**CHARACTERIZATION OF COAL COMBUSTION BY-PRODUCTS (CCBs) FOR THEIR EFFECTIVE MANAGEMENT AND UTILIZATION**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

**BACHELOR OF TECHNOLOGY**

**IN**

**MINING ENGINEERING**

By

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**DEPARTMENT OF MINING ENGINEERING**

**NATIONAL INSTITUTE OF TECHNOLOGY**

**ROURKELA, ORISSA - 769008**

**2009-2010**

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**Rourkela**

## CERTIFICATE

This is to certify that the thesis entitled **"*CHARACTERIZATION OF COAL COMBUSTION BY-PRODUCTS (CCBs) FOR THEIR EFFECTIVE MANAGEMENT AND UTILIZATION*"** submitted by Sri Patitapaban Sahu, Roll No. 10605004 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: Prof. H.K.NAIK

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**ABSTRACT**

The main use of coal in India is for generation of electricity, both currently and apparently also in the future. In India approximately 70% of power generation has been through coal-fired thermal power plants. About 60% of produced coal is used for power generation. The coal which is used in power plants has an ash content of about 30-50%. The Coal Ash Administration that was established in 1993 with the objective of coordinating the effort at a national level to solve the problem of ash accumulation at the power plants, chose to deal with the problem by advancing the use of coal ash as a resource having economic value, in various sectors, as is done in most of the developed countries in the world.

This site is intended to provide information regarding coal ash characteristics, beneficial uses of coal ash, both currently and in the future, in construction, infrastructures, industry and agriculture in India, to provide information on environmental quality issues, and to describe what is being done in this area to prevent damage to the environment and to improve it. Since coal fly ash consists of predominantly silt-sized particles, there is sometimes a concern about the possible frost susceptibility of fly ash as an embankment or structural backfill material, which can provide scope for environmentally safe. The major challenge with the introduction of the fly ash is its generation in unmanageable volumes which creates environmental problems in terms of land degradation, and degradation of air and water quality. The problem of storage and disposal of the fly ash creates a considerable pressure on land availability particularly in a densely populated country like India. Many researchers are working towards the large scale utilization of fly ash. The approaches include intermixing the fly ash with cement for civil construction work, manufacture of bricks, and utilization as a road pavement material and application as soil amendment medium for the plant growth.

# CHAPTER-1

## 1. INTRODUCTION

Coal ash is the mineral residue that is obtained as a byproduct of the combustion of coal for the production of electricity. Two types of coal ash are obtained i.e. fly ash and bottom ash. In each country utilization of fly ash depends on the local condition and has much to do with the fact that fly ash is multifunctional material and can be used for various purposes. In the building industry fly ash can be used in different ways for different products. In concrete fly ash can be used as partial replacement of cement and/or sand to enhance workability of fresh concrete, to reduce heat of hydration and to improve concrete impermeability and resistance to sulfate attack.

The properties of fly ash are varying depending on the coal kind and origin and on the power plant mode of operation. In certain uses some kind of beneficiation is required, either to improve its properties for the specific use or to achieve homogeneity. In concrete, fly ash can actually be used also "as is" when its properties fall within certain limits, but classification by particle size and/or control of the unburned coal greatly enhance the beneficial effects of the fly ash and of course its commercial value.

### 1.1 SOURCE AND DESCRIPTION

Coal ash is the mineral residue that is obtained as a byproduct of the combustion of coal for the production of electricity. Three types of coal ash are obtained:

- **Fly ash**, which constitutes 85% - 90% of the overall ash, is a fine, light gray powder made up of glassy spheres from sub-micron to more than 100 microns in size, (98%

smaller than 75 microns; 70% - 80% smaller than 45 microns). The material has a specific gravity between 1.9 - 2.4 and bulk density of about 0.8 - 1 ton per cubic meter and a maximal density (modified) of 1,000 - 1,400 kg per $m^3$. The specific surface area of fly ash varies between 2,000 to 6,800 $cm^2$ per gram. Fly ash contains cenospheres - hollow spherical particles having an especially low bulk density of 0.4 - 0.6 ton per cubic meter, which constitute up to 5% of the ash weight and are suitable to be utilized for special industrial applications.

- **Bottom Ash**, which constitutes about 10% - 15% of the overall ash, has an appearance similar to dark gray coarse sand, and its particles are clusters of micron-sized granules, up to 10 mm in diameter (60% - 70% smaller than 2 mm. 10% - 20% smaller than 75 microns). It has a bulk density of about 1 ton per cubic meter and a maximal density (modified) of 1,200 - 1,500 kg per $m^3$.
- **Pond Ash,** Fly ash and bottom ashes are mixed together with water to form slurry which is pumped to the ash pond area. In the ash pond the, ash gets settled and excess water is decanted. This deposited ash is called pond ash.

Along with coal ash gypsum (FGD - Flue Gas Desulfurization) is obtained as a result of removal of sulfur from exhaust gases, it is also one of the group of Coal Combustion Products, CCP's, or Coal Combustion Byproducts, CCB's.

## 1.2 DEFINITIONS:

### 1.2.1 FLY ASH

Fly ash is the finest of coal ash particles. It is called "fly" ash because it is transported from the combustion chamber by exhaust gases. Fly ash is the fine powder formed from the mineral matter in coal, consisting of the noncombustible matter in coal plus a small amount of carbon that remains from incomplete combustion. Fly ash is generally light in color and consists mostly of silt-sized and clay-sized glassy spheres. This gives fly ash a consistency somewhat like talcum powder. Properties of fly ash vary significantly with coal composition and plant-operating conditions.

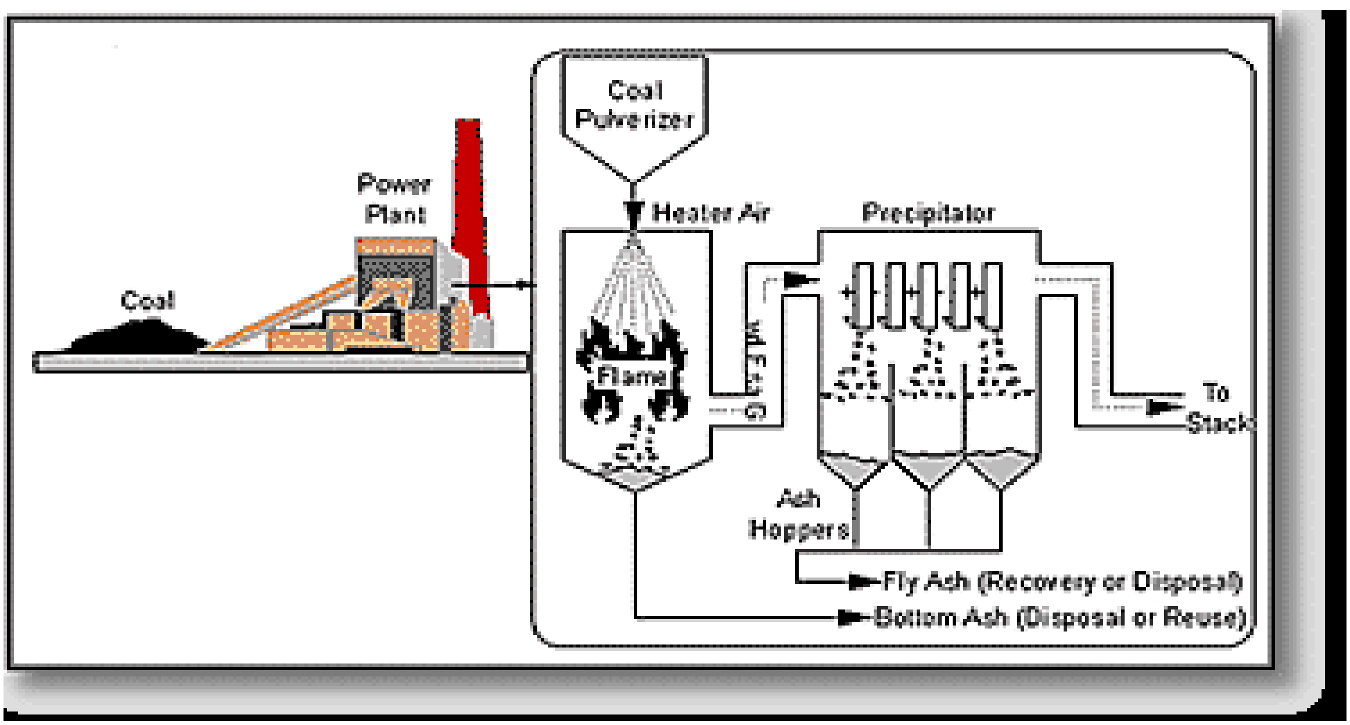
Fly ash can be referred to as either cementitious or pozzolanic. A cementitious material is one that hardens when mixed with water. A pozzolanic material will also harden with water but only after activation with an alkaline substance such as lime. These cementitious and pozzolanic properties are what make some fly ashes useful for cement replacement in concrete and many other building applications.

### 1.2.2 BOTTOM ASH

Coal bottom ash and fly ash are quite different physically, mineralogically, and chemically. Bottom ash is a coarse, granular, incombustible byproduct that is collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. Bottom ash is coarser than fly ash, with grain sizes spanning from fine sand to fine gravel. The type of byproduct produced depends on the type of furnace used to burn the coal.

### 1.3 GENERATION OF FLY ASH

Fly ash particles are swept along with the exhaust gases and are collected in electrostatic precipitators before they reach the stack. The ash is stored in silos in a dry state. From the silos, it is transferred in trucks to be used in industry as a pozzolanic additive in cement and concrete batch plants, or as a filler in various products. When the silos are full, it is conditioned by moistening (to 22% moisture) and sent for intermediate storage in open piles at the power stations or outside of them until it is utilized as a filler material in roads and infrastructure works. Transport of the moistened ash is done in semi-trailer trucks that are covered with canvas. The bottom ash falls into a water pool at the bottom of the boiler and is removed by a conveyor belt to storage facilities and from there to intermediate storage piles while in a water-saturated state. In the piles, the water content decreases to about 20%.




**(FIGURE 1.1 Generation of ash at the power plants)**

## 1.4 COMPOSITION OF FLY ASH

The ash is mainly composed of silica, alumina, and smaller quantities of oxides of iron, magnesium, calcium and other elements. It practically contains almost all the known elements, including toxic elements in trace quantities, which, to the extent of the concentration of their availability, may sometimes demands preventive environmental care. Furthermore, the ash contains radioactive elements in small quantities, but their concentration in ash is relatively larger than their concentrations in most natural rocks and soil. The ash also contains unburned carbon residue that gives it its dark color. The carbon content, as measured by a loss on ignition test, LOI, is commonly found in Indian coal ash to be in the range of 0.5 to 3.0%.

**(TABLE 1.1 Chemical Composition of Indian Fly Ash)**

| Constituent | Percentage Range (%) |
|---|---|
| Silica ($SiO_2$) | 49-67 |
| Alumia ($Al_2O_3$) | 16-29 |
| Iron Oxide ($Fe_2O_3$) | 4-10 |
| Calcium Oxide (CaO) | 1-4 |
| Magnesium Oxide (MgO) | 0.2-2 |
| Sulphur ($SO_3$) | 0.1-2 |
| Loss of Ignition | 0.5.3.0 |

## 1.5 CLASSIFICATION OF FLY ASH

### 1.5.1 Class F fly ash

The burning of harder, older anthracite and bituminous coal typically produces class F fly ash. This fly ash is not pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the addition of a chemical activator such as (water glass) to a Class F ash can lead to the formation of a geopolymer.

### 1.5.2 Class C fly ash

Fly ash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate ($SO_4$) contents are generally higher in Class C fly ashes.

At least one US manufacturer has announced a fly ash brick containing up to 50 percent Class C fly ash. Testing shows the bricks meet or exceed the performance standards listed in ASTM C 216 for conventional clay brick; it is also within the allowable shrinkage limits for concrete brick in ASTM C 55, Standard Specification for Concrete Building Brick. It is estimated that the production method used in fly ash bricks will reduce the embodied energy of masonry construction by up to 90%. Bricks and pavers are expected to be available in commercial quantities before the end of 2009

### 1.6 BENEFICIAL USES

From the standpoint of the electricity generation system, ash is a waste product (residue) that must be disposed of at the lowest possible cost, thus without harming the environment. By contrast, from a national economic standpoint, ash is a by-product which has an economic value. Coal ash is a substitute for dwindling natural raw materials (sand, aggregates, tuff, etc.) that are now in short supply, and whose quarrying harms the environment. The return to coal as an important energy source for electricity production at the start of the 1970's, on one hand, and the increasing awareness of environmental protection on the other hand, led to development and implantation efforts for a variety of ash uses around the world.

**(Table 1.2: Coal ash utilization)**

| | |
|---|---|
| In the construction centre sector | As a Pozolan additive to substitute for clinker and as a raw material to substitute for clay in the production of cement, as a partial substitute for cement and sand in concrete, as a fine aggregate in blocks and as a raw material in the production of lightweight and insulating aggregates. |
| In Infrastructure Sectors: | As fill material to amend inferior materials for paving roads, marine drying, landscape repair, stabilizing foothills and preserving soil. In foundations and filling of spaces. As an impervious layer in the restoration of landfills and the isolation of contaminated soils. |
| In Agriculture | As an ingredient in growth bed mixtures for plants and as a soil amendment. As an amendment for fertilizer made from municipal sewage sludge. |
| In Industry: | As filler in plastic, paint, asphalt and sealing materials and as a carrier for controlled - released fertilizers. As a raw material in ceramic glass materials and refractory materials. |
| In the Metal Market | As a source for the production of metals. |

The uses in the construction and infrastructure sectors are the most common and they exploit the coal ash as is. The other uses require processing of the ash, mainly classification according to size and purity by physical and/or chemical separation. Their potential use is relatively small; however the price of processing is compensated for by the prices obtained, from a few dollars up to hundreds of dollars per ton or even per kilogram, relative to competing materials.

The level of ash utilization and the entire scope of uses in various countries are dependent on the local characteristics of each country - economic, geological, geographic, environmental, etc.

## 1.7 ENVIRONMENT AND SAFETY

Since the source of coal is an agglomeration of organisms and minerals accumulated over extended geological time periods, it contains most of the natural elements at concentrations that are characteristic of the environment of the deposit from which it was mined, including heavy metals and radioactive elements. In the combustion of coal, some of the elements evaporate and others concentrate in the mineral residue in the form of ash. The ash is composed mainly of the inorganic constituents of the coal: oxides of silicon, aluminum, iron and calcium. However, in general, the availability of the hazardous materials is quite low, both because of their level of solubility that is limited as a result of chemical bonds that are created in the ash at high temperatures of the combustion compartment and the glassy structure of the particles, and because of their low concentration in the ash as trace elements.

This is the reason that coal ash itself is not defined as a hazardous or toxic material in any country or by any environmental organization in the world. In India, as in all countries of the world, coal ash has been defined as "a returnable by-product of the energy production that requires environmental supervision for its uses". This is due to the economic-social justification for preferring its beneficial utilization over its disposal as waste, and due to its contribution to the environment as a substitute for quarry materials, which prevents damage caused by quarrying and the air pollution that is inherent in converting those to industrial materials.

The environmental issues that must be addressed concerning the uses of coal ash concentrate on the following potential problems:

- Leaching of hazardous materials and the concern for pollution of water sources and land.
- Nuclear radiation and radon emissions in construction materials.
- Dust nuisances and exposure to free crystalline silica.

Under local hydro-geological conditions, the groundwater reservoirs are liable to be exposed to accumulated pollution of a few toxic elements, e.g. Cr, Se, whose availability in the coal fly ash is relatively high. However, since the exposure of the ash to the environment causes very rapid fixation processes to occur, the danger is lessened in a short period of time. Reducing direct contact of the coal ash with the environment minimizes the risk of pollutant leaching to a low level.

Nuclear radiation is liable to be a problem in construction materials that contain coal ash at very high levels (more than 50% by weight). Nevertheless, the physical structure of the raw ash particles and their being bound to the other construction materials, as well as the contribution of the ash to the compactness of the construction material, significantly reduce the amount of radon emission in construction materials, causing a reduction of the overall radiation from the materials to a level that has no risk of overexposure compared to radiation from natural raw materials and to the background radiation of the environment.

Coal ash dust is defined around the world as a nuisance, but in India it is included in the regulations concerning harmful dust. Although some of the silica that is in coal ash exists as Quartz, a crystalline substance that is liable to endanger those who are exposed to it in a consistent and prolonged manner, nevertheless, the means that are customarily used to prevent the dispersion of dust and for protection against exposure to the dust completely nullify this risk.

In any case, the presence of hazardous materials in coal ash requires an environmental examination of the ash itself and its uses. For this purpose, ash control mechanisms and characterization methods were developed in the developed countries of the world, as well as conditions and rules for usage that enable to exploit the economic benefits with reasonable environmental limitations. The Ministry of the Environment adopted the guidelines of the United States Environmental Protection Agency, which include a method for extraction of pollutants and a list of values that defines hazardous materials, and established a list of permitted maximum values in ash as a condition for use.

## 1.8 NEED FOR UTILIZATION OF FLY ASH

Fly ash can mainly be used for mine void filling which can provide scope for the environmentally safe and large volume utilization. This is only possible by the availability of fly ash in the proximity of a mining site and hydraulic conveyance is a potential technology both in terms of economics and environmental conservation.

The by-product applications of fly ash can be classified as high, medium and low technology. The high technology applications include the recovery of valuable materials, and filler material for polymer and matrix composites from fly ash. Medium technology includes the use of fly ash for manufacture of blended cement, light weight aggregates and bricks; blocks etc. Low technology applications include the use of fly ash for land reclamation.

**1.9 OBJECTIVES OF THE PRESENT STUDY**

1. Investigation into the physical, chemical and engineering properties of fly ash
2. Investigation into settling characteristics of the fly ash samples collected.
3. Investigation into slump test of the fly ash

**1.10 EXPERIMENTAL STUDY PLAN**

In order to achieve the objectives outlined, the study plan is divided into the following stages.

1. Collection of the fly ash samples from the thermal power plants.

2. For the samples collected, determination of physicochemical properties of relevance using standard physical and chemical analysis procedures and using of different instruments such as SEM, XRD, BET, SLUMP TEST.

3. Characterization of the fly ash samples with respect to the engineering properties of composite material.

# CHAPTER 2

## 2. LITERATURE REVIEW

### 2.1 CURRENT FLY ASH GENERATION

The current electricity generation in India is about 112,058MW, 65-70% of which is thermal (mostly coal based). According to an estimate 100,000 MW capacity or more would be required in the next 10 years due to continually increasing demand for electricity. In India fly ash generation is around 110 million tones / year and is set to continue at a high rate into the foreseeable future. Presently majority of the coal ash generated is being handled in wet form and disposed off in ash ponds which are harmful for the environment and moreover ash remains unutilized for gainful applications. India has sufficient coal reserves. In India almost 65-70% of electricity production is dependent on coal which produces a huge quantity of Fly Ash as residue which is allegedly a waste product in Thermal Power Stations. Fly Ash has a vast potential for use in High Volume fly ash concrete especially due its physico-chemical properties. A good amount of research has already been done in India and abroad on its strength and other requisite parameters.

The thermal power plant ash generation has increased from about 40 million tons during 1993-1994 to about more than 120million tones during 2008-09 and is expected to be in the range of 175 million tons per year by 2012, on account of the proposal to double the power generation. Coupled with this, the deteriorating quality (increasing ash quantity) of coal is expected to aggravate the situation. However the emergence of the clean coal technology may provide some relief in terms of ash quantity. Till the early 1990s' only a very small percentage (3%) of the fly ash was used productively in India, and the balance material was being dumped in slurry form in the vast ash ponds close to power plants. The number of governmental and institutional actions taken since then has increased the ash utilization to 43% during 2004-05. Current fly ash generation and utilization in six major states; Gujarat, Maharashtra, Tamil Nadu, Rajasthan, Andhra Pradesh and Uttar Pradesh is presented in the present report.

### 2.2 FLY ASH TRANSPORTATION

Fly ash can be supplied in four forms:

**Dry**: This is currently the most commonly used method of supplying fly ash. Dry fly ash is handled in a similar manner to Portland cement. Storage is in sealed silos with the associated filtration and desiccation equipment, or in bags.

**Conditioned**: In this method, water is added to the fly ash to facilitate compaction and handling. The amount of water added being determined by the end use of the fly ash. Conditioned fly ash is widely used in aerated concrete blocks, grout and specialist fill applications.

**Stockpiled**: Conditioned fly ash not sold immediately is stockpiled and used at a later date. The moisture content of stockpiled ash is typically 10 to 15%. This is used mainly in large fill and bulk grouting applications.

**Lagoon**: Some power stations pump fly ash as slurry to large lagoons. These are drained and when the moisture content of deposited fly ash has reached a safe level may be recovered. Because of the nature of the disposal technique, the moisture content can vary from around 5% to over 30%. Lagoon fly ash can be used in similar applications to stockpiled conditioned fly ash.

## 2.3 ASH UTILIZATION

### 2.3.1 FLY ASH UTILIZATION

Initially, local fly ash was of irregular quality, some of it with high LOI. It was used by the cement industry mainly as an additive to the ground clinker. The high LOI ash had been utilized as a structural fill for embankments around the power station and irregularly as a raw material for the kiln. Later, when the quality of the fly ash was improved and with the increased demand for cement, due to the construction boom, most of the fly ash was consumed by the cement industry for inter-grinding and as a raw material. But with the decline in the cement demand and with the restriction to use fly ash for road construction, due to environmental aspects, the unused fly ash, caused also by introduction of new power plants, was dumped into the sea. However, from 1997, when the price of dune sand went up significantly, the "conservative" concrete industry decided to start using fly ash with the necessary investment in the required additional facilities. Moreover, the Electric Corporation provided free fly ash, up to ten thousand tons, to the ready-mix companies for "experiments" with technical consultancy given by the NCAB. At the beginning fly ash was used only as sand replacement, with economical saving, but after getting some experience also some replacement of cement was done and fly ash was used for its technical merits. At first, only one major ready-mix concrete company used fly ash but later, most of the concrete producers followed.

#### 2.3.1.1 CEMENT

The cement industry found that with this amount they can use the fly ash "as is" without any beneficiation except for a limit on the maximum LOI. The cement industry can also use high LOI fly ash but as part of the raw material that goes to the kiln.

### 2.3.1.2 CONCRETE

Concrete is the main structural material; steel and wood are used on very small scale. Most of the concretes are produced in ready-mix concrete plants and the most common concrete is B-30. Production is the year-round as the winter in Israel is mild; hence there is no need for extensive storage facilities. Use of fly ash by ready-mix plant is subjected to permission from the government environmental authority, and is sometimes precluded due to some other environmental problems of the concrete plant.

A unique situation exists regarding fly ash as a sand replacement. On the one hand there is a shortage of sand in close proximity to the center and particularly to the northern region while on the other, the use of crushed sand (quarry sand), that was allowed just recently, impaired the workability of the fresh concrete.

The natural sands from the dunes along the coastline were the main supply source until recently. However, this source was depleted due to the intensive building activity. Hence, as the electrical power stations are located in the center of Israel utilization of fly ash as sand replacement, with some cement reduction is economical.

The use of crushed sand instead of natural dune sand presents some disadvantages on the workability of fresh concrete. In general, the particle shape of crushed sand is more angular with a rougher surface texture, and usually flakier and more elongated than that of natural sand. By contrast, the fly ash particle has a spherical shape and a smooth surface. Thus, a combination of fly ash and crushed sand yield a far superior concrete mix than crushed sand alone and obviates the disadvantage of partial or total replacement of the natural sand with crushed sand. Moreover, as sand replacement, the utilization of fly ash can be done without beneficiation, but with limits on LOI.

### 2.3.2 BOTTOM ASH UTILIZATION

Bottom ash utilization was delayed due to environmental restriction. It's utilization in road construction, land reclamation and agricultural were done only recently.

#### 2.3.2.1 ROAD CONSTRUCTION

Bottom ash and fly ash, 260 thousand tons, were used in road construction and land reclamation during 2005. Most of these materials used for the construction which was suffered from lack of structural material sources. In view of the increased synchronization between fly ash production and concrete demand, we do not anticipate significant surpluses of fly ash in the near future, so that less will be available for road construction.

#### 2.3.2.2 AGRICULTURE

Bottom ash is used in small amount, 20 thousand tons, for agricultural applications.

Its coarse fraction, ≥2 mm, serves as substrates for plant growth – a substitute for tuff in detached beds, and the fine fraction, ≤ 2 mm, for cowshed bedding and in poultry breeding, as a secretion absorbent.

## 2.4 FLY ASH MANAGEMENT

### 2.4.1 Fly Ash Management - Eliminating Waste and Abating $CO_2$ Emissions

Different methods of processing coal, different coal washery systems, clean coal technologies and particularly the development of ultra clean coal can, and do, have a dramatic effect on the quality and quantity of fly ash, generated by the combustion of pulverized coal. This type of solution, while reducing the problem of fly ash disposal, still leaves us with a problem of disposal of coal washery refuse, or some other form of processed coal waste.

There are other potential possibilities for modifying the characteristics of fly ash to advantage, converting it from waste into a value added product. Two examples are increasing pozzolanicity and enhancing the cenosphere content of fly ash.

### 2.4.2 INCREASING POZZOLANICITY

The pozzolanicity of fly ashes can vary widely. This reflects both the amount and nature of the mineral matter in the pulverized coals being used as fuel and the combustion conditions under which the fly ash is formed. It is believed that the production of fly ash of very high pozzolanicity is possible, without compromising the operation of a power station, through the judicious selection of appropriate coals or through slight modification of the chemical composition of the mineral matter present in the pulverized coal, and also through controlling the combustion process.

Much higher Portland cement replacement rates with fly ash in concretes can be achieved using highly reactive ash, and still comply with the relevant Australian standards.

Pozzolanic reactivity of fly ash is enhanced under steam-curing conditions. If concrete block manufacturing plants could be located near electric power stations, eliminating the need for transportation of ash and making full use of the available steam, again there could be a significant increase in the use of the fly ash.

### 2.4.3 CENOSPHERES

Most fly ashes contain a small proportion of thin-walled hollow spheres which are called 'cenospheres'. Many of these have a specific gravity less than one and when the fly ash is sluiced to the ash disposal dam they float and can be recovered as a value-added product.

For example, cenospheres have been used as filler in plastic and paint manufacturing and in the production of insulating refractory, which are known for their excellent strength to density ratios and for the thermal shock resistance. In Australia cenospheres after appropriate processing can fetch prices well in excess of $500/t when used in these applications.

The cenosphere content of fly ashes varies from coal to coal and with combustion conditions (furnace load). If we can understand and control the factors responsible it should be possible to increase significantly the cenosphere content of selected fly ashes, again without compromising the operation of a power station for electricity production.

If the amount of cenospheres in fly ash can be increased significantly, and hence become available in sufficient quantities on a reliable long-term basis, at a reduced unit cost, a range of excellent lightweight building materials and other products can be manufactured at a competitive market price.

Ultra lightweight concrete of about 600 kg/ml (as compared with 2300–2400 kg/ml for conventional concretes), but of very high strength in excess of 40 MPa (the highest commercial standard Grade is 50 MPa), has been produced from cenospheres under laboratory conditions.

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### 2.4.4 ASH HANDLING

- Dry Ash Handling & Transportation
- Dry handling at all power stations
- Delivery silos outside operation / security area
- Dense phase conveying
- Collection from selective fields to suit end application
- Indigenous plant & equipment suppliers and engineering expertise – A major industry
- Dry fly ash bagging & grading

### 2.4.5 SLURRY DISPOSAL

- Dense phase conveying
- Reduced water requirement
- Nil or negligence water discharge
- Accelerated decanting
- Re-cycling of pond water
- Separate handling & transportation of fly ash & bottom ash
- Peripheral / garland deposition of bottom ash

### 2.4.6 ASH PONDS

- Impervious strata selection or lining (may be fly ash based)
- Faster decantation
- Recycling of water, safe and economical design of dykes
- Use of fly ash for dyke construction
- Dyke-instrumentation & maintenance
- Vertical expansion rather than horizontal

- Periodic / ultimate densification
- End use oriented design plan

### 2.4.7 DRY FLY ASH MOUNDS

- Effective filters and collection systems for leaches and runoff water
- Dust arresters
- Separate mounds for fly ash and bottom ash
- Design and maintenance suitable for partial excavation
- Development as green areas

### 2.4.8 COMPLETED ASH PONDS / MOUNDS

- Densification
- Development / reclamation for human settlement / agriculture, floriculture /industrial / entertainment activities
- Seismic stability
- Environment friendly maintenance

### 2.4.9 ASH UTILIZATION

- Dense packing of mine fills
- Roller compacted concrete technology for hydraulic structures
- Reclamation / structural filling of low lying areas.
- Building components-bricks, blocks, cement, concrete, mortar, wood substitute (door shutters / wall panel etc.), paints and enamels, sintered aggregates, ceramic tiles pavement blocks etc.
- Roads and embankment construction
- Dyke raising

- High value added applications like extraction of alumina, cenospheres etc.

### 2.4.10 FACILITATION

1. On-line testing of fly ash

2. Control / modify un-burnt carbon percentage

3. Amendment of chemical composition

4. Grinding

5. Proportioning

6. Grading & packaging

7. Granulation / briquetting

8. Crashing of bottom ash for sand substitution

## 2.5 CHARACTERIZATION OF FLY ASH

The ash is characterized by physical (lightweight, small spherical particles, hardness) and chemical (cement-like) properties that provide it with an economic value as a raw material in many applications.

### 2.5.1 PHYSICAL PROPERTIES

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of silt (less than a 0.075 mm or No. 200 sieve). Although sub-bituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes.

The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area (measured by the Blaine air permeability method) may range from 170 to 1000 $m^2/kg$.

The color of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the color of the fly ash the lower the carbon content. Lignite or sub-bituminous fly ashes are usually light tan to buff in color, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous fly ashes are usually some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash.

### 2.5.2 CHEMICAL PROPERTIES

The chemical properties of fly ash are influenced to a great extent by those of the coal burned and the techniques used for handling and storage. There are basically four types, or ranks, of coal, each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin. The four types, or ranks, of coal are anthracite, bituminous, sub-bituminous, and lignite. In addition to being handled in a dry, conditioned, or wet form, fly ash is also sometimes classified according to the type of coal from which the ash was derived.

The principal components of bituminous coal fly ash are silica, alumina, iron oxide, and calcium, with varying amounts of carbon, as measured by the loss on ignition (LOI). Lignite and sub-bituminous coal fly ashes are characterized by higher concentrations of calcium and magnesium oxide and reduced percentages of silica and iron oxide, as well as a lower carbon content, compared with bituminous coal fly ash. Very little anthracite coal is burned in utility boilers, so there are only small amounts of anthracite coal fly ash.

Table compares the normal range of the chemical constituents of bituminous coal fly ash with those of lignite coal fly ash and sub-bituminous coal fly ash. From the table, it is evident that lignite and sub-bituminous coal fly ashes have a higher calcium oxide content and lower loss on ignition than fly ashes from bituminous coals. Lignite and sub-bituminous coal fly ashes may have a higher concentration of sulfate compounds than bituminous coal fly ashes.

The chief difference between Class F and Class C fly ash is in the amount of calcium and the silica, alumina, and iron content in the ash. In Class F fly ash, total calcium typically ranges from 1 to 12 percent, mostly in the form of calcium hydroxide, calcium sulfate, and glassy components in combination with silica and alumina. In contrast, Class C fly ash may have reported calcium oxide contents as high as 30 to 40 percent. Another difference between Class F and Class C is that the amount of alkalis (combined sodium and potassium) and sulfates ($SO_4$) are generally higher in the Class C fly ashes than in the Class F fly ashes.

**TABLE 2.1 Comparison of the chemical constituents of different coal fly ash**

| Component | Bituminous | Sub-bituminous | Lignite |
|---|---|---|---|
| $SiO_2$ | 20-60 | 40-60 | 15-45 |
| $Al_2O_3$ | 5-35 | 20-30 | 10-25 |
| $Fe_2O_3$ | 10-40 | 4-10 | 4-15 |
| CaO | 1-12 | 5-30 | 15-40 |
| MgO | 0-5 | 1-6 | 3-10 |
| $SO_3$ | 0-4 | 0-2 | 0-10 |
| $Na_2O$ | 0-4 | 0-2 | 0-6 |
| $K_2O$ | 0-3 | 0-4 | 0-4 |
| LOI | 0-15 | 0-3 | 0-5 |

Although the Class F and Class C designations strictly apply only to fly ash meeting the ASTM C618 specification, these terms are often used more generally to apply to fly ash on the basis of its original coal type or CaO content. It is important to recognize that not all fly ashes are able to meet ASTM C618 requirements and that, for applications other than concrete, it may not be necessary for them to do so.

The loss on ignition (LOI), which is a measurement of the amount of unburned carbon remaining in the fly ash, is one of the most significant chemical properties of fly ash, especially as an indicator of suitability for use as a cement replacement in concrete.

### 2.5.3 COMPACTION BEHAVIOR

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 median grain size. The tendency for fly ash to be less sensitive to variation in moisture content than for soils could be explained by the higher air void content of fly ash. Soils normally have air void content ranging between 1 and 5% at maximum dry density, whereas fly ash contains 5 to 15%. The higher void content could tend to limit the buildup of pore pressures during compaction, thus allowing the fly ash to be compacted over a larger range of water content.

### 2.5.4 LEACHING BEHAVIOR

Permeation of the contaminated pore water out of the porous matrix due to any driving force is called “leaching.” The contaminated water that is generated as water passes through a porous matrix is called “leachate.” The capacity of the waste material to leach is called its “leachability.” Depending on the sources of coals used in thermal power plants, fly ash may contain various toxic elements. Due to serious environmental problems involved, the leaching of these toxic elements from ash ponds is gaining considerable importance. The leachate characteristics are highly variable and even within a given landfill site, leachate quality varies over time and space.

### 2.5.5 PERMEABILITY BEHAVIOR

The permeability 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 a silty sand to silty clay soil. The permeability of a material is affected by its density or degree of compaction, its grain size distribution, and its internal pore structure. Since fly ash consists almost entirely of spherical shaped particles, the particles are able to be densely packed during compaction, resulting in comparatively low permeability values and minimizing seepage of water through a fly ash embankment.

Permeability is an important parameter in the design of liners to contain leachate migration, dykes to predict the loss of water as well as the stability of slopes and as a sub-base material. The coefficient of permeability of ash depends upon the grain size, degree of compaction and pozzolanic activity. The permeability of fly ashes is in the range of $8 \times 10^{-6}$ cm/s to 1.87 x 10–4 cm/s, $5 \times 10^{-5}$ cm/s to $9.62 \times 10^{-4}$ cm/s for pond ashes, and $9.9 \times 10^{-5}$ cm/s to $7 \times 10^{-4}$ cm/s for bottom ashes.

### 2.5.6 SETTLING PROPERTIES

The separation of solid-liquid in slurries depends on the settling rates. It also determines the recycled water quality. The settling rates depend much on the fly ash. The rapid of settling rate is taken as the engineering parameter.

### 2.5.7 SHEAR STRENGTH:

Shear strength tests conducted on freshly compacted fly ash samples show that fly ash derives most of its shear strength from internal friction, although some apparent cohesion has been observed in certain bituminous (pozzolanic) fly ashes. The shear strength of fly ash is affected by the density and moisture content of the test sample, with maximum shear strength exhibited at the optimum moisture content. Bituminous fly ash has been determined to have a friction angle that is usually in the range of 26° to 42°. A test program involving shear strength testing for 51 different ash samples resulted in a mean friction angle value of 34°, with a fairly wide range.

### 2.5.8 CONSOLIDATION CHARACTERISTICS

An embankment or structural backfill should possess low compressibility to minimize roadway settlements or differential settlements between structures and adjacent approaches. Consolidation has been shown to occur more rapidly in compacted fly ash than in silty clay soil because the fly ash has a higher void ratio and greater permeability than the soil. For fly ashes with age-hardening properties, including most "high lime" fly ashes from lignite or sub-bituminous coals, the age-hardening can reduce the time rate of consolidation, as well as the magnitude of the compressibility.

### 2.5.9 BEARING STRENGTH

California bearing ratio (CBR) values for "low lime" fly ash from the burning of anthracite or bituminous coals have been found to range from 6.8 to 13.5 percent in the soaked condition (an optional procedure in the test method) to 10.8 to 15.4 percent in the un-soaked condition. For naturally occurring soils, CBR values normally range from 3 to 15 percent for fine-grained materials (silts and clays), from 10 to 40 percent for sand and sandy soils, and from 20 to 80 percent for gravels and gravelly soils.

## 2.6 DESIGN CONSIDERATIONS

Virtually any fly ash can be used as an embankment or structural backfill material, including pond ash that has been reclaimed from an ash lagoon. The principal technical considerations related to the design of a fly ash embankment or structural backfill are essentially the same as the considerations for the design of an earthen embankment or backfill. There are certain special design considerations, however, that should be considered when fly ash is used in embankment or fill applications.

### 2.6.1 SITE DRAINAGE

Fly ash, because of its predominance of silt-size particles, tends to wick water into itself, making it possible that the lower extremities of a fly ash embankment could become saturated, resulting in a loss of shear strength. It is, therefore, important that the base of a fly ash embankment not be exposed to free moisture, wetlands, or the presence of a high water table condition. Adequate provisions should be made to handle maximum flows anticipated from surface waterways, swales, or seepage from springs or high water table conditions.

An effective way to prevent capillary rise or the effects of seepage in fly ash embankments and backfills is the placement of a drainage layer of well-drained granular material at the base of the embankment. An ASTM recommended practice for the use of fly ash in structural fills recommends placement of a drainage layer at a height that is at least 5 feet above the historical high water table.

### 2.6.2 SLOPE STABILITY

To determine a safe and appropriate design slope ratio (the ratio of vertical to horizontal distance); an analysis of the slope stability of a design cross-section of the fly ash embankment must be performed. The basic principle of slope stability analysis is to compare the factors contributing to instability with those resisting failure. The principal resistance to failure is the shear strength of the embankment material. For long-term stability of fly ash embankments, a factor of safety (ratio of the resisting forces to the driving forces along a potential failure surface) of 1.5 is recommended using the Swedish circle method of slope stability analysis. Unless the fly ash is self-hardening, the cohesion (c) value should be zero for these calculations.

### 2.6.3 EROSION CONTROL ANALYSIS

The slope ratio described above is also a factor in the potential for erodibility of compacted fly ash slopes. These slopes must be protected as soon as possible after attaining final grade because they are subject to severe erosion by runoff, or even high winds, if left unprotected. One way to prevent such erosion is to construct a fly ash embankment within dikes of granular soil, which serves to protect the slopes throughout construction. Another way is to cover the slopes with topsoil as the embankment is being constructed. It is also possible to overfill the slopes and trim the excess fly ash back to the appropriate slope once the final layer is completed. Finally, short-term erosion control may be accomplished by stabilizing the surface fly ash on the slopes with a low percentage of Portland cement or lime, or covering with a blanket of coarse bottom ash.

### 2.6.4 SOIL BEARING CAPACITY

The ability of the top portion of a fly ash embankment to support a pavement structure can be predicted by a determination of the California Bearing Ratio (CBR) for a flexible asphalt pavement system or by a determination of the modulus of sub-grade reaction (K-value) for a rigid or concrete pavement system. These bearing values can then be used to design pavement layer thicknesses in accordance with the AASHTO Design Guidelines.

### 2.6.5 CLIMATIC CONDITIONS

Although no frost susceptibility criteria have been established in the United States, the British Road Research Laboratory has developed a test method to evaluate frost susceptibility. The test method involves subjecting a compacted 150 mm (6 in) high specimen to freezing temperatures that simulate actual field conditions. The test is run over a 250-hour time period, after which the total amount of frost heaves of the test specimen, is measured. Frost-susceptible materials heave 18 mm (0.7 in) or more after testing of the top portion of a fly ash embankment to frost heaving can be substantially increased by the addition of moderate amounts of cement or lime.

Objections to the use of compacted fly ash within the frost depth can be overcome by substituting a soil that is not susceptible to frost for fly ash within the frost zone.

During times of heavy or prolonged precipitation, the delivered moisture content of the fly ash may have to be reduced to compensate for the effects of the precipitation. Fly ash, unlike most soils, can usually be compacted throughout much of the winter, although it is recommended that fly ash not be spread and compacted when the ambient air temperature is below -4°C (25°F).

### 2.6.6 PROTECTION OF UNDERGROUND PIPES AND ADJACENT CONCRETE

Chemical and/or electrical resistivity tests of some fly ashes have indicated that certain ash sources may be potentially corrosive to metal pipes placed within an embankment. Each source of fly ash should be individually evaluated for its corrosivity potential. If protection of metal pipes is deemed necessary, the exterior of the pipes may be coated with tar or asphalt cement, the pipes may be wrapped with polyethylene sheeting, or the pipes can be backfilled with sand or an inert material.

The sulfate content of fly ash, particularly self-cementing ash, has caused some concern about the possibility of sulfate attack on adjacent concrete foundations or walls. Precautions that can be taken against potential sulfate attack of concrete include painting concrete faces with tar or an asphalt cement, using a waterproof membrane (such as polyethylene sheeting or tar paper), or possibly even using a Type V sulfate-resistant cement in the adjacent concrete.

## 2.7 CONSTRUCTION PROCEDURES

### 2.7.1 MATERIAL HANDLING AND STORAGE

Bituminous (pozzolanic) fly ash is usually conditioned with water at the power plant and hauled in covered dump trucks with sealed tailgates. Sub-bituminous or lignite (self-cementing) fly ash may be partially conditioned at the plant and hauled in covered dump trucks to the project site, or hauled dry in pneumatic tank trucks from the plant to the project site, where it is placed in a silo and conditioned with water when ready for placement.

If a temporary stockpile of fly ash is built at the project site, the surface of the stockpile must be kept damp enough to prevent dusting. The stockpile should be placed in a well-drained area so the ash is not inundated with water following a rainfall.

### 2.7.2 PLACING AND COMPACTING

The minimum amount of construction equipment needed to properly place and compact fly ash in an embankment or structural backfill includes a bulldozer for spreading the material, a compactor, either a vibrating or pneumatic tired roller, a water truck to provide water for compaction (if needed) and to control dusting, and a motor grader, where final grade control is critical.

The suitability of any proposed construction equipment should be verified by using it on a test strip prior to its use in actual construction. The test strip may also be used to evaluate the specified compaction procedure, as well as any proposed modifications to the procedure. If fly ash from a power plant's landfill or lagoon contains any lumps when spread for compaction, it may be necessary to break down the lumps using a disk harrow or a rotary tiller as a supplemental piece of equipment.

Fly ash should be placed in uniform lifts no thicker than 0.3 m (12 in) when loose. Experience has shown that steel-wheel vibratory compactors and/or pneumatic tired rollers have provided the best performance. If a vibratory roller is used, the first pass should be made with the roller in the static mode (without any vibration), followed by two passes with the roller in the vibratory mode and traveling relatively fast. Additional passes should be in the vibratory mode at slow speed.

In general, six passes of the roller are usually needed to meet specified compaction requirements. In most cases, 90 to 95 percent of a standard Proctor maximum dry density is the minimum specified density to be achieved. This is almost always achievable when the moisture content of the fly ash is within 2 or 3 percent of optimum, preferably on the dry side of optimum.

For each project, the type of compactor, the moisture content of the fly ash at placement, the lift thickness, and the number of passes of the compaction equipment should be evaluated using a test strip before the actual construction. If a vibratory compactor is to be used, the test strip can be used to evaluate the speed at which the compactor should be operated, the static weight, dynamic force and frequency of vibration of the compactor, and the number of passes required to achieve the specified density.

During periods of moderate rainfall, construction may proceed by reducing the amount of water added at the power plant or jobsite to compensate for precipitation. Dry fly ash can also is mixed into excessively wet fly ash to reduce the moisture content to an acceptable level.

Because fly ash obtained directly from silos or hoppers dissipates heat slowly, fly ash may be placed during cold weather. If frost does penetrate a few inches into the top surface of the fly ash, the ash can be removed from the surface by a bulldozer, or re-compacted after thawing and drying. Construction should be suspended during severe weather conditions, such as heavy rainfall, snowstorms, or prolonged and/or excessively cold temperatures.

### 2.7.3 QUALITY CONTROL

Quality control programs for fly ash embankments or structural backfills are similar to such programs for conventional earthwork projects. These programs typically include visual observations of lift thickness, number of compactor passes per lift, and behavior of fly ash under the weight of the compaction equipment, supplemented by laboratory and field testing to confirm that the compacted fly ash has been constructed in accordance with design specifications.

## 2.8 SPECIAL CONSIDERATIONS

### 2.8.1 DUST CONTROL

If allowed to dry out, fly ash surfaces can be susceptible to dusting. Dust control measures that are routinely used on earthwork projects are effective in minimizing airborne particulates at ash fill projects. Typical controls include hauling fly ash in covered dump trucks (for "low lime") or in pneumatic tankers (for "high lime"), moisture conditioning fly ash at the power plant (especially "low lime"), wetting or covering exposed fly ash surfaces, and sealing the top surface of compacted fly ash by the compactor at the conclusion of each day's placement.

### 2.8.2 DRAINAGE/EROSION PROTECTION

Fly ash surfaces must be graded or sloped at the end of each working day to provide positive drainage and prevent the ponding of water or the formation of runoff channels that could erode slopes and produce sediment in nearby surface waters. Compacted fly ash slopes must be protected as soon as possible after being finish graded because, if left unprotected, they can be severely eroded. Erosion control on side slopes is usually provided by placing from 150 mm (6 in) to 600 mm (2 ft) of soil cover on the slopes. An alternative approach is to build outside dikes of soil to contain the fly ash as the embankment is being constructed.

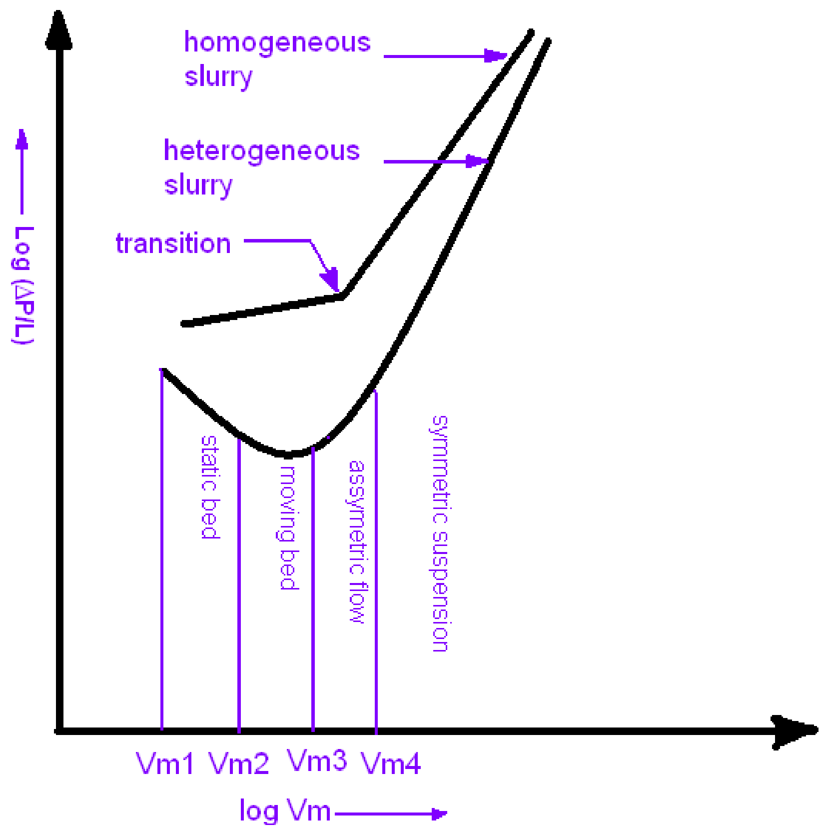
## 2.9 SLURRY FLOW BEHAVIOR:

When a solid –liquid mixture is conveyed through a pipe, different conditions of flow may be encountered depending on the properties of the solids, conveyed liquid, and the characteristics of the pipeline. The different hydraulic flow conditions of slurry are homogeneous, intermediate and saltation flow. As the name suggests, the flow is homogeneous if the various properties of the suspensions (like solid concentration, density, viscosity) do not change across the pipe.

Homogeneous flow of suspension is possible if the following conditions are satisfied (Seshadri 1997):

- The solid particles are very finely dispersed and light.
- The slurry flow rate is sufficiently high.
- The solid concentration is high.

For homogeneous flow it is essential to have the terminal settling velocity of the particles as small as possible so that the concentration gradients do not exist. Homogeneous suspensions behave like single component fluids and their flow can be described using a suitable rheological model. This homogeneous flow can occur either in laminar mode or in turbulent mode. The transition from laminar to turbulent mode is indicated by the change in the slope of the pressure drop -flow rate relationship.




**(FIGURE 2.1 Flow regimes in slurry transportation)**

In actual practice, no particulate suspension of practical interest behaves like a homogeneous mixture at all flow velocities. If the mean flow velocity Vm is high enough then all the particles are fully suspended and systematically distributed across the section of the pipe. This is called the" symmetric suspension regime". At these velocities, the turbulent and the other lifting forces are sufficient to keep all the particles under suspension and prevent them from sliding over the pipe wall. As slurry velocity (and hence the intensity of turbulence and lift forces) is decreased, the settling tendency of the particles causes a distortion of the concentration profile and flow will become asymmetric. The concentration of solid particles will be more at the bottom of the pipe.

This result in the skewness of the velocity profile with mixture velocities being higher at top half of the pipeline as compared to the bottom half of the pipeline. This skewness in both the concentration profile as well as in velocity profile will increase with decrease in mixture velocity. Thus the flow will become more and more heterogeneous.

At the velocities below $VM_2$ particles tends to accumulate at the bottom of the pipe, first in the form of dunes and then as continuous 'moving bed'. The dunes or the bed moves at a considerably lower velocity as compared to that of liquid or solid particles above it. The particles at the top of the dunes or bed are made to roll and tumble by the shear stresses caused by the flow above. It is obvious that the concentration of the particles in the flow above moving bed will be much lower as compared to the average concentration of solids. The mixture velocities of these upper regions are high enough to keep the particles in suspension.

As the slurry velocity is further reduced ($VM<VM_3$) the lowermost particles of the bed become stationary and the bed thickens. The bed motion occurs essentially by the uppermost particles tumbling over one another (saltation). This region of flow is called stationary bed and flow will be somewhat unstable. Below a mixture velocity of $VM_4$ the bed up and high pressure gradient will be required to maintain flow. In fact as soon as the bed starts forming below a velocity, $VM_2$ the pressure gradient would show a reversal and the pressure increases with decreasing mixture velocity resulting in the chocking of the pipeline (Seshadri, 1997). Above mentioned flow behavior would be strictly valid as long as the particles are equal in size. However in applications such as stowing and filling the particle size in the solids transported varies over a wide range. Hence, at any given mixture velocity the smallest particles may be homogeneously distributed across the pipe cross-section, whereas, concentration gradients would be prominent for the larger particles. Also the largest sized particles would tend to settle first while the other

fractions are still under suspension. Thus, for given mixture if all the particles are in suspension then the concentration profile would be uniform for smallest size from, whereas it tends to become increasingly, non-uniform as the size of the particles increases. This would make the Suspension flow near the bottom of the pipe increasingly coarser as compared to that flow at the top of the pipe. As the mixture velocity is reduced all the particles belonging to larger size fractions would be traveling in the bottom half the pipe and they tend to settle first. Thus, for multisided particulate suspensions there will be a combination of homogenous and heterogeneous flow. Further, the transition velocities ($VM_1$ to $VM_4$) are not clearly defined and the different flow regions are not clearly distinguishable.

Within the transition zone between heterogeneous and saltation regimes, there is a unique velocity corresponding to minimum head loss in the pipeline, below which the settling of solids will occur, but above which, the flow is homogeneous. This velocity is termed the critical velocity $V_C$. For a given concentration of solids critical velocity for the slurry flow refers to conditions of least frictional pressure losses. The conveyance of the slurry at this velocity regime results in decreased power requirements on the transportation system and at the same time ensures reduced pipe damage due to wear. Further, the addition of polymeric medium such as the Polyacrylamide and its various graft components, in small quantities, is noted to have an effect on pressure reduction in slurry transportation.

It is almost impossible to derive general correlations for the estimation of various transition velocities in slurries of different materials. This is because it is not feasible to take into account the effect of so many parameters which, differ from the slurry to another. The presence of fine particles would increase the viscosity of the slurry resulting in increased resistance to settling behavior of large particles. Thus, the particles in the slurry might be fully suspended even at moderate mixture velocities, whereas in the absence of fine particles the larger particles would have settled down.

Although several attempts have been made to incorporate the effect of different parameters into the correlations, the studies have been only partially documented in literature with each study having its own limitations and range of applications.

Essentially the prediction of critical flow velocity in pipelines carrying solid liquid mixtures with a sufficient accuracy is of considerable importance to researchers and practicing engineers. On account of the minimum cost of slurry transportation at this velocity, the work done by Kokpmar and Gogus (2001) refers extensively to the various empirical expressions that have been generated by earlier researchers for critical velocity. The terminal settling velocity of the solid particles is taken into consideration in the proposed model of Kokpmar and Gogus (2001), for the determination of critical velocity of slurry flow. The approach differs from the earlier formulations on account of the consideration of the settling velocity of particles. The Kokpmar and Gogus (2001), model is given by:

$$\frac{V}{gD}=0.055\left(\frac{d}{D}\right)^{-0.6}C_V^{0.27}(S-1)^{0.07}\left[\frac{Pf*Wm*ds}{\mu f}\right]^{0.30}$$

where

V = mean critical flow velocity of solid—liquid mixture (m/s);

C = concentration of solid materials by volume;

D = pipe diameter (m);

Ds =mean particle diameter (m);

S = specific gravity,

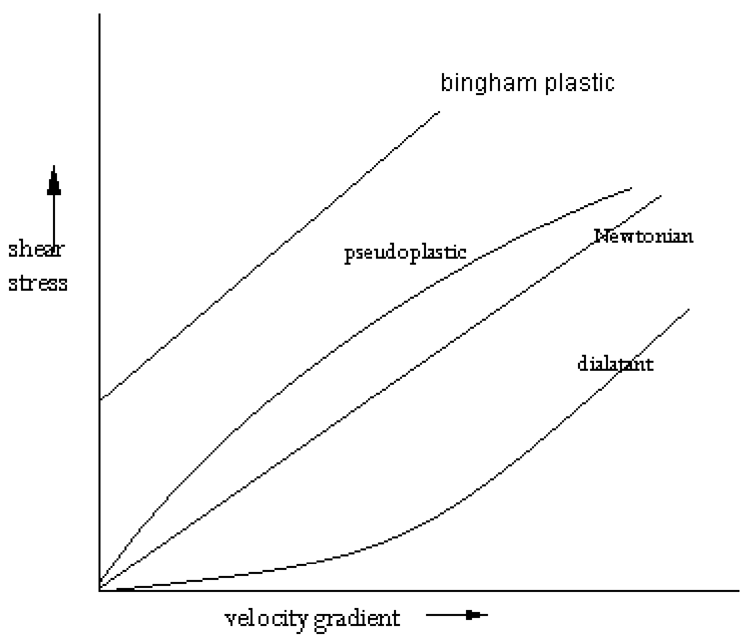
Wm = particle settling velocity in mixture flow (m/s);

uf= dynamic viscosity of fluid (kg/m-s);

pf. =density of fluid (kg/m3); and

g= gravitational acceleration (m/s2).

Depending upon the relationship (rheogram) between shear stress and rate of shear strain, fluids are classified into different categories as shown in Figure 2.2. The relationship between these two parameters is linear when the fluids are Newtonian. With respect to this behavior an upwardly concave curve represents pseudo plastic behavior, whereas a downwardly concave curve represents dilatants behavior. The fluids which do not exhibit any flow until threshold shear stress.




**(FIGURE 2.2 shear stress vs rate of shear strain)**

In the Georgia Iron Works (GIW) pipeline design manual Addie (1982 indicated that the flow of a solid—liquid mixture through a pipe is complex phenomenon with the flow characteristics and subsequent pipe friction being dependent upon size distribution, shape, density, and concentration of the solids, pipe diameter, mean velocity, slope of the pipeline and so on. Many authors have categorized slurries into settling and non-settling types depending on the settling velocity of the solid particulates in the slurry. Slurries containing particles with settling velocities higher than 1.5 mm/s are termed as settling slurries, whereas, the slurries with particles having settling velocities below 1.5 mm/s and termed as slurries of non-settling slurries.

Non-settling slurries flowing in a pipe have a uniform distribution of particles across the flow section and exhibit axi-symmetric velocity distribution.

It may be generally stated that, no reliable method exists for the estimation of the flow properties of non-settling slurries based on calculations from the properties of the solids and carrier liquid. In practice, slurry transport of non-settling slurries in laminar flow regime is avoided primarily because larger particles may settle to the bottom of the pipe forming a stationary bed. In most cases, systems are designed to run at velocities slightly in excess of those of the transition point.

Settling slurry in a pipe normally flows as a heterogeneous mixture in which a portion of the solid particles are carried as suspended load and the remainders are carried as bed load. The bed load or stratification ratio (R), which is the ratio of the bed load transport to total transport, is a useful parameter to characterize the flow conditions. Since the mechanism of suspension and turbulence, is a function of mean velocity in the pipe, the value of R is also a function of Vm. At a sufficiently high mixture velocity, all of the solid particles will be conveyed as suspended load or as a pseudo homogeneous suspension for which R=O. At slower velocities the solid particles tends to settle towards the bottom of the pipe with the result that some of the transport is bed load transport and little additional resistance resulting from suspended—load transport; therefore, the friction pressure gradient diverges more and more from the water curve as R increases due to reducing Vm. The lower limit of the heterogeneous suspension occurs when the velocity is reduced to the deposit velocity and the solids start to form a stationary bed. A small stationary bed is harmless, but there is no reason to waste a part of the flow cross section with a stationary bed. In order to preclude a stationary bed, pipelines are designed so that Vm > deposit velocity. For settling slurries with centrifugal pumps as prime movers, the conveying velocity is normally well above the deposit velocity in order to operating velocity. The velocity Uu, at the threshold of turbulent suspension is given by the formula:

$$Uu = 0.6Vt\sqrt{\frac{8}{ft}}e45(d/D)$$

Vt = terminal Settling velocity,

ft= friction factor of fluid flowing at velocity Vm,

d = particle diameter,

D = internal pipe diameter.

Specific Energy Consumption (SEC) is the energy required to move one kg of solids in a horizontal distance of one meter. The most efficient slurry transport is achieved when the SEC is minimum (Addle, 1982).

$$SEC = I_m / Ss * C_{vd}$$

Where:

Im= friction pressure gradient in ft of water per ft of pipe,

Ss = specific gravity of the solids and

C = delivered volume concentration.

Panda and Singh (2000), described the viscous effects of transportation of fly ash slurries at 30-70% solids concentration (by weight) using Hakke rotational viscometer (RV 100). The study showed that the slurry represented Newtonian behavior up to 50% concentration by weight of solids in the slurry. Beyond this concentration slurry exhibited pseudo plastic behavior. When the mixture of fly ash and bottom ash was examined the viscosity was reported to be minimum at fly ash-bottom ash ratio of 3:2. The study also suggested that slurry transportation was possible at a higher concentration, i.e., up to 70% by weight by adding small amount (1.2%) of additive 'SHMP'.

## 2.10 TRANSPORTATION PROCESS SYSTEM WITH ADDITIVE FEEDINGSYSTEM

The flow chart of pipeline transportation system is shown in Figure 2.3. It consists of a storage system, a mixing system, a pumping system, and slurry pipeline, an additive feeding system, and water return system. A rotary valve supplies fly ash accurately into a slurry blender at a controlled rate. An impact weigher located under the rotary valve enables fly ash flow metering. About half of the total water is added into the slurry blender. Conditioned fly ash is fed into the slurry, and further water is added to bring the slurry up to the desired concentration. A pump then feeds the slurry into a pipeline for transportation to a controlled deposit site. Before the pipeline is stopped for an extended period, the stabilizing additives (S-194) and NSF are added into the slurry mixer and pipeline. Stable fly ash slurry, produced by the mixer and line mixers, is fed into the pipeline instead of normal slurry. At the deposit site, the water is collected and returned to the mixing system by a water pump.

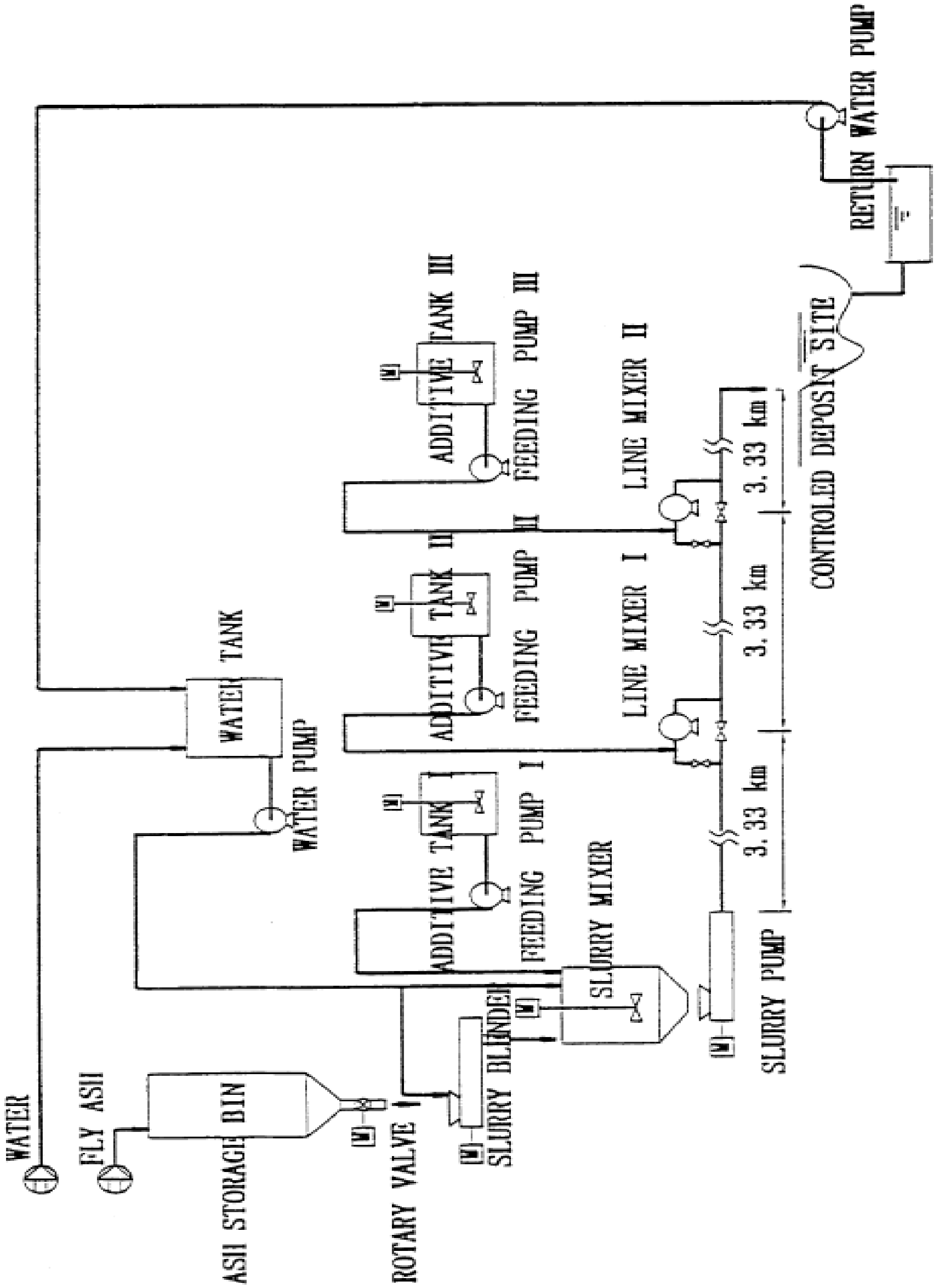
If the solid concentration exceeded 60 wt%, highly concentrated fine-grained CWM can be regarded as homogeneous during the pipeline transportation. The transportation can be carried out in the laminar flow region. Pressure loss can be estimated by using rheological characteristics of slurry. The concentration of fly ash–water slurry used in this study is more than 68 wt%. The fly ash density is 2,242 kg/m3. The diameter of typical fly ash particle is smaller than that of the typical coal particles. Therefore, fly ash–water slurry can also be regarded as homogeneous during transportation.

The model is combined with maximum packing volume fraction and results in the estimation of inter-particle bonding energy between primary particles in a cluster. It has been proven that the viscosity of fly ash–water slurries for different solid concentration and shear rate may be calculated by using the different values determined for one experimental condition.

We can obtain the relationship $\dot{\gamma} = f(\tau)$ between shear stress and shear rate from the predicted apparent viscosity of the present model. Then the laminar volumetric flow rate can be calculated by

$$Q = \frac{8\pi L^3}{\Delta P^3} \int_{\tau=0}^{\tau_m} \tau^2 f(\tau) d\tau,$$

where $\tau_m (= R\Delta P/2L)$ is the shear stress at the pipe wall, and L, $\Delta P$, and R are the pipe length, pressure drop, and pipe radius, respectively.




(FIGURE 2.3 Flow sheet of the transportation process of fly ash)

# CHAPTER 3

## 3. MATERIALS AND METHODS

The study of the physicochemical and engineering properties of fly ash is necessary to understand the variation in the properties of fly ash In the Indian context, in order to utilize the same as large volume backfill material. In addition to this the study is required to establish properties such as permeability, particle size distribution, and morphological characteristics of the fly ash which influence the settling behavior and flow properties during hydraulic transportation. In the present context experimental studies are conducted for fly ash samples to determine the properties of importance for mine void filling and to understand the variability among these properties.

### 3.1 ASH SAMPLING

Fly ash samples were directly collected from Electrostatic Precipitators (ESPs) in gunny bags from Jindal Power and Steel Company Limited, Raigarh, Chhatishgarh.

### 3.2 PHYSICOCHEMICAL PROPERTIES.

Collected fly ash samples are examined under the different processes to know the major physicochemical properties and settling properties of all the samples. The properties studies are chemical composition, particle size distribution, specific gravity, true density, and morphology.

#### 3.2.1 SEM (Scanning Electron Microscope)

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20x to approximately 30,000x, spatial resolution of 50 to 100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using EDS), crystalline structure, and crystal orientations (using EBSD). The design and function of the SEM is very similar to the EPMA and considerable overlap in capabilities exists between the two instruments.

### 3.2.2 SPECIFIC GRAVITY (ASTM D 854)

Specific gravity is one of the important physical properties needed for the use of coal ashes for geotechnical and other applications. In general, the specific gravity of coal ashes varies around 2.0 but can vary to a large extent (1.6 to 3.1). Because of the generally low value for the specific gravity of coal ash compared to soils, ash fills tend to result in low dry densities. The reduction in unit weight is of advantage in the case of its use as a backfill material for retaining walls since the pressure exerted on the retaining structure as well as the foundation structure will be less.

This lab test is performed to determine the specific gravity of fly ash by using a pycnometer. Specific gravity is the ratio of the mass of unit volume of fly ash at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature.

**Test Procedure:**

(1) Determine and record the weight of the empty clean and dry pycnometer, $W_P$.

(2) Place 10g of a dry fly ash sample (passed through the sieve No. 10) in the pycnometer. Determine and record the weight of the pycnometer containing the dry fly ash, $W_{PS}$.

(3) Add distilled water to fill about half to three-fourth of the pycnometer. Soak the sample for 10 minutes.

(4) Apply a partial vacuum to the contents for 10 minutes, to remove the entrapped air.

(5) Stop the vacuum and carefully remove the vacuum line from pycnometer.

(6) Fill the pycnometer with distilled (water to the mark); clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and contents, $W_B$.

(7) Empty the pycnometer and clean it. Then fill it with distilled water only (to the mark). Clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and distilled water, $W_A$.

(8) Empty the pycnometer and clean it.

Calculate the specific gravity of the fly ash using the following formula:

$$\text{Specific Gravity}, G_S = \frac{W_0}{W_0 + (W_A - W_B)}$$

Where:

$W_0$ = weight of sample of oven-dry fly ash, g = $W_{PS}$ - $W_P$

$W_A$ = weight of pycnometer filled with water

$W_B$ = weight of pycnometer filled with water and fly ash

**3.2.3 TRUE DENSITY**

The density of the particles that make up a powder or particulate solid in contrast to bulk density, which measures the average density of a large volume of the powder in a specific medium.

Take a measuring jar graduated in ml. Clean it thoroughly with pure water. Take water into the flask up to certain level and note down its level (initial reading).

Drop slowly 20 gms of the supplied fly ash sample into the jar. Shake the jar for some time. Now note down the level of water in the reading (final reading). Repeat this for 5 samples and tabulate the results. Divide the difference of the final reading and initial reading by weight of the sample to obtain true density.

### 3.2.4 MOISTURE CONTENT

About 1 gm of finely powder (-212µ) air dried fly ash sample is weighed in a silica crucible and then placed inside an electric hot air oven, maintained at $108 \pm 2^0$C. The crucible with the fly ash sample is allowed to remain in the oven for 1.5 hours and is then taken out with a pair of tongues, cooled in a desicator for about 15 minutes and then weighed. The loss in weight is reported as moisture (on percentage basis.). The calculation is done as per the following formula:

$$\% \text{ Moisture} = (Y-Z)/(Y-X)*100$$

Where X = Weight of empty crucible

Y= weight of crucible + coal (before heating)

Z= weight of crucible + coal (after heating)

### 3.2.5 SPECIFIC SURFACE AREA (BET METHOD)

The BET method involves the determination of the amount of the adsorbate or adsorptive gas required to cover the external and the accessible internal pore surfaces of a solid with a complete monolayer of adsorbate. This monolayer capacity can be calculated from the adsorption isotherm by means of the BET equation.

The gases used as adsorptives have to be only physically adsorbed by weak bonds at the surface of the solid (Van der-Waals forces) and can be desorbed by a decrease of pressure at the same temperature. The most common gas is nitrogen at its boiling temperature (77. 3 K). In the case of a very small surface area (below 1 $m^2/g$), the sensitivity of the instruments using nitrogen is insufficient and krypton at 77.3 K should be used.

In order to determine the adsorption isotherm volumetrically, known amounts of adsorptive are admitted stepwise into the sample cell containing the sample previously dried and out gassed by heating under vacuum. The amount of gas adsorbed is the difference of gas admitted and the amount of gas filling the dead volume (free space in the sample cell including connections). The adsorption isotherm is the plot of the amount of gas adsorbed (in mol/g) as a function of the relative pressure p/p0.

$$\frac{1}{v\left[(P_0/P)-1\right]} = \frac{c-1}{v_m c}\left(\frac{P}{P_0}\right) + \frac{1}{v_m c} \qquad (1)$$

$P$ and $P_0$ are the equilibrium and the saturation pressure of adsorbates at the temperature of adsorption, $v$ is the adsorbed gas quantity (for example, in volume units), and $v_m$ is the monolayer adsorbed gas quantity. $c$ is the BET constant, which is expressed by (2):

$$c = \exp\left(\frac{E_1 - E_L}{RT}\right) \qquad (2)$$

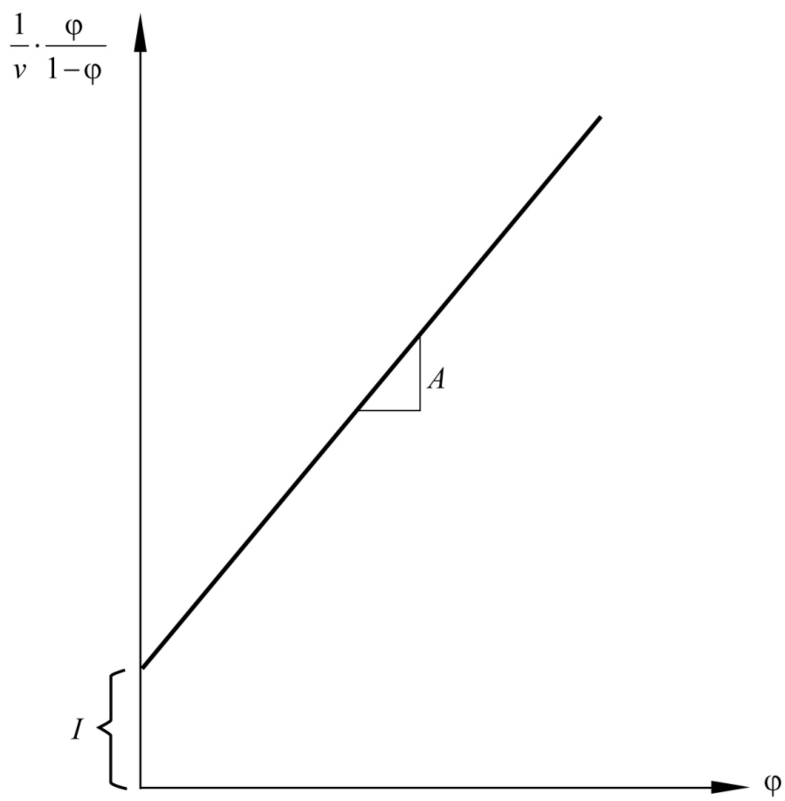
$E_1$ is the heat of adsorption for the first layer, and $E_L$ is that for the second and higher layers and is equal to the heat of liquefaction.

Equation (1) is an adsorption isotherm and can be plotted as a straight line with $1 / v[(P_0 / P) - 1]$ on the y-axis and $\varphi = P / P_0$ on the x-axis according to experimental results. This plot is called a **BET plot**. The linear relationship of this equation is maintained only in the range of $0.05 < P /$

$P_0 < 0.35$. The value of the slope $A$ and the y-intercept $I$ of the line are used to calculate the monolayer adsorbed gas quantity $v_m$ and the BET constant $c$. The following equations can be used:

$$v_m = \frac{1}{A + I} \qquad (3)$$

$$c = 1 + \frac{A}{I} \qquad (4)$$




**(FIGURE 3.1 BET Plot)**

The specific surface area of a powder is estimated from the amount of nitrogen adsorbed in relationship with its pressure, at the boiling temperature of liquid nitrogen under normal atmospheric pressure. The observations are interpreted following the model of Brunauer, Emmett and Teller (BET Method).

The BET method is widely used in surface science for the calculation of surface areas of solids by physical adsorption of gas molecules. A total surface area $S_{total}$ and a specific surface area $S$ are evaluated by the following equations:

$$S_{BET,total} = \frac{(v_m N s)}{V} \qquad (5)$$

$$S_{BET} = \frac{S_{total}}{a} \qquad (6)$$

$N$: Avogadro's number, $s$: adsorption cross section, $V$: molar volume of adsorbent gas $a$: molar weight of adsorbed species.

### 3.2.6 PARTICLE SIZE ANALYSIS

The **particle size distribution (PSD)** of a powder, or granular material, or particles dispersed in fluid, is a list of values or a mathematical function that defines the relative amounts of particles present, sorted according to size. PSD is also known as **grain size distribution**. The coarse size fraction generally refers to the material from greater than 10 mm to the top size of 100-150 mm. The fine aggregate is considered to be the material less than 10 mm in size. The fine aggregate should make up about one quarter to one-third of the total aggregate weight.

A suspension of powder in isopropanol is measured with a low angle laser beam, and the particle size distribution is calculated

Procedure:

1. Look at the particle size in a microscope and choose a lens capable of measuring the largest particles.

2. Prepare the instrument for measuring in wet mode using IPA as the liquid, as described in the user manual.

The stirrer regulator should be set at 2000 rpm on the Malvern unit.

3. Measure the background for IPA.

4. Quickly add a sufficient amount of powder and measure as soon as the powder is dispersed and not later than 20 seconds after addition of the powder. For detailed instructions about measuring, see the Malvern user manual.

5. Rinse twice with IPA.

All measurements are made in duplicate.

The ideal grading those results from minimizing the void space is given by

P $(u) = 100(u/u_{max})$ 0.5

where,

P $(u)$ = probability of material finer than sieve opening u

$u$ = opening size, mm

$u_{max}$ = maximum particle size

### 3.3 SETTLING CHARACTERISTICS OF FLY ASH

The tests on settling rates determine the ease with which solid-liquid separation takes place in slurries during filling activity, and tests also provide a means of determining the clarity of the supernatant. Clear supernatant solution free of suspended matter can in most circumstances be readily recycled, thus leading to water conservation. The rapidity with which the separation takes place is an important engineering parameter. This is because the fill may be required to provide the bearing strength soon after the deposition either for safety or for machinery deployment. The ready percolation of water creates safer conditions. However the grain size of the fill, among other parameters plays a crucial role characterizing the separation process. The introduction of coagulant or a flocculants is typical industrial and engineering practice to enhance the solid-liquid separation process. The generation of larger or macroscopic particulates creates conditions for increased gravitational forces, and thereby leads to a rapid settling of solid matter of the medium.

Take a measuring flask graduated in ml. Clean it thoroughly with pure water. Take water into the beaker up to certain level.

Drop slowly certain weights of supplied fly ash sample into the beaker and then the mixtures are stirred by stirrer for some time. The mixtures slowly dropped into the flask through the funnel. Note down the initial upper reading and initial lower reading of the mixtures. Note down the time at each one ml interval of the lower reading.

### 3.4 SLUMP TEST

In construction and civil engineering, the **slump test** (or simply the slump test) is an in situ test or a laboratory test used to determine and measure how hard and consistent a given sample of concrete is before curing.

The slump test is, in essence, a method of quality control. For a particular mix, the slump should be consistent. A change in slump height would demonstrate an undesired change in the ratio of the ingredients; the proportions of the ingredients are then adjusted to keep a batch consistent. This homogeneity improves the quality and structural integrity of the cured material.

**Steps**

1. Place the mixing pan on the floor and moisten it with some water. Make sure it is damp but no free water is left.
2. Place the fly ash in the pan. Add water to it.
3. Add the additives if any and thoroughly mix.
4. Mix the water and dry fly ash ingredients thoroughly using the trowel.
5. Firmly hold the slump cone in place using the 2 foot holds.
6. Fill one-third of the cone with the fly ash mixture. Then tamp the layer 25 times using the steel rod in a circular motion, making sure not to stir.
7. Add more fly ash mixture to the two-thirds mark. Repeat tamping for 25 times again. Tamp just barely into the previous layer (1")
8. Fill up the whole cone up to the top with some excess fly ash coming out of top, and then repeat tamping 25 times. (If there is not enough fly ash from tamping compression, stop tamping, add more, then continue tamping at previous number)
9. Remove excess fly ash from the opening of the slump cone by using tamping rod in a rolling motion until flat.
10. Slowly and carefully remove the cone by lifting it vertically (5 seconds +/- 2 seconds), making sure that the fly ash sample does not move.

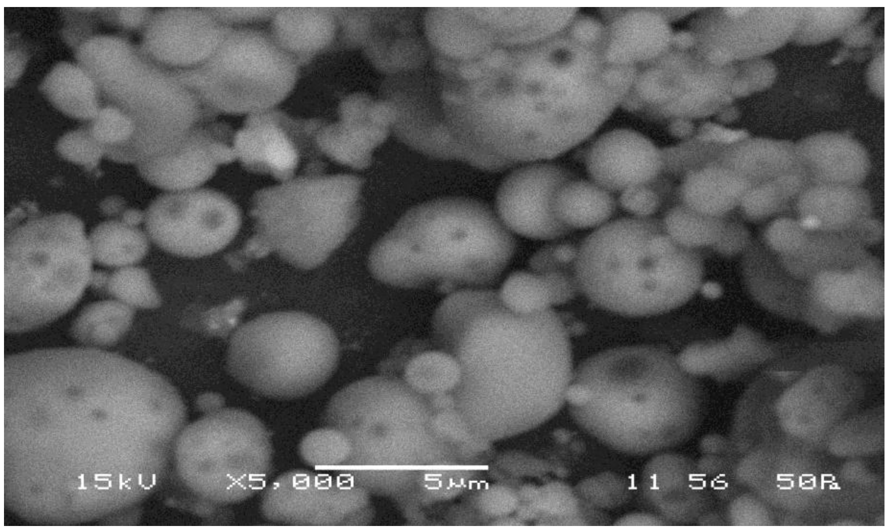
11. Wait for the fly ash mixture as it slowly slumps.
12. After the mixture stabilizes, measure the slump-height by turning the slump cone upside down next to the sample, placing the tamping rod on the slump cone and measuring the distance from the rod to the ORIGINAL DISPLACED CENTER.

# CHAPTER 4

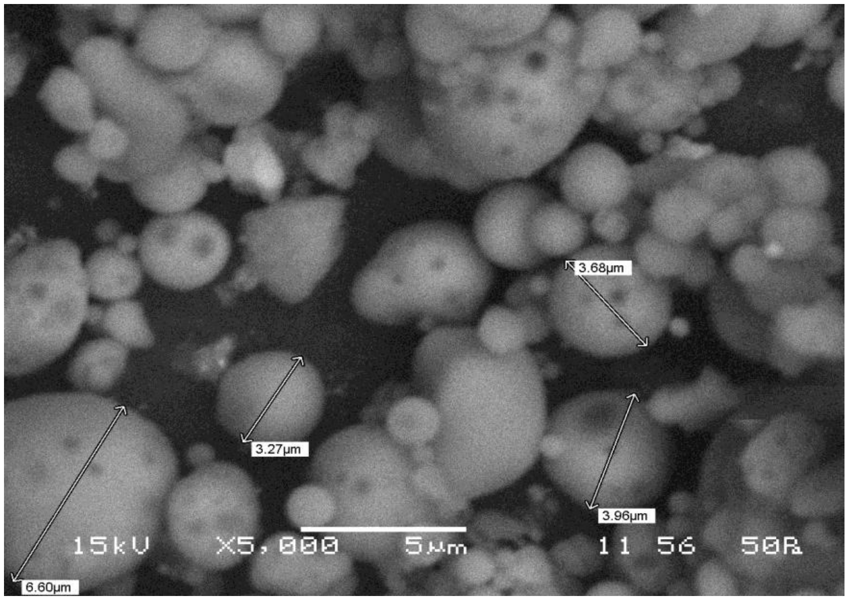
## 4. RESULTS AND DISCUSSION

### 4.1 SEM (Scanning Electron Microscope)

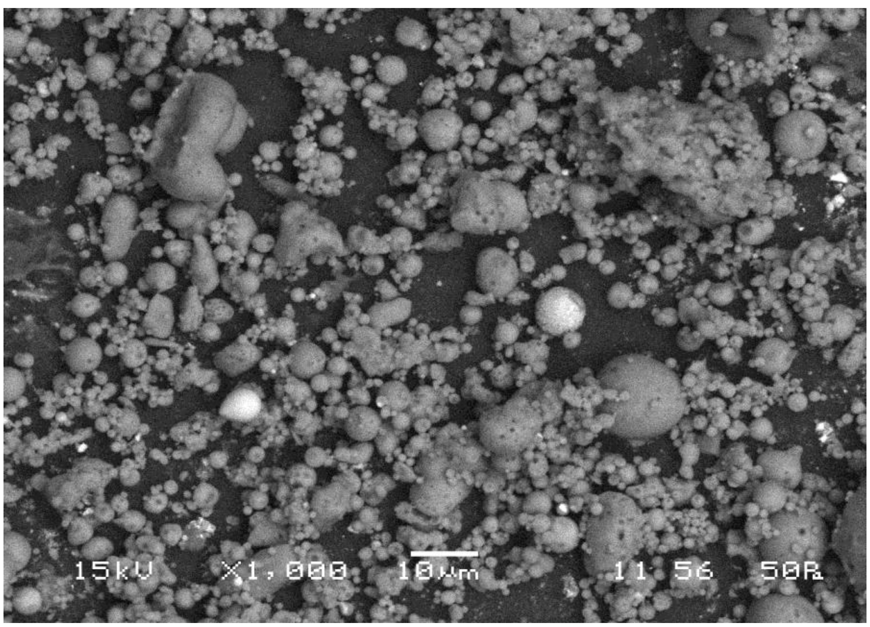
**FIGURE-4.1: (SEM MICROPHOTOGRAPHS OF FLY ASH UNDER DIFFERENT MAGNIFICATION LEVELS)**




**(Fly Ash Sample magnified 5,000X under SEM)**




**(Fly Ash Sample magnified 5,000X under SEM)**




**(Fly Ash Sample magnified 1,000X under SEM)**

The SEM data indicated intermixing of Fe and Al-Si mineral phases and the predominance of Ca non-silicate minerals**.** The fly ash samples consisted mostly of amorphous alumino-silicate spheres with a lesser number of iron-rich spheres. The majority of the iron-rich spheres consisted of two phases: an iron oxide mixed with amorphous alumino-silicate. The calcium-rich material was distinct in both elemental composition and texture from the amorphous alumino-silicate spheres. It was clearly a non-silicate mineral possibly calcite, lime, gypsum or anhydrite. In spite of the inherent variability of fly ash samples, this analysis indicated that the primary mineral/morphological structures are fairly common. Quartz and alumino-silicates are found as crystals and as amorphous particles. Iron-rich particles typically exist as mixed iron oxide/alumino-silicate particles. Calcium is associated with sulfur or phosphorus, not with the alumino -silicates.

## 4.2 SPECIFIC GRAVITY (ASTM D 854)

### TABLE 4.1 (SPECIFIC GRAVITY OF FLY ASH)

| Sl.no. | Mass of empty, clean pycnometeter(WP), (grams) | Mass of empty pycnometer + dry soil (WPS), (grams) | Mass of pycnometer + dry soil + water (WB),(grams) | Mass of pycnometer + water(WA), (grams) | Specific gravity (GS) | Average Specific gravity |
|---|---|---|---|---|---|---|
| 1 | 41.69 | 73.42 | 157.28 | 139.38 | 2.294 | |
| 2 | 49.93 | 79.67 | 157.29 | 142.40 | 2.254 | **2.275** |

The specific gravity of the fly ash collected from Jindal Power and Steel Company Ltd. was found to be 2.275.

## 4.3 TRUE DENSITY

**TABLE 4.2 (TRUE DENSITY OF FLY ASH)**

| Sl. No. | Weight of sample (gram) | Initial reading(ml) | Final reading(ml) | Change in volume | True density | Average True density |
|---|---|---|---|---|---|---|
| 1 | 20 | 80 | 89 | 9 | 2.23 | |
| 2 | 20 | 80 | 90 | 8 | 2.5 | |
| 3 | 20 | 81 | 90 | 9 | 2.23 | |
| 4 | 20 | 81 | 90 | 9 | 2.23 | **2.29** |

The true density of fly ash collected from Zindal Power and Steel Company Limited was found to be 2.29**.**

## 4.4 MOISTURE CONTENT

**TABLE 4.3 (MOISTURE CONTENT OF FLY ASH)**

| **Weight of empty crucible(gm)** | **Weight of sample(gm)** | **Weight of crucible and sample before heating(gm)** | **Weight of crucible and sample after heating(gm)** | **Moisture content(%)** | **Average moisture content(%)** |
|---|---|---|---|---|---|
| 15.236 | 1.001 | 16.237 | 16.102 | 0.135 | |
| 15.125 | 1.005 | 16.130 | 15.914 | 0.210 | |
| 16.856 | 1.004 | 16.860 | 16.679 | 0.180 | **0.175** |

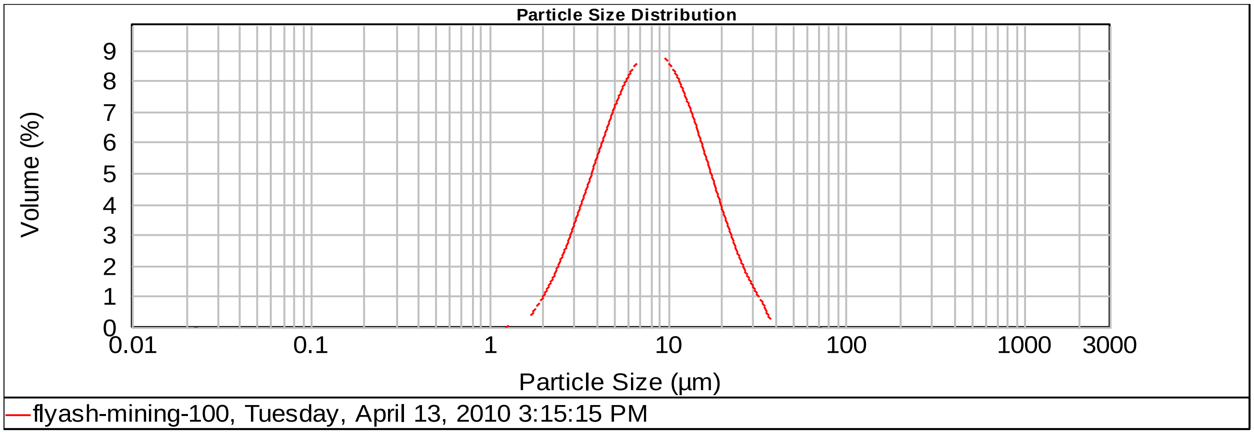
The moisture content of fly ash collected from Jindal Power and Steel Company Ltd. was found to be 0.175%. The moisture content of the sample were found out to be around 0.175% indicating that all the moisture have been evacuated and they are suitable for the construction works etc.

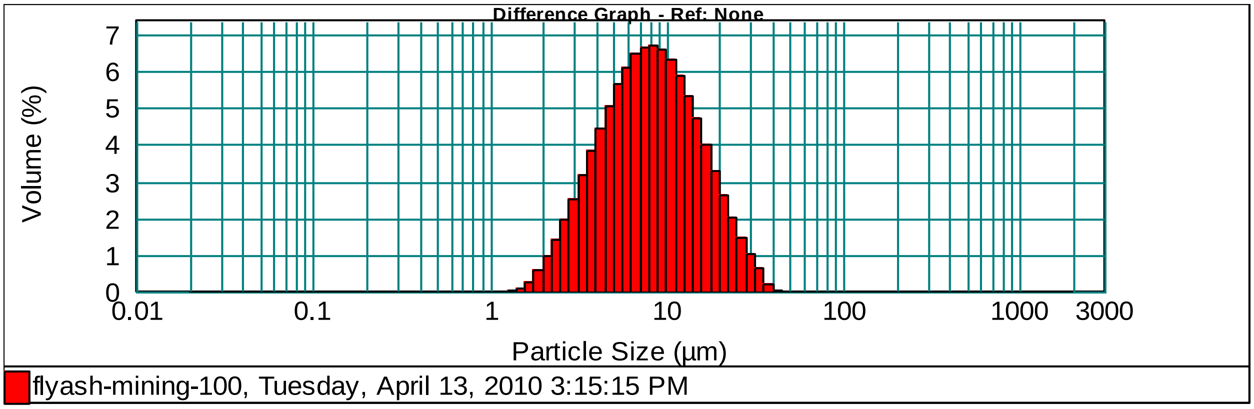
## 4.5 SPECIFIC SURFACE AREA

The specific BET surface area of the fly ash collected from the Zindal Power and Steel Company Limited was found to be 0.44 square meter per gram.

## 4.6 PARTICLE SIZE ANALYSIS

**FIGURE:-4.2 (PARTICLE SIZE ANALYSIS OF FLY ASH)**




The following calculations are done automatically:

1. The volume median diameter D (v, 0.5) is the diameter where 50% of the distribution is above and 50% is below.

2. Two determinations of mean particle size should not differ by more than 5% relative. The shape of the curves in the two determinations should be the same.

3. D (v, 0.9), 90% of the volume distribution is below this value.

4. D (v, 0.1), 10% of the volume distribution is below this value.

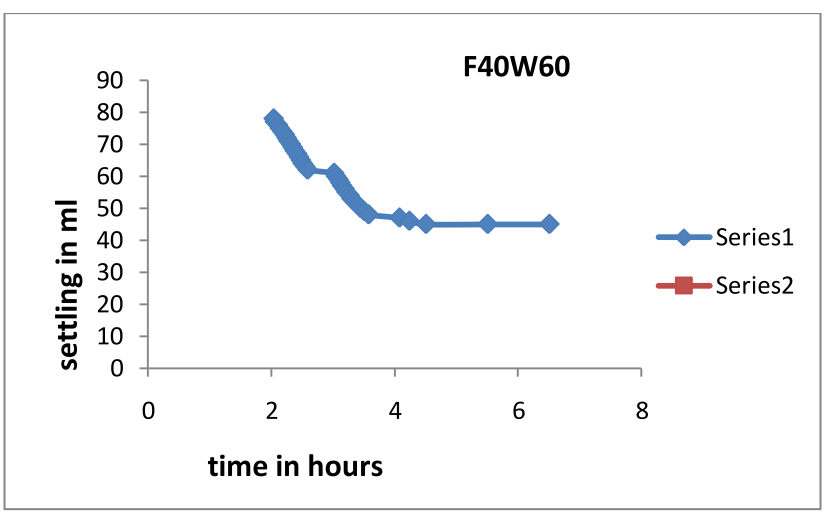
5. The span is the width of the distribution based on the 10%, 50% and 90% quantile.

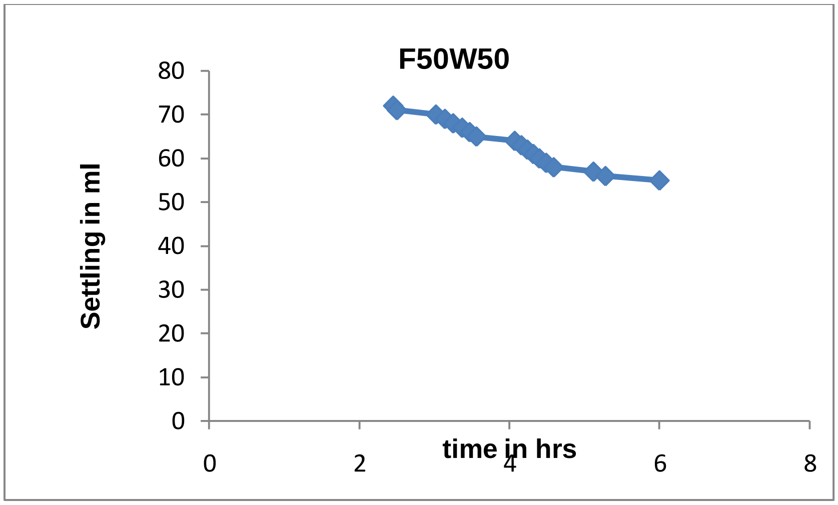
Particle size- min-3.44 µm mean-8.080µm max-18.585 um

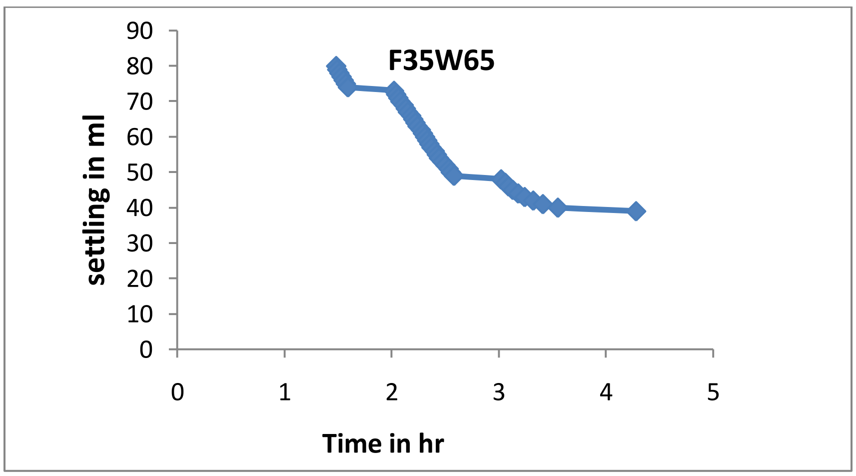
The size, density, type of reinforcing particles and its distribution have a pronounced effect on the properties of particulate composite. Size range of fly ash particles is reported in the below figure. The size range of the particles is very wide i.e. 0.1 micron to 100 micron. The size ranges of the fly ash particles indicate that the composite prepared can be considered as dispersion strengthened as well as particle reinforced composite. As is seen from the particle size distribution there are very fine particles as well as coarse ones (3.44-18.585µm). Thus the strengthening of composite can be due to dispersion strengthening as well as due to particle reinforcement. Dispersion strengthening is due to the incorporation of very fine particles, which help to restrict the movement of dislocations, whereas in particle strengthening, load sharing is the mechanism. Strengthening of matrix may occur because of solid solution strengthening.

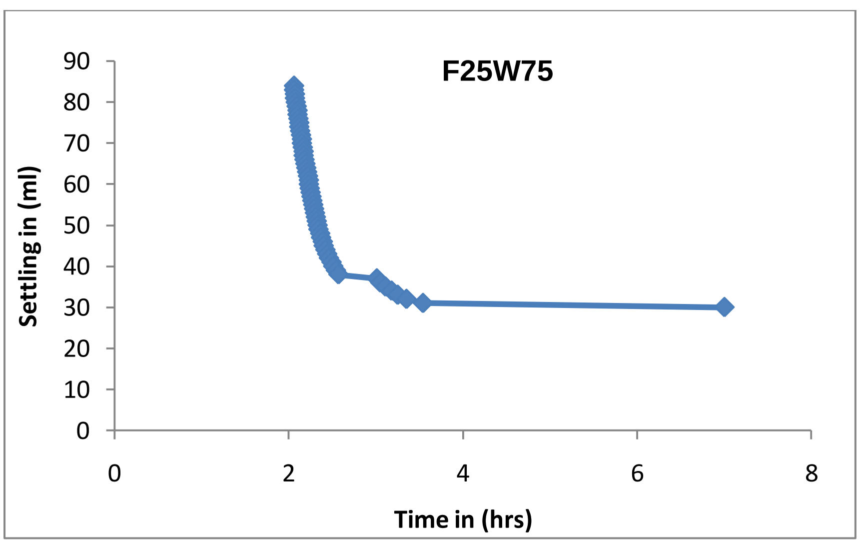
**4.7 SETTLING CHARACTERISTICS OF FLY ASH**

**FIGURE:-4.3 (VARIATION OF SETTLING CHARACTERISTICS OF FLY ASH WITH DIFFERENT COMPOSITION OF FLY ASH AND WATER)**




F50W50
Settling in ml
0
10
20
30
40
50
60
70
80
0
2
4
6
8
time in hrs


F35W65
settling in ml
0
10
20
30
40
50
60
70
80
90
0
1
2
3
4
5
Time in hr


F25W75
Settling in (ml)
0
10
20
30
40
50
60
70
80
90
0
2
4
6
8
Time in (hrs)

**For fly ash: 40 gm and water: 60ml**

Upper reading: 79 ml, lower reading: 78 ml

The total time taken for settling of the mixtures was found to be 2 hours 47 minutes at the reading 45ml of the mixtures in the flask.

**For fly ash: 50 gm and water: 50 ml**

Upper reading: 74 ml, lower reading: 72 ml

The total time taken for settling of the mixtures was found to be 3 hours and 15 minutes at the reading 55ml of mixtures in the flask.

**For fly ash: 35 gm and water: 65 ml**

Upper reading: 82 ml, lower reading: 80ml

The total time taken for settling of the mixtures was found to be 2 hours 40 minutes at the reading 39ml of the mixtures in the flask.

**For fly ash: 25 gm and water: 75ml**

Upper reading: 87 ml, lower reading: 84 ml

The total time taken for settling of the mixtures was found to be 1 hours and 50 minutes at the reading 31ml of mixtures in the flask. From the above figure, the composition of fly ash: 25 gm and water: 75ml was found to be the better parameter among the other parameters for the separation of solid-liquid in slurries during the filling activity.

### 4.8 SLUMP TEST

The slump-height of the fly ash collected from Jindal Power and Steel Company Ltd. was found to be 80mm.

# CHAPTER 5

## 5. SUMMARY AND CONCLUSIONS

- From the compositions of fly ash sample collected, it can be concluded that the fly ash sample belongs to ASTM class F.
- As the fly ash belongs to Class F category which acts as pozzolanic in nature, so it needs alkaline substance for becoming the strengthening.
- Visual observations of the SEM images show a distinct spherical nature for the grains for the fly ash samples.
- The specific gravity attribute to the mineralogical composition i.e presence of silica content and CaO.
- The moisture content of the samples were found out to be around 0.175% indicating that all the moisture have been evacuated and they are suitable for the construction works etc.
- Due to the fine grained nature of the solid constituents, the fly ash slurries exhibit marked sluggishness for settling and also did not provided clear supernatant solutions.
- The composition of fly ash: 25 gm and water: 75ml is the good parameter for the separation of solid-liquid in slurries during the filling activity.
- Pozzolanic properties of fly ash can be identified by presence/absence of calcium oxide. So class F fly ash is the weak in pozzolanic as very less amount of calcium oxide present.
- Strengthening of composite is due to dispersion strengthening, particle reinforcement and solid solution strengthening.

- The chemical, physical and mineralogical properties of fly ash had appreciable effects on performance of fly ash in filling low lying and mine void areas.
- Huge amount of fly ash is available for mine void filling and frequently in the vicinity of mines.

Bituminous (pozzolanic) fly ash is more frequently used to construct embankments and structural backfills than sub-bituminous or lignite (self-cementing) fly ash. This is due in part to the self-cementing characteristics of the latter type, which hardens almost immediately after the addition of water.

# REFERENCES


- Kumar, V. (2006): Fly ash- A resource for sustainable development, Proceedings of the International Coal Congress & Expo-2006, New Delhi, pp.191-199.
- Mishra, M.K. and Rao, K.U.M. (2006): Geotechnical characterization of fly ash composites for backfilling mine voids, Journal of Geotechnical and Geological Engineering, Vol.24, Issue 6, pp: 1749-1765.
- Bunn, T.F. (1989): Dense Phase Hydraulic Conveying of Power Station Fly Ash and Bottom Ash, Third International Conference on Bulk materials, Storage, Handling and Transportation, Newcastle 27-29 June, pp. 250-255.
- Bunn, T.F. and Chambers, A.J. (1993): Experiences with Dense Phase Hydraulic Conveying of Vales Point Fly Ash, Intl. Journal of Powder Handling and Processing, Vol.5, No-1, pp.35-45.
- Seshadri, V., Singh, S.N., Jain, K.K., and Verma, A.K. (2005): Rheology of fly ash slurries at high concentrations and its application to the design of high concentration slurry disposal system (HCSD), Proceeding of the International Conference on Fly Ash Utilization, New Delhi, pp. V.1.1-10.
- Verma, A.K, Singh, S.N., and Seshadri, V. (2008): Effect of Particle Size Distribution on Rheological Properties of Fly Ash Slurry at High Concentrations, Intl. Journal of fluid Mechanics Research, pp.445-457.
- Biswas, A., Gandhi, B.K., Singh, S.N. and Seshadri, V. (2000): Characteristics of coal ash and their role in hydraulic design of ash disposal pipelines, Indian Journal of Engineering and material science, Vol.7, pp. 1-7.
- Vlasak. P. and Chara, Z. (2007): Flow behavior and drag reduction of fluidic ash-water slurries, Hydro transport 17. The 17$^{th}$ International conf. on the Hydraulic Transport of solids, the South African Institute of Mining and Metallurgy and the BHR Group, pp. 39-55.
- Li, L., Usui, H. and Suzuki, H. (2002): Study of pipeline transportation of dense fly ash water slurry, Coal Preparation, Vol-22, pp. 65-80.
- Usui, H., Li, L. and Suzuki, H. (2001): Rheology and Pipeline Transportation of Dense Fly Ash-water Slurry, Korea-Australia Rheology Journal, Vol.13, No.1, pp. 47-54.

- IS codes (1987): Compendium of Indian Standards on Soil Engineering, Part-I, Bureau of Indian Standards, Nov., New Delhi, India.
- ASTM D422 63 (1994): Standard test method for particle size analysis of soils, Annual Book of ASTM Standards, 04.08, pp. 10-6.
- Jackson, M.L. (1958): Soil Chemical Analysis, Prentice-hall International, London.
- Clayton T. Crowe (2006), Multiphase flow handbook
- Ward, T. Bunn, and J. Chambers, (1999), The Bays water Fly Ash Transportation System, Coal Preparation, 21, 125–147.
- Y. Takahashi and T. Kinoshita, (1998), Experimental Study on Dense Phase Slurry of Fly Ash, Proc. of Int. Symp. on Upgrading and Slurrification of Low Rank Coals, Kobe,Japan, , pp. 102–115.
- Rai, A., et. al., Environment friendly building materials from mining and metallurgical industries waste, pp.-231-241
- K. C. Sahu, S. Tripathy and C. Samuel, (1991), Geochemistry of Indian coal and fly ash. Environmental considerations, Proc. Int. Conf. on Environmental Impact of Coal Utilization from Raw Materials to Waste Resources (K. C. Sahu, ed.), Indian Institute of Technology, Bombay, pp. 23–38.
- K. C. Sahu, (1991), Coal and fly ash problem, Proc. Int. Conf. on Environmental Impact of Coal Utilization from Raw Materials to Waste Resources (K. C. Sahu, ed.), Indian Institute of Technology, Bombay, pp. 11–22.
- Bumjoo Kim *et al.* (2005), "Geotechnical Properties of Fly and Bottom Ash Mixtures for Use in Highway Embankments", Journal of Geotechnical And Geo-environmental Engineering, ASCE; p. 914 – 924
- http://cobweb.ecn.purdue.edu/~mprezzi/pdf/10900241_geotechnical_properties.pdf
- V. Kumar, (2006), Handling and transportation of fly ash –A national level seminar conducted by -Technology information forecasting and assessment council, New Delhi.
- ASTM D 854-92, 1995, Standard Test Method for Specific Gravity of Soils, Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Vol. 04.08, pp. 80-83.

- V. S. R. Murthy, (1996), Fly ash construction of roads and embankments, Ash ponds and ash disposal systems (V. S. Raju et al., eds), Narosa Publishing House, New Delhi, pp. 222–237.


- V. S. R. Murthy, (1996), Fly ash construction of roads and embankments, Ash ponds and ash disposal systems (V. S. Raju et al., eds), Narosa Publishing House, New Delhi, pp. 222–237.


**Websites visited:**


- **http://www.tfhrc.gov/hnr20/recycle/waste/cfa51.htm**
- **http://www.hvfacprojectindia.com/Summary_Report.pdf**
- **http://www.coal-ash.co.il/docs/ashtech.pdf**
- **http://www.coal-ash.co.il/english/index.html**
- **http://www.rheology.or.kr/pdf/13-1%286%29.pdf**
- **http://en.wikipedia.org/wiki/BET_theory**
- **http://flyashbricksinfo.com/articles/current-fly-ash-generation-and-utilization-in-india.html**
- **http://www.tfhrc.gov/hnr20/recycle/waste/cfa54.htm**