficient of permeability. The permeability was evaluated at the temperature on the day of testing and was transformed through calculations to evaluate the value of coefficient of permeability at 27 ºC. Three readings were taken for each sample and their mean has been expressed as the value of coefficient of permeability. The value of coefficient of permeability was found to be 9.51×10^{-6} cm/s.

CONCLUSION

A detailed experimental investigation was carried out on fly ash from the Dadri Thermal Power Station. The test program included determination of chemical properties, morphological properties (SEM, EDX), grain size distribution, unconfined compressive test, unconsolidated undrained triaxial compression test, falling head permeameter, etc. The following conclusions were drawn.

1. The Dadri fly ash was classified as class F in accordance with ASTM Specifications.
2. SEM demonstrated that Dadri fly ash consisted mostly spherical particles.
3. The value of specific gravity of Dadri fly ash was found to be 2.19.
4. Dadri fly ash may be equivalent to ML type soil having uniformity coefficient, C_u and coefficient of curvature, C_c as 5.60 and 0.72, respectively.
5. The liquid limit (W_L) and plastic limit (W_P) of Dadri fly ash were found to be 24% and 0%, respectively.
6. Optimum moisture content, unit weight and maximum dry density were found to be 22%, 14.39 kN/m^3 and 11.8 kN/m^3, respectively by conducting proctor compaction test. It shows that fly ash is light weight material so it is easy to handle, compact without large lump masses and less variation in density with changes in moisture content.
7. Unconfined compressive strength of Dadri fly ash was 39 kN/m^2.
8. c and φ values of Dadri were evaluated and found to be 35 kPa and 23°, respectively and shows that Fly ash is almost cohesion-less material.
9. The value of coefficient of permeability was 9.51×10^{-6} cm/s which ensures free and efficient drainage. After rainfall, water gets drained out freely ensuring better workability than soil.

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