CHAPTER 1

INTRODUCTION

1.1 GENERAL

Fly ash is the finely divided mineral residue resulting from the combustion of powdered coal in thermal power generating plants. The products formed during the combustion of coal are bottom ash, fly ash and vapour. Fly ash which tries to escapes with the combustion gas from the boiler is collected by either mechanical or electrostatic precipitator. The distribution of the ash between the bottom ash and fly ash fractions is a function of type of burner coal and boiler bottom (wet or dry). The burner type is especially a significant factor in determining the distribution of ash.

1.2 FLY ASH - INDIAN SCENARIO

In India, 75% of the total installed power generation is coal-based. Every year, 230 - 250 million tonnes of coal is being used for power generation. Indian coal has high ash content (30% – 50%) and thus it contributes to large volumes of ash after combustion. Around 110 million tonnes of ash is being generated every year. This figure is likely to go up to 170 million tonnes by the year 2010. Such a huge quantity of ash does pose challenging problems, in the form of land use, health hazards, and environmental degradation. Utmost care has to be taken both in disposal as well as in utilization to safeguard the interest of human life, wild life, and environment. Presently, 65,000 acres of land is being occupied by ash ponds.
It is estimated that by the year 2015, disposal of coal ash would require one square meter of land per person. Therefore, management of ash has become an important area of national concern.

Fly Ash is an excellent resource material for construction industry. In order to utilize the fly ash in construction industry, Ministry of Power, Government of India brought out the guidelines in the year 1996 based on the recommendations of the working group constituted. Subsequently, the Ministry of Environment and Forest (MoEF) brought out a Gazette notification on utilization of fly ash in 1999. Further, Ministry of Road Transport and Highways (MoRT&H) has notified amendments to Ministry’s Specifications for Roads and Bridge Works in the year 2003 to promote utilization of fly ash in embankment works. Also, the Indian Road Congress (IRC) has brought out many guidelines on use of fly ash in rigid and semi-rigid pavement specifications. In addition, use of fly ash for rural road works has been comprehensively covered in Rural Roads Manual IRC SP:20-2002. The guidelines regarding design/construction of embankments using fly ash are given in IRC SP: 58-2001.

Bureau of Indian standard BIS-1489 suggested that fly ash up to 35% by mass of cement conforming to BIS-3812 can be used in the manufacture of Portland pozzolanic cement (PPC). Also, IS 456-2000 suggested that up to 35% by mass of cement can be replaced with fly ash in RCC works. The Central Public Works Department, in its circular dated 13.05.2004, permitted to use fly ash in ready mixed concrete (RMC).

Fly ash is currently utilized in variety of applications such as cement manufacture, concrete mixes, fly ash bricks/blocks, light weight aggregates, cellular light weight concrete blocks, autoclaved aerated concrete blocks, roads/embankments etc.
The utilisation of fly ash in construction of pavement effectively serves to conserve the natural resources such as soil, coarse aggregate, river sand and cement. However, savings in construction cost decrease significantly with the lead less than 60 km and 90 km for flexible and rigid pavements respectively (Subodh Kumar et al 2006).

Statistics from the Ministry of Environment and Forest shows that only 30% of ash is being used. Out of this, about 22%, amounting to 7.75 million tonnes, is being used in road embankments. The MoEF has notified that all thermal power stations shall achieve 100% ash utilization within 4 years. Therefore, a much more aggressive strategy has to be developed and executed to utilize fly ash. High volume of fly ash in the form of flowable slurry is one of the ways to utilize large volume of fly ash. Flowable slurry is a mixture made of 90% - 95% fly ash and 5% - 10% Portland cement and sufficient quantity of water.

National Thermal Power Corporation (NTPC), Dadri, India has experimented on use of flowable slurry to control the growth of wild grass in switchyard area at Kahalgaon. Though the use of fly ash as flowable slurry has been initiated in India, it is yet to take momentum to utilize the large quantity of fly ash in the form of flowable slurry.

**Phosphogypsum**

Phosphogypsum (PG) is a by-product resulting from the phosphoric acid process in fertilizer manufacturing. Only 15% of the PG is being utilized by the cement and gypsum industries as a setting moderator for cement and for making gypsum plaster. The remaining 85% of PG is likely to cause an environmental problem. Around 6 million tons phosphogypsum available annually in India can be used as a resource to activate fly ash so as to
conserve natural resources, protection of the environment and energy savings (Mridul Garg et al 1996 and Manjit Singh 2007).

Quarry Waste

Crushed stone is a prosaic but nearly indispensable construction material. About 3 billion tonnes are produced worldwide from a great variety of rocks. Residue from stone crusher called quarry waste, a by-product in the production of crushed coarse aggregate, is about 1% of aggregate production.

1.3 Flowable Slurry

Conventional soil backfilling is common in all types of excavation. In many cases, the material was dumped into the trench leading to poor compaction. This made the researchers to use a low strength flowable material which does not require compaction. The controlled low strength material (CLSM) is relatively new and is different from conventional soil. In 1964, the U.S. Bureau of Reclamation documented the first known use of controlled low-strength material. It is perhaps the most revolutionary material which found one of its earliest applications in the year 1964 as the bedding material for 515 km long pipe line in the Canadian River Aqueduct project by the US Bureau of Reclamation. The use of CLSM reduced the project cost by 40% compared to conventional soil fill (Brewer 1994).

In the early 1970, the Detroit Edison Company in co-operation with Guhlman Corporation, a ready mix concrete producer, developed a backfill material called as flowable fly ash. It is made of fly ash with 4% to 5% cement. Application of flowable fly ash in the Belle River project saved approximately $1 million (Funston 1984). In due course, a company known as K-Krete Inc was formed and patented K-Krete as CLSM in 1977. Four
patents were received from United States for mix design, backfill technique, pipe bedding and dike construction (Brewer 1994).

Following K-Krete’s emergence as a replacement material for conventional compacted soil fill, other similar materials have been developed and used throughout United States and Canada. In order to pool up and disseminate information, ACI Committee was established in 1984 under the title Controlled Low Strength Material (CLSM) and a report was published in the year 1994. Subsequently, first revision was made in the year 1999 followed by second revision in the year 2005. This report provides basic information on applications, advantages of CLSM over conventional soil fill, material properties; mix proportioning, construction and quality control procedures.

Conventional CLSM mixtures usually consist of water, Portland cement, fly ash or other similar by-products and fine or coarse aggregates or both. Some mixtures consist of water, Portland cement and fly ash only. Special low density CLSM consists of water, Portland cement and performed foam. Air entraining admixtures have been used to enhance insulating characteristics and reduced density. Water reducing admixtures have been used to reduce water content and accelerate hardening. Although materials used in CLSM mixtures may meet ASTM or other standard requirements, the use of standardized materials is not always necessary. Selection of material should be based on availability, cost and specific application.

ACI 229R (2005) defines flowable slurry or controlled low strength material (CLSM) as a cementitious material that is in flowable state at the time of placement and has a specified compressive strength of 8.3 MPa (1200 psi) or less at the age of 28 days. The flowable slurry with a maximum compressive strength of 8.3 MPa is used where future excavation is unlikely such as structural fill under buildings. Lower compressive strength of 2 MPa
or less is necessary to facilitate future excavation of CLSM. CLSM is known by a variety of terms, including flowable slurry, flowable fill, unshrinkable fill, manufactured soil, controlled-density fill, flowable mortar, plastic soil-cement, soil-cement slurry and K-Krete.

For more than 40 years, CLSM is being used as a suitable alternative material for conventional soil fill. It is ideal for situations where placing and compaction of soil is difficult. It has numerous advantages such as easy to place, strong, durable, free from settlement, free from compaction, excavatability and allows fast return to traffic. Further, flowable slurry is a cost effective and environment friendly material suitable for variety of applications. Also, major attraction is its ability to utilize industrial by-products. CLSM is beneficial in the areas of backfilling, structural filling, insulation fills, isolation fills, conduit bedding, erosion control, pavement bases, void fillings, nuclear facilities and under ground construction. Proper setting and hardening of each layer has to be ensured to avoid hydrostatic pressure while the placing of CLSM along base walls in under ground construction (Ramme 1994). Also, sufficient care needs to be taken during back filling the pipes, conduits and power lines to avoid floating of these materials. The general requirements of CLSM are usually flowability, strength, excavatability and compressibility (Brewer 1994, Bhat and. Lovell 1997).

Flowability, removabilty and strength are the essential characteristics to be considered for back filling. The properties such as corrosion resistivity, flowability, removabilty and strength have to be evaluated to use CLSM for back filling and anti corrosion fill for pipes. The “R” value, flowability, removabilty and strength are the important characteristics of CLSM as thermal fill. In case of structural fill and pavement bases, it requires flowability and strength.
1.3.1 Mixture Proportioning of CLSM

Industrial by-products can be used in flowable slurry mixtures depending upon the requirements. Mixture proportioning can be done by trial and error until mixture with suitable properties is achieved. Also, the characteristics of the ingredients for flowable slurry are to be determined to assess their suitability to use in CLSM. Also, ACI prescribed guide lines to design CLSM mix.

1.3.2 Mixing, Transporting and Placing

Based on the requirements of project, CLSM may be mixed in central-mixed concrete plants and ready-mixed concrete trucks. Concrete pumps, ready mixed concrete trucks, portable batch plants and volumetric mobile mixers are commonly used to transport CLSM. Spillage and splashing should be considered on higher flowable mixtures during transit and placement. Also, segregation of CLSM with coarse aggregate materials can be a consideration on very wet (high water content) mixtures that are expected to flow long distances. CLSM may be placed by chutes, conveyors, buckets or pumps depending upon the application and accessibility. For trench fill, it is placed continuously. In case of pipe bedding CLSM is placed in lifts to prevent floating of the pipe (Ramme 1997).

1.3.3 Properties of CLSM

The properties of CLSM lie between soil and concrete. Both plastic an in-service properties need to be considered to use CLSM for various applications.
1.3.3.1 Plastic properties

**Flowability:** Flowability is the unique property of CLSM, which enables the materials to be self-leveling, flow and readily fill voids and be self-compacting. Flowability can be varied from stiff to fluid depending upon the requirements. Concrete slump cone (ASTM C 143), flow cone (ASTM C 939) and modified flow test (a open-ended cylinder of size 75 mm × 150 mm) are used for determining the flowability. Flowability ranges associated with the slump cone can be expressed as follows:

- Low flowability upto 150 mm (6 inches)
- Normal flowability 150 – 200 mm (6 to 8 inches)
- High flowability above 200 mm (> 8 inches)

Flowability mainly depends on amount of water and fly ash. Increasing the fly ash content has a dramatic effect on reducing water demand for a given flow. Use of air-entrained agent is not mandatory, but its addition in flowable slurry reduces the water demand (Thomas 1989).

**Segregation:** Separation of constituents in the mixture can occur at very high levels of flowability. With proper proportioning, a high degree of flowability can be attained without segregation. For highly flowable CLSM without segregation, adequate fines are required to provide required cohesiveness.

**Subsidence:** Subsidence deals with the reduction in volume of CLSM as it releases its water and entrapped air during consolidation. Subsidence of 10 mm to 20 mm per meter (1/8 to 1/4 inch per foot) of depth has been found with mixtures of high water content.
**Hardening time:** Hardening time is the time required for CLSM to change from the plastic state to a hardened state with sufficient strength to support the weight of a person. It is influenced by the amount and rate of bleed water released. Normal factors affecting the hardening time are:

- Type and quantity of cementitious material
- Permeability and degree of saturation of surrounding soil.
- Fluidity of CLSM.
- Proportioning of CLSM
- Mixture and ambient temperature
- Humidity
- Depth of fill.

Hence, hardening time of CLSM varies between 1 hr to 5 hr under normal conditions. Penetration resistance test according to ASTM C 403 can be used to measure the hardening time.

**Pumping:** CLSM can be delivered by conventional concrete pumping equipments. Careful proportioning is required to provide adequate void filling in the mixture. Inadequate void filling results segregation in the pump and may cause line blockage. Also, it is important to maintain a continuous flow through a pump line to avoid segregation and line blockage.

1.3.3.2 **In service properties**

**Strength (Bearing Capacity):** Unconfined compressive strength is a measure of the load carrying ability of CLSM. CLSM having compressive strength of 0.3 MPa to 0.7 MPa equates to an allowable bearing capacity of a well-compacted soil. The strength depends on the type of fly ash and amount
of Portland cement being added. The amount of Portland cement does not exceed 4% to 5% for excavatable flowable slurry produced with Class F fly ash. Curing methods specified for concrete are not considered essential for CLSM.

**Density:** Wet density of normal CLSM in place is in the range of 1840 kg/m$^3$ - 2320 kg/m$^3$, which is greater than most compacted materials. Mixes having a density of 800 kg/m$^3$ or more are generally classified as regular (Reg) CLSM and mixes with a density less than that are classified as low density (LD) CLSM. The air content of Reg- CLSM mixes does not exceed 30%, whereas, LD- CLSM can have air content up to 70%. The Reg-CLSM mixes consist of Portland cement and/or fly ash, fine aggregate and/or coarse aggregate, and water and air-entraining admixtures. LD- CLSM mixes usually consists of Portland cement and/or fly ash, water and a foaming agent (Charles et al 1997).

**Settlement:** Compacted fills by soil may undergo settlement even after proper compaction. However, such problem may not arise in the fills with CLSM.

**Thermal Insulation / Conductivity:** Where insulation is desired, the mixture should be proportioned to obtain low density and high porosity. Air entrained conventional mixtures reduce the density and increase the insulation.

Lightweight aggregate including bottom ash is used to reduce density. Foamed or cellular mixtures have very low densities and exhibit good insulation properties.

**Permeability:** Permeability of most excavatable CLSM is similar to compacted granular fills. It is in the range of $10^{-4}$ cm/sec to $10^{-5}$ cm/sec.
CLSM mixtures of higher strength and high fines content can achieve permeability as low as \(10^{-7}\) cm/sec.

**Shrinkage (Cracking):** Shrinkage and Shrinkage cracks do not affect the performance of CLSM. The linear shrinkage of CLSM is about 0.02%.

**Excavatability:** CLSM with a compressive strength of 0.34 MPa or less may be excavated manually. Mechanical equipment such as backhoes is used for excavating material having compressive strengths in range of 0.69 MPa to 1.38 MPa. The type and quantity of cementitious material are important parameters where, later age excavation is required.

When fly ash is incorporated in concrete, the silica reacts with free lime liberated by Portland cement to form additional cementitious compounds. As the cement used in CLSM is only 4% to 5%, amount of free lime liberated will be reduced and thereby amount of cementitious compounds is limited.

**Shear Modulus:** The shear modulus of normal density CLSM is in the range of 160 MPa to 380 MPa. The shear modulus is used to evaluate the expected shear strength and deformation of CLSM material.

**Corrosion:** The potential of corrosion resistance of CLSM is quantified by electrical resistivity tests. The moisture content of CLSM is one of the important parameters that influence the resistivity. The uniformity of CLSM reduces the possibility of corrosion caused by the use of dissimilar backfill materials and their varying moisture content.

**Compatibility with Plastics:** High, medium and low density polyethylene materials are commonly used as underground pipes. CLSM is
compatible with these materials. The fine gradation of CLSM minimizes scratching and nicking these polyethylene surfaces.

### 1.3.4 Quality Control

The American Society for Testing and Materials (ASTM) has introduced five standard test methods for testing freshly mixed controlled low strength material (CLSM). The standard methods are as follows:

i. ASTM D 6103 - Standard Test Method for flow Consistency of Controlled Low Strength Material (CLSM)

ii. ASTM D 6023 - Standard Test Method for Unit Weight, Yield, Cement Content and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM)

iii. ASTM D 6024 - Standard Test Method for the Ball Drop on Controlled Low Strength Material (CLSM) to determine suitability for load application

iv. ASTM D 5971 - Standard Practice for Sampling Freshly Mixed Controlled Low-Strength Material

v. ASTM D 4832 - Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders

### 1.4 NEED FOR PRESENT STUDY

The concept of controlled low strength material (CLSM) has revolutionized the construction industry globally during the past four decades but India is yet to catch up with the concept.
Normally, 5% of OPC and 95% of fly ash is used as a binder in CLSM. Recent investigations showed that ordinary portland cement can be completely replaced by alkalies and sulphates (industrial by-product/reagent grade) to obtain a binder with similar properties. The activated fly ash by industrial by-products as a binder in CLSM will boost the large-scale utilization of both fly ash and industrial wastes (Amitava Roy et al 1992, Narasimha et al 1995 and 2003, Poon et al 2001).

Phosphogypsum (PG) is a by-product resulting from the phosphoric acid process in fertilizer manufacturing. Only 15% of the PG is being utilized by the cement and gypsum industries as a setting moderator for cement and for making gypsum plaster. The remaining 85% of PG is likely to cause an environmental problem. Around 6 million tons phosphogypsum available annually in India can be used as a resource to activate fly ash so as to conserve natural resources, protection of the environment and energy savings (Mridul Garg et al 1996 and Manjit Singh 2007).

Crushed stone is a prosaic but nearly indispensable construction material. About 3 billion tones are produced worldwide from a great variety of rocks. Residue from stone crusher called quarry waste, a by-product in the production of crushed coarse aggregate, is about 1% of aggregate production.

It is possible to use quarry waste as fine aggregate in construction industry as a replacement for natural river sand. This will reduce not only the demand for river sand but also the environmental degradation. River sand which is used as a filler material in flowable slurry can be replaced by quarry waste (Nagaraj and Zahida Banu 1996 and Narasimhan 1999).

Water Bound Macadam (WBM) pavement is the most common and low cost pavement. It consists of large sized aggregates bound together using a suitable binder. Normally, locally available soil or gravel is used as binders.
In developed and urban areas, source of these binders are scarce and expensive. In most of the cases, these binders do not satisfy standard specifications. These dry binders are applied on the surface of the compacted aggregate and the required quantity of water is used to wash them down to fill the voids in the aggregates. It is not possible to ensure the binder to fill all the voids. This makes the pavement most vulnerable for fast deterioration. They are very sensitive to water and prone to erosion. They become dusty under traffic and also lead to pot holes.

In this context, there is a need to look for an alternative binder, which is economically viable, environment friendly and performs better under moving vehicles. Hence, there is an immense need to carry out investigation on developing self settling flowable slurry which will not only fill all the voids between aggregates but also bind the aggregate.

In view of the above, an attempt has been made in the present work to develop flowable slurry using industrial waste by-products such as fly ash, gypsum and quarry waste and to assess the feasibility of flowable slurry as a binder in pavement base course.

1.5 OBJECTIVES OF PRESENT STUDY

An attempt has been made in the present work to develop flowable slurry using industrial waste by-products such as fly ash, gypsum and quarry waste and to assess the feasibility of flowable slurry as a binder in pavement base course.

The following are the set objectives in the present work:

- To investigate flow characteristics of fly ash - gypsum slurry (F-G slurry) and fly ash-gypsum-quarry waste slurry (FGQWS)
To evaluate the engineering properties of flowable slurry such as compressive strength, density and plastic properties.

To study the durability of FGQWS under different environments.

To study the mineralogical and morphological studies to understand the strength development and durability of FGQWS mixture.

To study the characteristics of slurry bound macadam such as penetrability of FGQWS, compressive strength and modulus of elasticity of fly ash gypsum slurry bound macadam (FGSBM).

To evaluate the performance of FGSBM as sub base/base pavement material using semi-field investigations.

1.6 ORGANIZATION OF THE CHAPTERS

The present work on properties of high volume fly ash gypsum slurry with quarry waste and its use in pavement base course is organized in five chapters.

Chapter 1 provides brief introduction, advantages, applications, materials used, mixture proportioning, mixing, transporting and placing, properties and quality control of flowable slurry.

Chapter 2 deals with critical review of literature on various factors affecting the activation of fly ash, use of waste materials in flowable slurry, fly ash in stabilized base, asphalt concrete and rigid pavement.

Chapter 3 presents the materials and methodology adopted in the present work. It includes methodology adopted to study the characteristics of
material used, fly ash gypsum (F-G) slurry, F-G slurry bound aggregate and F-G slurry bound macadam.

Chapter 4 presents results and detailed discussion related to the characteristics of F-G slurry such as flowability, density, plastic properties, compressive strength, durability and morphology. Also, the characteristics of F-G slurry bound aggregate such as density, penetrability, compressive strength and modulus of elasticity are presented. Further, the results related to semi-field investigation are also presented in this chapter.

Chapter 5 presents the conclusion of this experimental investigation along with suggestions for further research work.