Civil Engineering and Urban Planning: An International Journal (CiVEJ) Vol.1,No.1,June 2014

# GEOTECHNICAL CHARACTERIZATION OF TWO LOW LIME INDIAN FLY ASHES AND THEIR POTENTIAL FOR ENHANCED UTILIZATION

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## ABSTRACT

*In India the present availability of fly ash produced from coal based thermal power plants has exceeded 130 million tons and likely to increase in coming years. The utilization of fly ashes needs to be increased to manage this waste stream, which is possible by understanding the geotechnical and geo-environmental behaviour of fly ash. This paper presents the findings of experimental studies with regard to important physical, chemical and geotechnical properties like grain size, specific gravity, mineralogy, morphology, compaction characteristics, unconfined compressive strength, California bearing ratio and hydraulic conductivity of fly ash. Two low lime fly ashes from Badarpur and Dadri thermal power plants, in and around Delhi have been used in the study. A brief account of various methods adopted in characterization is presented here. The importance of these properties in increasing the bulk utilization of fly ashes has also been brought out.*

## KEYWORDS

*Fly ash, Geotechnical, Geo-environmental*

## 1.INTRODUCTION

The increasing demand of power has led to the establishment of number of thermal power stations across the country. In India the current annual production of fly ash is 131 million tonnes during 2010-2011 and is increasing to higher levels [5]. The fly ash is disposed of in ash ponds which currently occupy nearly 65,000 acres of land and will require approximately 10,000 acres of land for its disposal. Occasional failure of such ponds not only affects vast tracts of agricultural land nearby but also pollutes river water even up to 100 kilometers endangering aquatic and human life. For proper utilization of fly ash physical, chemical and geotechnical characterization of fly ash is essential. Variability of material properties arising from different plants, same plant over period of time due to different coal supply [22, 23] further necessitate the need for characterization of fly ash. There are total 7 power stations in NCR, India, three in Delhi, three in Haryana (NCR) and one in UP. The fly ash generation from these plants is nearly 4 million tonnes and approximately 55% of generated fly ash is utilized in various applications [5]. After MoEF notification, 2009 [5], all the thermal power stations were supposed to achieve at least 60% fly ash utilization by 2011. From the above listed plants, only two plants have achieved nearly 60% utilization by the end of 2011 which shows that the fly ash utilization has to increase in many thermal power plants. To increase the utilization of fly ash, the characteristics and mechanical properties of fly ash need to be disseminated. Hence in this study fly ash from Badarpur and Dadri thermal power stations are collected and characterized based on physical, chemical, mineralogical and morphological properties. Also the compaction, unconfined compressive strength behaviour, California bearing ratio and hydraulic conductivity of both the fly ashes is studied. Based on the present study bulk amount of fly ash can be utilized in road construction application. This characterization of fly ash will help the researcher and stakeholders to decide whether stabilization of fly ash is required.

## 2. MATERIALS

Two low-lime fly ashes collected directly from the electrostatic precipitators of the thermal power plants located at Badarpur and Dadri in and around Delhi, India, named BFA and DFA, respectively, have been characterized in the present study.

## 3. PHYSICAL PROPERTIES

### 3.1. Specific gravity and loss of ignition

Specific gravity of fly ash depends considerably upon its iron and carbon content. Presence of iron content increases its specific gravity whereas more carbon content decreases its specific gravity. Specific gravity, *G*, of the fly ashes and lime sludge was determined as per ASTM D854-06 [3] using pycnometer and kerosene and an average value of three tests has been reported. The loss on ignition (*LOI*) was determined using muffle furnace at a temperature of 1000 ± 25° C. The specific gravity of BFA and DFA were 2.2 and 2.3 respectively. In general specific gravity of coal fly ashes lies around 2.0 but can vary to a large extent of 1.6 to 3.1 [13].The range of specific gravity of Indian coal ashes as reported by [20] is 1.46 to 2.66. The reason for a low specific gravity is due to the presence of a large number of hollow cenospheres from which the entrapped air cannot be removed, or the variation in the chemical composition, in particular the iron content, or both [15]. The variation of specific gravity of the coal ash is the result of a combination of many factors such as gradation, particle shape and chemical composition. The *LOI* was found to be as 3.76 and 0.4 for BFA and DFA respectively. The loss on ignition (*LOI*) indicating the unburned carbon is very less for Dadri fly ash than Badarpur fly ash. The maximum limit for LOI specified by ASTM C 618 [1] for class F fly ash is generally 6% and can be up to 12 %.

Table 1: Physical properties of Badarpur and Dadri fly ash

| Property | BFA | DFA |
|---|---|---|
| Color | Grey | Grey |
| Specific gravity, G | 2.2 | 2.3 |
| Loss on ignition, % | 3.76 | 0.24 |

### 3.2. Specific surface area

The surface area of particles is important because it controls the total adsorption capacity to some extent. The surface areas of fly ash particles generally vary inversely with the particle size (i.e., the smaller the particle, the larger the surface area). The specific surface area was determined by Blains air permeability test. The specific surface areas of BFA and DFA were found to be 3800cm$^2$/g and 3520 cm$^2$/g, respectively.

### 3.3. Particle size distribution

The dry and wet analysis was performed by sieve and hydrometer test respectively as per Indian standard IS 2720 procedure to determine the grain size of Badarpur fly ash and Dadri fly ash. The particle-size distribution curves of BFA and DFA are presented in Fig. 1. It is observed that DFA has greater finer particle content than BFA.

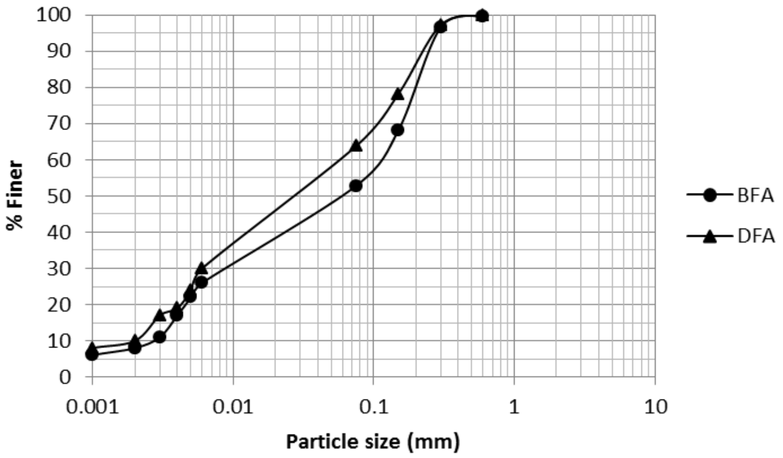


Figure 1: Particle size distribution curve of BFA and DFA

### 3.4. Atterberg's Limits

The properties such as liquid limit, plastic limit, and plasticity index are most commonly used in the geotechnical engineering field. These characteristics are not only important in classification and identification but also in predicting engineering behaviours such as strength, hydraulic conductivity, and compressibility. Liquid limit test in the present study was performed by the cone penetration method (British standards) because of its simplicity and reproducibility of test results. Liquid limit values of BFA and DFA were observed to be 39% and 30.5%, respectively. Since the fly ashes are non-plastic in nature, plastic limit and plasticity index values do not arise for them.

## 4. CHEMICAL PROPERTIES

### 4.1 Chemical composition

Chemical composition of fly ashes generally depends on the origin of the coal used in the thermal power stations. The chemical composition of fly ashes was determined using the facilities available at the Central Soil and Materials Research Station at New Delhi. It was determined by X-ray fluorescence spectrometry and atomic absorption spectrophotometry as per the standards and is presented in Table 1. The chemical compositions of both fly ashes and expressed in percentages with respect to the weight of fly ash. Like other fly ashes, these fly ashes also contain large amounts of silica and alumina and small quantities of $Fe_2O_3$, CaO, $TiO_2$ and $K_2O$. The sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ approximated to 96% and 97% for BFA and DFA respectively, which is greater than the 70% recommended by the ASTM C 618 standard for pozzolans.

Table 2: Chemical composition of fly ashes

| Element | BFA (%) | DFA (%) | Remark |
|---|---|---|---|
| Silica ($SiO_2$) | 57.9 | 60.03 | |
| Alumina ($Al_2O_3$) | 31.78 | 29.78 | |
| Ferric ($Fe_2O_3$) | 4.2 | 6.69 | |
| $SiO_2 + Al_2O_3 + Fe_2O_3$ | 96 | 97 | 70 (Minimum) |
| Titanium ($TiO_2$) | 0.81 | 0.81 | |
| Manganese (MnO) | 0.32 | 0.31 | |
| Magnesium (MgO) | 0.51 | 0.54 | |
| Calcium (CaO) | 0.87 | 0.99 | |
| Potassium ($K_2O$) | 0.28 | 0.120 | |
| Sodium ($Na_2O$) | 0.15 | 0.076 | |
| Phosphorus ($P_2O_5$) | 0.44 | 0.4 | |
| Sulphur ($SO_3$) | 0.075 | 0.075 | 6 (Maximum) |

## 4.2 X-ray Diffractograms

The presence of different phases in fly ashes necessitates thorough X-ray diagnosis. It is known that different phases of fly ashes yield different diffraction patterns. This makes X-ray diffraction a powerful tool for the study. In the present investigation, XRD was carried out using Bruker AXS (Bruker AXS GmbH, Germany) with (Cu - kα radiation, 40kV, 30 mA). The specimens were scanned from 2θ = 10° to 70°. The database of the 2000 JCPDS-International Centre for Diffraction Data was used to identify the mineralogical phases. The crystalline phases present were identified from the peaks in the pattern. XRD pattern showed the presence of crystalline phases quartz ($SiO_2$), hematite ($Fe_2O_3$), mullite (aluminum silicate), melilite (calcium magnesium aluminum silicate) in BFA and DFA as in figure 2(a) and 2(b) respectively.

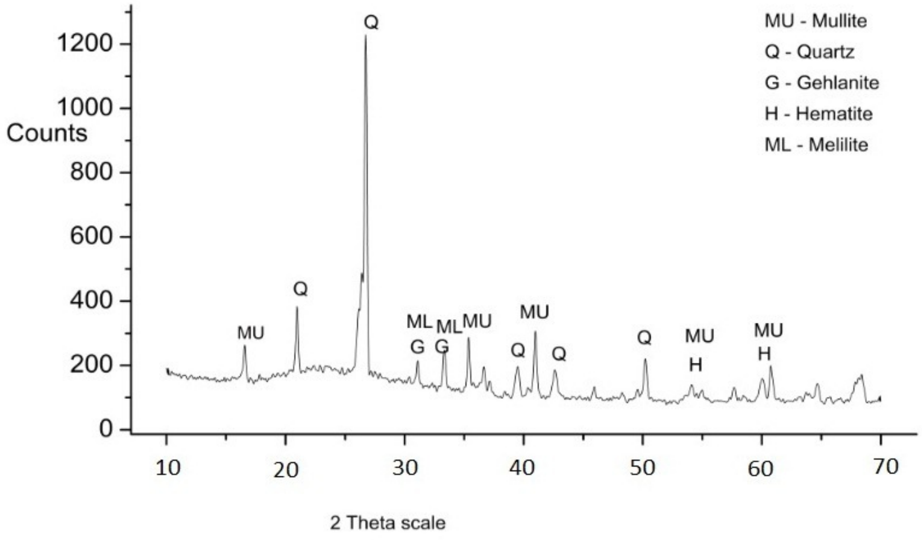


Figure 2 (a): X-ray diffraction pattern of Badarpur fly ash

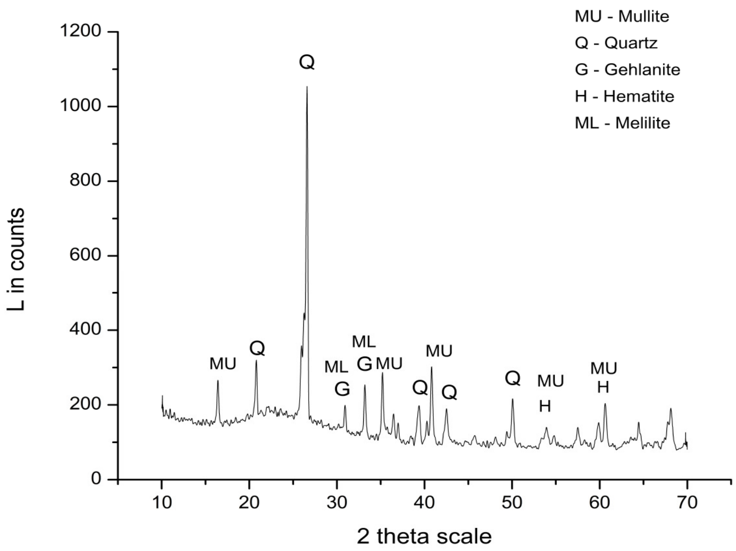
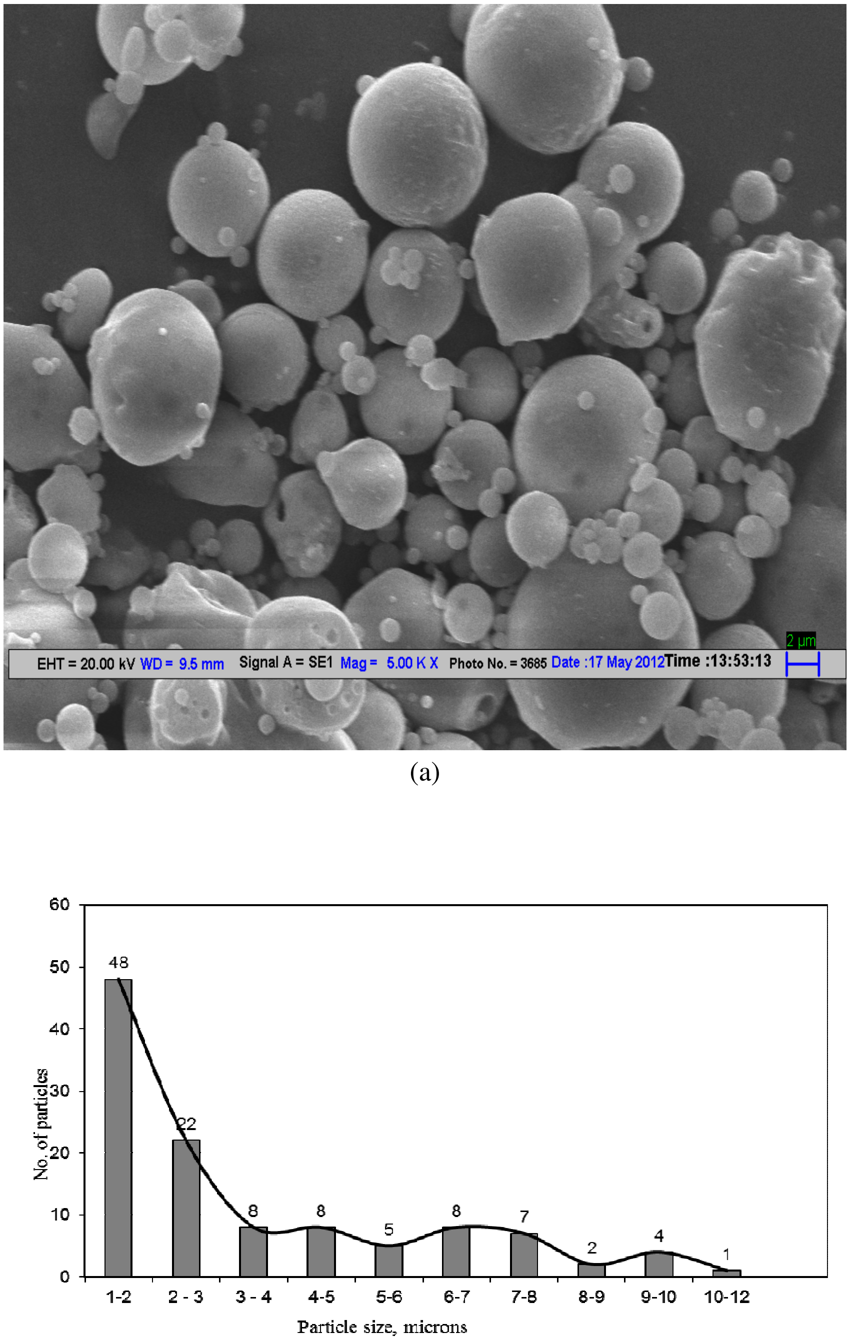


Figure 2 (b): X-ray diffraction pattern of Dadri fly ash

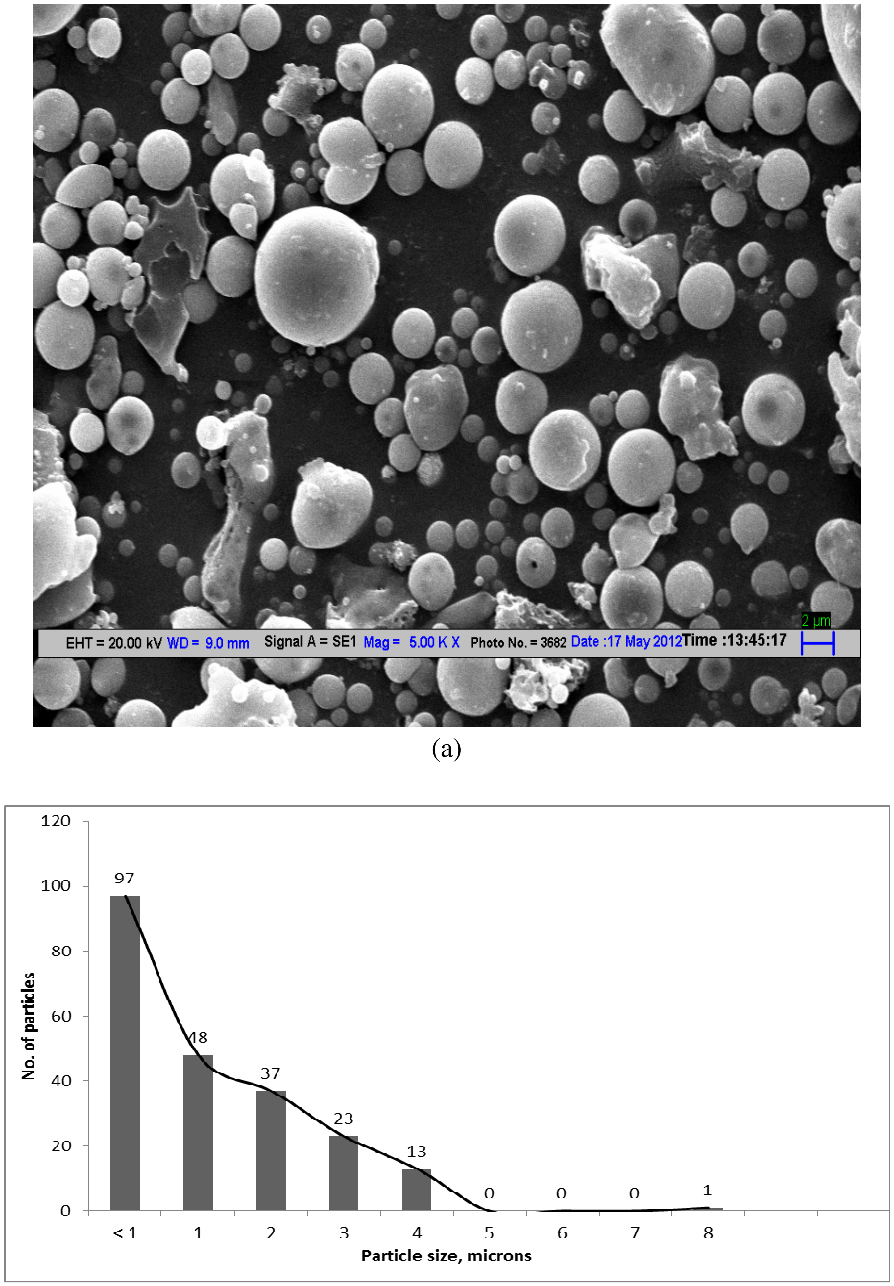
## 4.3. Scanning Electron Micrograph

The morphological characteristics of fly ashes were studied by scanning electron microscopic technique. A small portion of material was kept in the oven at 105ºC for 24 hours for drying. The specimen was mounted on a specimen holder. A thin conducting layer of gold about 50 Å thickness was coated on the specimen surface with the aid of sputter coater Emitech K550X. Zeiss EVO series scanning electron microscope model EVO 18 was used to examine the morphology of the materials. Figures 3 (a) and 4 (a) shows the scanning electron micrograph of BFA and DFA at 5000 times magnification. It showed that spherical and smooth particles of various size ranges were present in the fly ash. The distribution of particles is shown in fig. 3(b) and 4(b), the histogram (2 b) shows that the size less than 10 micron was more in BFA; nevertheless 1 particle of 12 micron was also observed. It can be seen from 3(b) particles less than 4 micron was present and 1 particle of size 8 micron was found. Hence DFA have finer particles as compared to BFA. The surface morphology of BFA reveals that it possesses rough surface compared to that of DFA. According to [6] the occurrence of cenospheres and plerospheres is limited in Indian fly ashes. Kaniraj and Gayathri [12] also observed the spherical particles, less than 10 µm in size in the Dadri fly ash.



(a)

Figure 3: (a) SEM of BFA (b) Histogram showing particle size distribution



(a)

(b)

Figure 4: (a) SEM of DFA (b) Histogram showing particle size distribution

## 4.4pH

The pH values of the Badarpur and Dadri ashes were determined by electrometric procedure. 30 gm of the dry fly ash was added to 75 cc of distilled water in a 100 cc beaker. The suspension was stirred thoroughly, covered with a glass plate, and left standing for an hour with occasional stirring. The suspension was again stirred well just before the test. The electrode connected to the digital pH meter was dipped into the solution and the value of pH was read. Three specimens of

Badarpur and Dadri fly ash were tested and the average of the three values was taken as the pH of the fly ash. The pH of the Badarpur fly ash was in the range of 8.1 to 8.3 with an average value of 8.2. This indicated that the BFA was slightly alkaline in nature. The pH of Dadri fly was in the range of 6.4 to 6.9 with an average value of 6.6. This indicated the slightly acidic nature of DFA.

# 5. GEOTECHNICAL CHARACTERISTICS

## 5.1 Compaction characteristics

The density of coal ashes is an important parameter since it controls the strength, compressibility, and permeability. In general, fly ashes show considerable variation in compaction due to the variation in the nature of fly ash produced from the same power plant over time [22, 23]. The variation of dry density with moisture content for fly ashes is less compared to that for a well- graded soil, both having the same medium grain size [16]. In the present study, the maximum proctor density values corresponding to each of the fly ashes were determined by employing the standard compaction test procedure as per IS 2720 [11]. The results of the compaction test were presented in a plot of dry density versus water content. From the plot, maximum dry density and optimum water content were determined. Proctor maximum dry density values of BFA and DFA were observed to be 11.37 kN/m$^3$ and 12.65 kN/m$^3$ and the optimum water content values were 28 and 24 %, respectively (Figure 5). These values are characteristic of typical silty loam soils, which exhibit better drainage and infiltration.

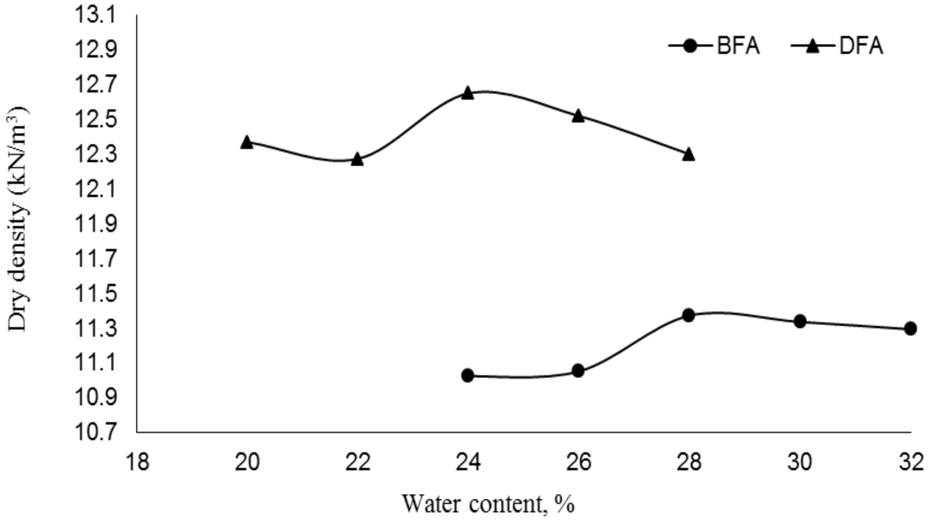


Figure 5: Dry density and water content relationships of the fly ash

## 5.2 Strength behaviour

The strength behaviour of fly ashes assumes great importance in their use for various geotechnical applications. The unconfined compressive strength test of the sample is the ratio of failure load and cross sectional area of the specimen when it is not subjected to any confining pressure. It may be used as a one of design parameters of base/subbase of road, embankment etc. The greatest advantage of pozzolanic materials such as fly ash is that the cohesion improves with the curing period increasing in turn the stability of structures. The increases of UCS with the increase in curing period were reported by Das and Yudhbir [7] with Panki and Parichha fly ash. The samples were prepared, cured and tested as per IS 2720 [11] and sheared at a strain rate of

0.4064 mm/min. The compacted specimens were kept in humidity chamber maintained at 25°C and a relative humidity of more than 95% and cured for 7 and 28 days. From the stress strain curves, the magnitude of peak stress and strain values corresponding to peak stress was noted. Generally, most of the fly ashes exhibit lowers unconfined compressive strength both in dry and fully saturated conditions due to the absence of cohesion for dry fly ash and loss of apparent cohesion upon total saturation [8]. Thus, it can be seen from Figure 6 that for both fly ashes the unconfined compressive strength increases with curing period.

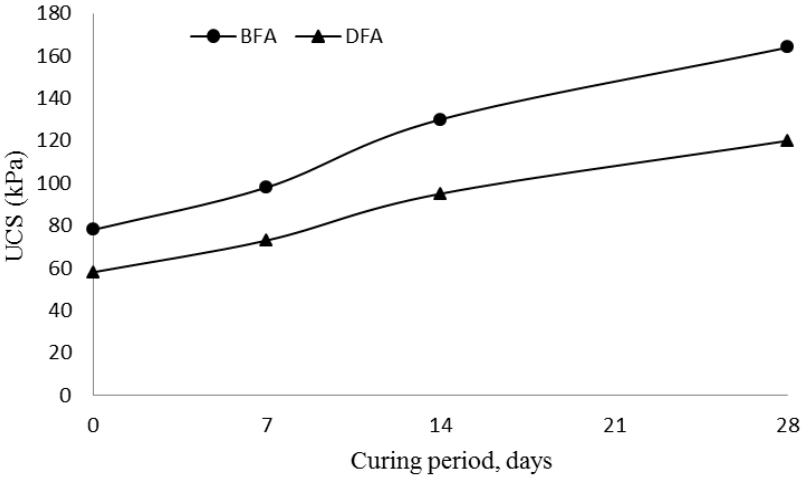


Figure 6: Variation of unconfined compressive strength with curing period

Table 3: Percent increase in UCS on curing

| Curing period | Percent increase in strength | |
|---|---|---|
| | BFA | DFA |
| 0 to 7 | 25 | 26 |
| 7 to 14 | 33 | 30 |
| 14 to 28 | 67 | 64 |

## 5.3 California bearing ratio

Utilization of fly ash in the construction of road and railway embankments is a step vigorously pursued globally to overcome the environmental and economic issues associated with importing quality construction materials from nearby terrains [15] Efforts to avert the problem have stimulated interest in utilizing alternative materials such as fly ashes which are ecologically safe and economically viable. For the use in highway embankments, fly ash and bottom ash mixtures were found to compare favourably with conventional granular materials [13] CBR values of fly ashes vary considerably depending on the type of fly ash, nature, curing period, and the condition under which the test is conducted. In this study, CBR tests were carried out on fly ashes after curing the compacted specimens for 0 and 4 days as per the standards. The loads corresponding to different depths of penetration for BFA and DFA after curing for 0 and soaked for 4 days are recorded and the CBR value for 2.5mm and 5mm penetrations obtained and presented in Table 2. Thus, higher CBR values are observed for 5 mm depth compared to 2.5 mm depth of penetration for pozzolanic fly ashes as could be seen from the results presented in Table 2. It is also observed from here that the CBR of BFA if higher than that of DFA. This may be due to more amount of coarser fraction in BFA as compared to DFA.

Table 4: Variation of CBR values for BFA and DFA under unsoaked and soaked conditions

| Mix | Fresh | | 4 days | |
|---|---|---|---|---|
| | Unsoaked | | Soaked | |
| | 2.5 mm | 5 mm | 2.5 mm | 5 mm |
| BFA | 11.6 | 15.3 | 5.7 | 8.4 |
| DFA | 10.2 | 13.4 | 4.6 | 6.9 |

## 5.4. Hydraulic Conductivity

Hydraulic conductivity is an important parameter in the design of liners to contain leachate migration, dykes to predict the loss of water, embankments as well as the stability of slopes and as a subbase material [15]. The hydraulic conductivity of well-compacted fly ash has been found to range from $10^{-4}$ to $10^{-6}$ cm/s, which is roughly equivalent to the normal range of permeability of silty sand to silty clay soils [10]. The hydraulic conductivity of fly ash is affected by its density or degree of compaction, its grain size distribution, pozzolanic activity, and its internal pore structure [17, 18]. The hydraulic conductivity of a fly ash is generally affected by its density or degree of compaction, grain size distribution, and internal pore structure. Since fly ash consists almost entirely of spherical shaped particles, they get densely packed during compaction, resulting in the reduction of hydraulic conductivity values. The hydraulic conductivity of fly ash is high because of its particle size and nonplastic nature and is analogous to the characteristics of nonplastic materials such as silts. For hydraulic conductivity study, the samples were prepared and tested as per ASTM D2166. The hydraulic conductivity mould with the compacted specimen was kept in a humidity chamber maintained at a temperature 25°C and relative humidity greater than 95% and cured for 7, 14, and 28 days. At the end of each curing period, the hydraulic conductivity values were determined for both fly ashes. Figure 8 shows the variation in hydraulic conductivity values with curing period. Lesser hydraulic conductivity values are observed for DFA as compared to BFA and may be due to the finer particle size of DFA. Also with increase in curing period, a marginal decrease in hydraulic conductivity values is observed which can be attributed to the formation of pozzolanic compounds blocking the pores and reducing the fluid conduction. The hydraulic conductivity can further reduce upon stabilizing it with lime, cement, clay etc.

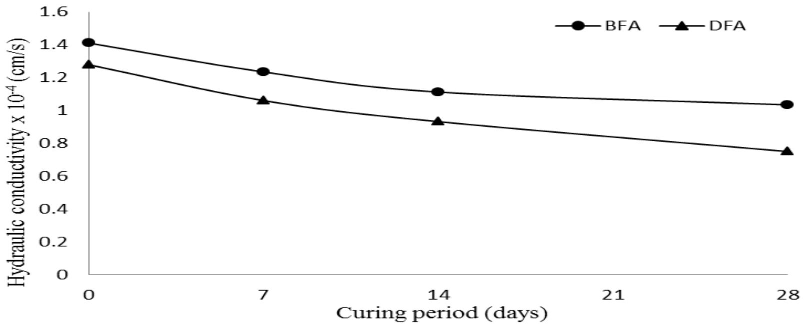


Figure 7: Variation of hydraulic conductivity with curing period

### 5.5. Free Swell Index

Free swell index is one of the most commonly used simple tests for getting an estimate of swell potential of any material. This test was first proposed by Holtz and Gibbs [9] and is expressed in cc or mL per one gram of material. The procedure established by Rao and Sridharan [19] has been followed in the present study for determining the free swell index. Oven-dried powdered sample of fly ash of 10 g was submerged in 40mL of distilled water in a 100 mL standardized graduated cylinder. The suspension was repeatedly stirred for thorough mixing and was allowed to equilibrate for 24 h to ensure thorough wetting of the sample. The suspension was then made up to the 100 mL mark by proper stirring. The cylinder was covered with a cap and left undisturbed for a further period of 24 h at which time the volume occupied by the sample particles on settling was noted. After the suspension reached an equilibrium value, sediment volume was noted. The free swell index was then calculated as sediment value per gram of fly ash; that is,

$$\text{Free swell index} = V_d/W \text{ in cc/gm}$$

where $V_d$ is the equilibrium volume of the oven-dried fly ash sample read from the graduated cylinder and W the weight of the oven-dried fly ash sample. The free swell index values obtained are 1.1 and 1.15 $cm^3$ /g for BFA and DFA, respectively. Based on these values, both fly ashes can be classified as non-swelling type [20].

## 6. CONCLUSIONS

Badarpur and Dadri fly ash were tested for utilization as geotechnical material. SEM and XRD techniques are used to study the morphology and mineralogy of fly ash. Based on findings of investigation following are the main conclusions.

1. The physical properties, namely, particle size, surface area, vary considerably for the fly ashes. DFA has greater finer particle content than BFA.
2. The chemical analysis shows that the sum of silica, alumina and ferric is more than 70% as specified by ASTM and is sufficient to form pozzolanic products.
3. SEM and XRD techniques help to study the geotechnical behaviour of fly ash. The surface morphological features reveal that BFA has rougher surface compared to that of DFA. Both fly ashes have predominantly quartz and mullite phases in them.
4. Upon curing, both fly ashes develop sufficient unconfined compressive strength and stiffness as revealed from the CBR characteristics. The strength and stiffness can be increased further by stabilizing it with cement, gypsum and lime.
5. The hydraulic conductivity of both the fly ashes is in the range of $10^{-4}$ cm/s and the same decreased on curing.
6. Further stabilization of both the fly ash could provide an opportunity to use it in various geotechnical applications by increasing the UCS, stiffness and durability and reducing the hydraulic conductivity.

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