HIGH VOLUME FLY ASH CONCRETE

Submitted in partial fulfillment of the Degree of
Bachelor of Technology

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ABSTRACT

Our goal is to make the planet a cleaner and safer place to live. We plan to accomplish this goal by reducing the CO_2 emissions from the production of Ordinary Portland Cement by replacing the cement content in concrete with fly ash which is a pozzolanic material, a by-product of coal.

Approximately 1 tonne of CO2 is released into the atmosphere during the production of 1 tonne of cement. More than 170 million MT of fly ash is generated every year. Presently 65,000 acres of land is occupied by ash ponds and as per the Ministry of Environment & Forest, 30% of ash is being used in fillings, embankments, construction, etc.

We have used Fly Ash as a partial replacement of OPC and studied the strength of concrete and changes in properties of cement.

CERTIFICATE

This is to certify that the work titled "HIGH VOLUME FLY ASH CONCRETE" submitted by Sarthak Puri, Vikas Dev Sharma and Ankit Verma in partial fulfillment for the award of degree of B.Tech Civil Engineering of Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

Signature of Supervisor ……………………..

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Date ……………………..

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1. INTRODUCTION

1.1 GENERAL

Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. Approximately 1 tonne of CO_2 is released into the atmosphere during the production of 1 tonne of cement. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. Cement manufacturing consumes large amount energy about 7.36 x 10^6 kJ per tonne of cement.

On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass (Malhotra and Mehta 2002), is a significant development.

1.2 FLY ASH-BASED CONCRETE

In this work, fly ash (ASTM Class F)-based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods.

As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, in geopolymer concrete. The silicon and the aluminium in the low-calcium (ASTM Class F) fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials.

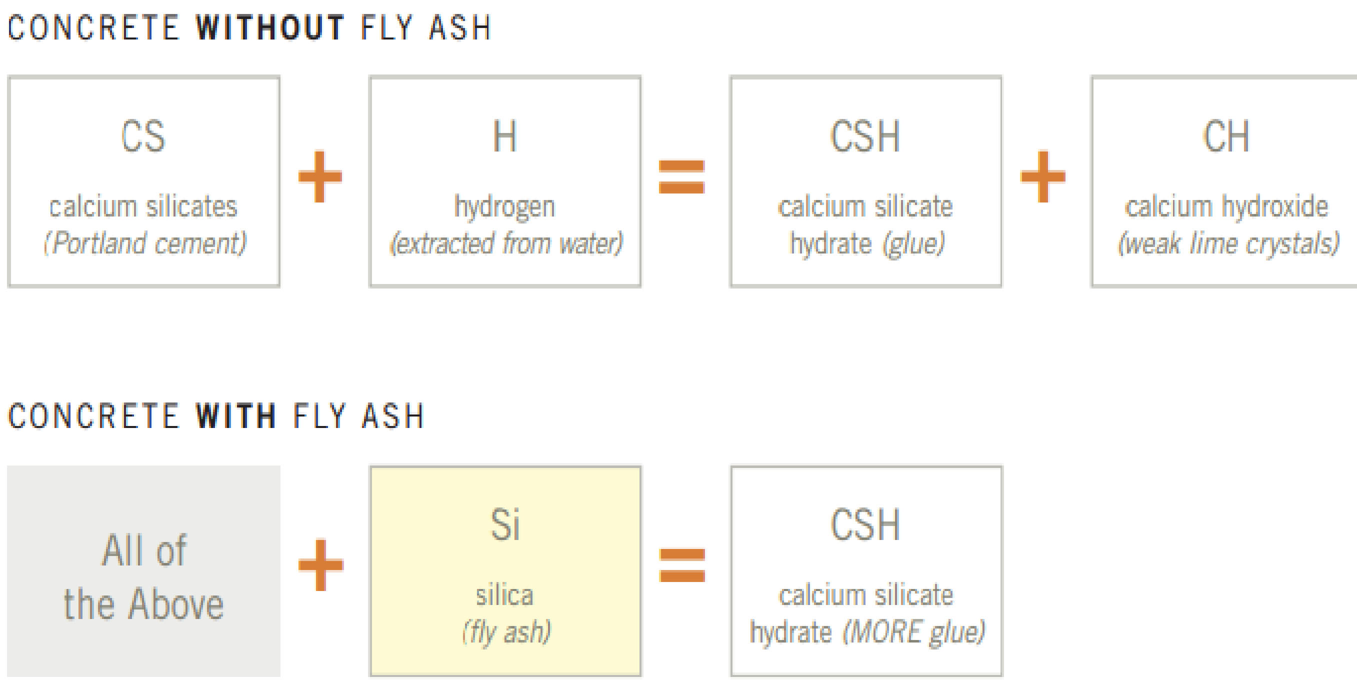


Fig 1.1: Difference in chemical composition

1.3 SCOPE

The research utilized low-calcium (ASTM Class F) fly ash as the base material for making geopolymer concrete. The fly ash was obtained from only one source. As far as possible, the technology and the equipment currently used to manufacture OPC concrete were used to make the geopolymer concrete.

The concrete properties studied include the compressive strength, and the workability of fresh concrete. The cement properties studied includes the initial and final setting time (IST and FST), tensile strength of cement, consistency with different proportions of fly ash.

1.4 EXAMPLES OF USE OF FLY ASH IN CONCRETE

Some of the structures wherein fly ash has been utilized are as under:

1. Fly ash concrete was used in Prudential Building the first tallest building in Chicago after World War II.

2. About 60,000 cum of fly ash concrete with an estimated saving of 3,000 tonnes of Ordinary Portland cement was used in Lednock Dam construction in UK during the year 1955.

3. About 60,000 $m^3$of fly ash concrete with 80/20 Ordinary Portland Cement/ fly ash having average slump of 175 mm was used in the piles and the foundation slab to meet the requirement of sulphate resistance concrete of Ferry bridge power station in UK during 1964.

4. In the 1980's, in Sizewell B Nuclear Power station fly ash has been used in about 3,0 0,000 m^3 concrete to improve workability for pumping, reduce temperature rise and increased resistance to chlorides and reduced risk of alkali aggregate reaction.

5. Fly ash has been used in construction of world's tallest building (then) "Petronas towers of Kuala Lumpur. The concrete used in the building was of two grades 80 MPa and 60 MPa. The fly ash content was about 37.5 % of total cementitious content in mix. Construction completed in the year 1998.

Fig 1.2: Petronas Tower of Kuala Lumpur

1.5 PRESENT SCENARIO ON FLY ASH IN INDIA

1. Over 75% of the total installed power generation is coal-based.
2. 230 – 250 million MT coal is being used every year.
3. More than 170 million MT of ash is generated every year.
4. Presently 65,000 acres of land occupied by ash ponds.
5. Presently as per the Ministry of Environment & Forest Figures, 30% of Ash is being used in Fillings, embankments, construction, block & tiles, etc.

1.6 INDIAN CASE STUDIES

1. Hiranandani Builders, Mumbai

A. Frame structures with buildings up to 20 stories, both in Powai, Thane and other locations.

B. Uses 30% fly ash in all structural concrete of grade M35.

C. Uses 40% fly ash in non-structural concrete.

D. Uses 50% Fly ash in Masonry.

2. Delhi metro rail

Used 30% fly ash in all structural concrete & 70% slag in underground sections.

View of tunnel of Delhi Metro Rail Corporation where fly ash has been used

Fig. 1.3: A Delhi Metro Tunnel Where Fly Ash Has Been Used.

3. Bandra-Worli Sea link

Fly ash concrete (M-30 grade and high performance M-60 grade) was utilized for tremie seal concrete and pile cap concrete in Bandra-Worli Sea link project. Fly ash was taken from Dahanu thermal power station, Mumbai.

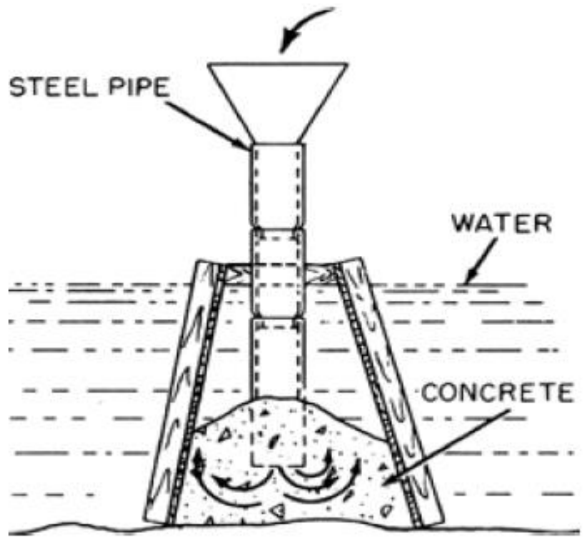


Fig. 1.4: Tremie seal concreting done in Bandra-Worli Sea Link

Fig. 1.5: Delhi Metro project – M35 HVFAC showed strengths close to 75 N/mm2 after 270 days

2. LITERATURE REVIEW

This Chapter presents the background to the needs for the development of alternative binders to manufacture concrete and the use of fly ash in concrete.

2.1 CONCRETE AND ENVIRONMENT

The trading of carbon dioxide (CO_2) emissions is a critical factor for the industries, including the cement industries, as the greenhouse effect created by the emissions is considered to produce an increase in the global temperature that may result in climate changes.

The climate change is attributed to not only the global warming, but also to the paradoxical global dimming due to the pollution in the atmosphere. Global dimming is associated with the reduction of the amount of sunlight reaching the earth due to pollution particles in the air blocking the sunlight. With the effort to reduce the air pollution that has been taken into implementation, the effect of global dimming may be reduced; however it will increase the effect of global warming. From this point of view, the global warming phenomenon should be considered more seriously, and any action to reduce the effect should be given more attention and effort.

The production of cement is increasing about 3% annually. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as the result of de-carbonation of limestone in the kiln during manufacturing of cement and the combustion of fossil fuels (Roy 1999).

The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth’s atmosphere (Malhotra 2002). Cement is also among the most energy-intensive construction materials, after aluminium and steel. Furthermore, it has been reported that the durability of ordinary Portland cement (OPC) concrete is under examination, as many concrete structures, especially those built in corrosive environments, start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life (Mehta and Burrows 2001).

The concrete industry has recognized these issues. For example, the U.S. Concrete Industry has developed plans to address these issues in 'Vision 2030: A Vision for the U.S. Concrete Industry'. The document states that *'concrete technologists are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice.*

Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases. In this document, strategies to retain concrete as a construction material of choice for infrastructure development, and at the same time to make it an environmentally friendly material for the future have been outlined (Mehta 2001; Plenge 2001).

In order to produce environmentally friendly concrete, Mehta (2002) suggested the use of fewer natural resources, less energy, and minimize carbon dioxide emissions. He categorized these short-term efforts as '*industrial ecology'*. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption. Likewise, McCaffrey (2002) suggested that the amount of carbon dioxide (CO_2) emissions by the cement industries can be reduced by decreasing the amount of calcined material in cement, by decreasing the amount of cement in concrete, and by decreasing the number of buildings using cement.

2.2 FLY ASH

According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as '*the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system'*(ACI Committee 232 2004). Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1 μm to no more than 150 μm.

The types and relative amounts of incombustible matter in the coal determine the chemical composition of fly ash. The chemical composition is mainly composed of the oxides of silicon (SiO_2), aluminum (Al_2O_3), iron (Fe_2O_3), and calcium (CaO), whereas magnesium, potassium, sodium, titanium, and sulphur are also present in a lesser amount.

The major influence on the fly ash chemical composition comes from the type of coal. The combustion of sub-bituminous coal contains more calcium and less iron than fly ash from bituminous coal. The physical and chemical characteristics depend on the combustion methods, coal source and particle shape.

The chemical compositions of various fly ashes show a wide range, indicating that there is a wide variation in the coal used in power plants all over the world. Fly ash that results from burning sub-bituminous coals is referred as ASTM Class C fly ash or high-calcium fly ash, as it typically contains more than 20 percent of CaO. On the other hand, fly ash from the bituminous and anthracite coals is referred as ASTM Class F fly ash or low-calcium fly ash. It consists of mainly an aluminosilicate glass, and has less than 10 percent of CaO. The color of fly ash can be tan to dark grey, depending upon the chemical and mineral constituents.

Aside from the chemical composition, the other characteristics of fly ash that generally considered are loss on ignition (LOI), fineness and uniformity. LOI is a measurement of unburnt carbon remaining in the ash. Fineness of fly ash mostly depends on the operating conditions of coal crushers and the grinding process of the coal itself. Finer gradation generally results in a more reactive ash and contains less carbon.

In 2001, the annual production of fly ash in the USA was about 68 million tons. Only 32 percent of this was used in various applications, such as in concrete, structural fills, waste stabilization/solidification etc. (ACAA 2003). Worldwide, the estimated annual production of coal ash in 1998 was more than 390 million tons. The main contributors for this amount were China and India. Only about 14 percent of this fly ash was utilized, while the rest was disposed in landfills (Malhotra 1999). In the year 2010, the amount of fly ash produced worldwide was about 780 million tonnes (Malhotra 2002). The utilization of fly ash, especially in concrete production, has significant environmental benefits, viz, improved concrete durability, reduced use of energy, diminished greenhouse gas production, reduced amount of fly ash that must be disposed in landfills, and saving of the other natural resources and materials (ACAA 2003).

2.3 USE OF FLY ASH IN CONCRETE

One of the efforts to produce more environmentally friendly concrete is to reduce the use of OPC by partially replacing the amount of cement in concrete with by-products materials such as fly ash. As a cement replacement, fly ash plays the role of an artificial pozzolan, where its silicon dioxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (C-S-H) gel. The spherical shape of fly ash often helps to improve the workability of the fresh concrete, while its small particle size also plays as filler of voids in the concrete, hence to produce dense and durable concrete.

An important achievement in the use of fly ash in concrete is the development of high volume fly ash (HVFA) concrete that successfully replaces the use of OPC in concrete up to 60% and yet possesses excellent mechanical properties with enhanced durability performance. HVFA concrete has been proved to be more durable and resource-efficient than the OPC concrete (Malhotra 2002). The HVFA technology has been put into practice, for example the construction of roads in India, which implemented 50% OPC replacement by the fly ash (Desai 2004).

2.4 DEFINITION OF HIGH VOLUME FLY ASH CONCRETE (HVFA)

In recent years economic and environmental considerations have increased the incentive to use fly ash at higher replacement levels than those traditionally used. In some cases, fly ash has replaced more than 50% of the Portland cement in concrete mixtures. The term **High Volume Fly Ash Concrete (HVFA)** was coined in 1985 by Malhotra. The HVFA concrete has excellent workability, low heat of hydration, adequate early-age strength and very high later-age strength, low drying shrinkage, and excellent durability (Malhotra and Mehta, 2002). HFVA concrete has generally been found to be an economical and durable concrete system for structural concrete and many other concreting projects. HVFA concrete can be mixed, transported, placed, and finished by conventional means. The two most important factors that have to be addressed in order to ensure HVFA concrete be durable is a low water to cementitious materials ratio and an extended period of moist curing. It is perhaps for this reason that specifications have been reluctant to permit higher levels of fly ash to be used for general concreting purposes (Thomas, 2003).

2.5 EFFECT OF HVFA ON CONCRETE PROPERTIES / POTENTIAL PROBLEMS

2.5.1 Workability of Concrete

Fly ash particles are generally spherical in shape and reduce the water requirement for a given slump. The spherical shape helps to reduce friction between aggregates and between concrete and pump line and thus increases workability and improve pumpability of concrete. Fly ash use in concrete increases fines volume and decreases water content and thus reduces bleeding of concrete.

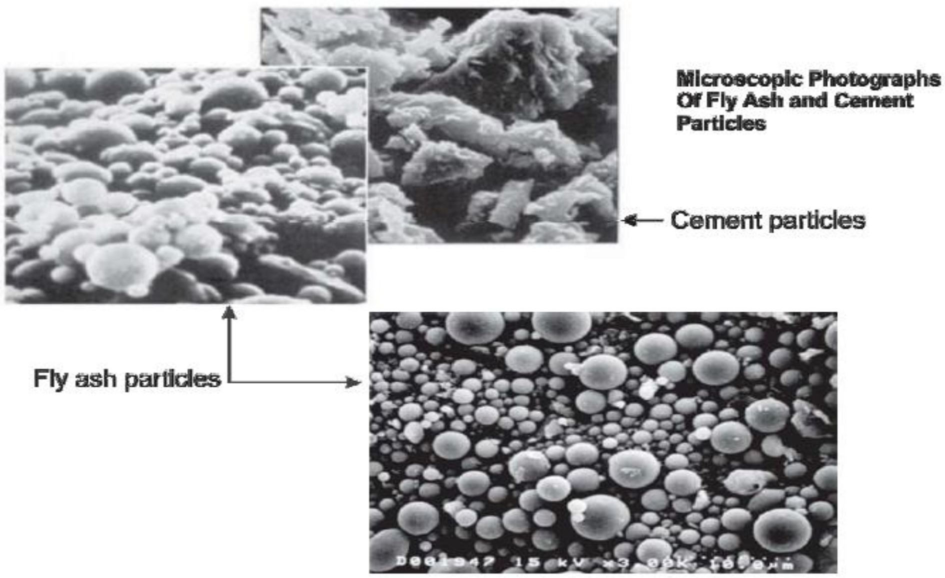


Fig: 2.1 Microscopic View of Fly Ash.

2.5.2 Plastic Shrinkage

Plastic shrinkage occurs on the surface of freshly mixed concrete soon after it has been placed, while it is being finished or shortly thereafter. Plastic shrinkage occurs when environmental conditions produce rapid evaporation of moisture from the concrete surface. These cracks occur when water evaporates from the surface faster than it can rise to the surface during the bleeding process. This creates rapid drying shrinkage and tensile stresses in the surface that often result in short, irregular cracks. Plastic shrinkage is a potential problem of HFVA concrete. The amount of bleed water available for evaporation of HVFA concrete is very low because of its low unit water content, and therefore it is recommended that moist curing of HVFA concrete be started as soon as the concrete is poured to limit the amount of evaporable water and reduce plastic shrinkage (Malhotra and Mehta, 2002).

2.5.3 Heat of Hydration

Replacing Portland cement with fly ash can reduce the exothermic reaction between cement and water. Because of the slower pozzolanic reaction, partial replacement of Portland cement with fly ash results in a release of heat over a longer period of time. Therefore, the concrete temperature remains lower because heat is dissipated as it is produced. It has been estimated that the contribution of fly ash to early age heat generation ranges from 15-30% of that of an equivalent mass of Portland cement. Although most low calcium fly ashes (Class F) will reduce the rate of temperature rise when used as Portland cement replacement, high calcium fly ashes (Class C) do not always cause reduced heat evolution because of their self cementitious properties (Joshi and Lohtia, 1997). In general, the rate of heat evolution parallels the rate of strength development.

Temperature rise in concrete depends upon the following factors: rate of heat generated by hydration and pozzolanic reactions, rate of heat loss and the thermal properties of the concrete and surrounding environment, and the size of the concrete member.

2.5.4 Strength

Both the strength at a given age and the rate of strength gain of fly ash concrete are affected by the characteristics of the fly ash (properties, chemical composition, particle size, reactivity), the cement with which it is used, the proportions of each used in the concrete, the temperature and other curing conditions. Although concrete mixtures containing fly ash tend to gain strength at a slower rate than concrete without fly ash, the long-term strength is usually higher (Bremner and Thomas, 2004).

Concrete containing fly ash with equivalent or lower strength at early ages may have equivalent or higher strength at later ages than concrete without fly ash as long as the concrete is moist cured or exposed to sufficient quantities of moisture during service.

The strength gain will continue with time and results in higher later-age strength than can be achieved by using additional cement. However, by using accelerators, activators, water reducers, or by changing the mixture proportions, equivalent 3 or 7-day strength may be achieved.

High calcium fly ashes (Class C) will show a more rapid strength gain at early ages than concrete made with a lower calcium fly ash (Class F) because Class C ashes often exhibit a higher rate of reaction at early ages than Class F ashes. However, Class F ashes will contribute to greater long-term strength gain of concrete than Class C ashes in spite of its slower rate of strength development at early age. Because of its fineness and pozzolanic activity, fly ash in concrete improves the quality of cement paste and the microstructure of the transition zone between the binder matrix and the aggregate.

With respect to HVFA concrete, there is concern within the industry that the low early strength is a potential problem. However, many studies have been conducted regarding this issue and the findings are positive. Siddique (2003) reports that replacement of cement with 40%, 45%, and 50% fly ash content reduces the compressive strength of concrete at 28 days, but there is a continuous and significant improvement of strength beyond 28 days when compared to conventional Portland cement concrete. He also states that the strength of concrete with 40%, 45%, and 50% fly ash content, even at 28 days is sufficient for use in reinforced concrete construction.

2.5.5 Permeability

Permeability is the most important aspect of concrete durability. To be durable, concrete must be relatively impervious. In general, lower permeability means greater durability. Permeability of concrete is governed by many factors such as the amount of cementitious material, water content, aggregate grading, consolidation, and curing. Through its pozzolanic properties, fly ash chemically reacts with $Ca(OH)_2$ and water to produce C-S-H gel.

The incorporation of fly ash can result in considerable pore refinement. The transformation of large pores to fine pores, as a result of the pozzolanic reaction between Portland cement paste and fly ash, substantially reduces permeability in cementitious systems. After 6 months of curing, fly ash concretes are much less permeable than ordinary Portland cement concretes due to the slow pozzolanic reaction of fly ash.

The permeability of HFVA concrete is very low. The estimated permeability (hydraulic conductivity) of HVFA concrete is less than 10-13 m/s. As a comparison, normal Portland cement concrete with a W/C of 0.40 would have an estimated permeability of 10-12 m/s (Malhotra and Mehta, 2002).

2.5.6 Sulphate Attack

Sulphate attacks in concrete occur due to reaction between sulphate from external origins or from atmosphere with surplus lime leads to formation of etrringite, which causes expansion and results in volume destabilization of the concrete. Increase in sulphate resistance of fly ash concrete is due to continuous reaction between fly ash and leached out lime, which continue to form additional C-S-H gel. This C-S-H gel fills in capillary pores in the cement paste, reducing permeability and ingress of sulphate ions.

2.5.7 Reduced alkali- aggregate reaction

Certain types of aggregates react with available alkalis and cause expansion and damage to concrete. These aggregates are termed as reactive aggregates. It has been established that use of adequate quantity of fly ash in concrete reduces the amount of alkali aggregate reaction and reduces/ eliminates harmful expansion of concrete. The reaction between the siliceous glass in fly ash and the alkali hydroxide of Portland cement paste consumes alkalis thereby reduces their availability for expansive reaction with reactive silica aggregates.

2.5.8 Environmental benefits of fly ash use in concrete

Use of fly ash in concrete imparts several environmental benefits and thus it is ecofriendly. It saves the cement requirement for the same strength thus saving of raw materials such as limestone, coal etc. required for manufacture of cement.

Manufacture of cement is high-energy intensive industry. In the manufacturing of one tonne of cement, about 1 tonne of CO^2 is emitted and goes to atmosphere. Less requirement of cement means less emission of CO^2 result in reduction in greenhouse gas emission.

Due to low calorific value and high ash content in Indian Coal, thermal power plants in India are producing huge quantity of fly ash. This huge quantity is being stored / disposed off in ash pond areas. The ash ponds acquire large areas of agricultural land. Use of fly ash reduces area requirement for pond, thus saving of good agricultural land.

2.6 SALIENT ADVANTAGES OF USING FLY ASH IN CEMENT CONCRETE

• Reduction in heat of hydration and thus reduction of thermal cracks and improves soundness of concrete mass.
• Improved workability / pumpabilty of concrete.
• Converting released lime from hydration of OPC into additional binding material – contributing additional strength to concrete mass.
• Pore refinement and grain refinement due to reaction between fly ash and liberated lime improves impermeability.
• Improved impermeability of concrete mass increases resistance against ingress of moisture and harmful gases result in increased durability.
• Reduced requirement of cement for same strength thus reduced cost of concrete.

2.7 CONCLUDING REMARKS

Based on the reported literature on the use of fly ash as a binder in mortar / concrete, following observations have been done:

1. Fly ash has been generally considered as a partial replacement of cement, in varying quantities ranging from 20% to 70%) and to some extent partial replacement of fine aggregate.
2. Studies on fly ash-cement pastes were focused towards understanding the hydration process.
3. Studies on high-calcium fly ash based concrete, in general, have not been that extensively carried out and reported, when compared to low- calcium fly ash-based systems.
4. Even the exhaustive investigations carried out at International level and reported, especially, on the alkali-activation of natural pozzolans and fly ashes, have been carried out on 'demonstration scale' or confined only up to their application as a mortar.

3. MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter summarizes the materials used in performing the various tests of fly ash concrete and the procedure to find out the various mix designs.
Fly ash occupies huge disposal area and has a potential threat of local ground water and surface water pollution by leaching of metal. To mitigate the problem is to recycle the fly ash as a safe construction material and other purposes. Due to inherent self-hardening properties of fly ash it is used in different civil engineering applications. But it lacks adequate strength or durability. Suitable mixture is one of the methods to enhance the strength of the fly ash.

3.2 MATERIALS USED

For the development of concrete in the laboratory, materials used were ordinary Portland cement, fly ash, fine aggregates, coarse aggregate and water.

Cement: Type of cement used i.e. 43 grade ordinary Portland cement (OPC), as per IS 12269, manufactured by Ambuja Cement and Portland-pozzolona cement (PPC), as per IS 1489, manufactured by Ambuja cement, containing approximately 30% fly ash.

Water: Ordinary tap water was used in the production of concrete.

Aggregates: Sizes of coarse aggregates used in this project i.e. 20-mm graded aggregate as per IS: 383 was used for different grades of concrete.

Fly ash: The fly ash used is from Jaypee Cement Plant at Baga and of class F (ASTM).

3.3 GRADING OF FINE AGGREGATES – Acc. To IS: 383-1970

The sieve analysis of fine aggregates was done in order to find out the zone of the fine aggregates which is required for the calculation of the mix grade designing.

Table 3.1 Sieve Analysis of Fine Aggregate

IS SIEVE SIZE	Wt. RETAINED	% RETAINED	CUMM. % RET.	% PASSING
10mm	0gm	0	0	**100**
4.75mm	3.1gm	0.31	0.31	**99.69**
2.36mm	34.6gm	3.46	3.77	**96.23**
1.18mm	155.7gm	15.57	19.34	**80.66**
600micron	116.1gm	11.61	30.95	**69.05**
300micron	175.1gm	17.52	48.47	**51.53**
150micron	397.6gm	39.76	88.23	**11.77**
PAN	117.7gm	11.77	100	**0**

Weight of sample: 1000gm

Acc. to IS: 383-1970, zone of sand came out to be **GRADING ZONE III.**
The grading limits of the fine aggregates according to the IS: 383-1970 are shown in the Table 1 in APPENDIX.

3.4 MIX PROPORTIONS (IS: 10262: 2009)

Proportioning of concrete mixes can be regarded as procedure set proportion for the most economical concrete mix for specified durability and grade for required site conditions.
Mix Designing Methods according to Indian Bureau of Standard is adopted as a general guideline along with the field experience of Project Guide for this work programme to arrive at mix proportioning for the three grade of concrete (M20,M30 and M40).

3.4.1 Mixture Proportioning Procedure

The basic steps involved in the Indian Standard method of concrete mix design can be summarized as follows:

Step 1: Determination of Target Mean Strength or field strength

Target Mean Strength is determined as follows**:**

$f_t = f_{ck} + k\ s$

Where f_t = target mean compressive strength at 28 days,

f_{ck} = characteristics compressive strength at 28 days,

k = a statical value depending upon the accepted portions of low results and the number of tests,

s = assumed standard deviation,

Note: As per **IS: 456-2000**, the value of 'k' is taken 1.65, assuming that characteristic strength is expected to fall not more than 5 percent of test result. And value of 's' is also taken from IS 10262-2009 table 1, which is given for each grade of concrete. **The value of 's' for M20 is 4 MPa and 5 MPa for M30 and M40 grade of concrete.**

Step 2: Selection of water-cement ratio

The water-cement ratio is chosen from table no.5 of IS: 456-2000, which specify the minimum cement content, maximum water cement ratio and minimum grade of concrete for the different exposure conditions.The value selected is compared with available relations in SP: 23-1982, for the determination of water-cement ratio for the target mean compressive strength at 28 days.

It is noted here that water-cement ratio for the determined target mean compressive strength at 28 days gives lower value than specified maximum value in table 5 of IS: 456-2000. Even curve-E, which is applicable for 53 grade of OPC, in figure 47 of SP: 23-1982, which consider 28 days compressive strength of cement, incorporated in the mix proportions, also gives slightly lesser value of water-cement ratio.

Step 3: Estimation of mixing water

The approximate water content is selected from the table 35 and 38 of SP: 23-1982, applicable for normal concrete mix, which considers the aggregate type (whether crushed or uncrushed), maximum size of the aggregate and required slumps as a measure of level of workability.

Step 4: Estimation of air content

The estimated entrapped air content is taken (2%) from table No. 41 of SP: 23-1982, based on nominal maximum size of the aggregate.

Step 5: Determination of cement content

The cement content is calculated from the selected water-cement ratio and estimated water content. The cement content so calculated is compared with the minimum required cement content as per the durability consideration as stipulated in the IS: 456-2000. The greater of the two values is adopted. It is noted that the quantity adopted is inclusive of the addition of part supplementary cementitious material to OPC.

Step 6: Estimation of percentage of sand in total aggregates

The percentage of sand in total aggregates depends upon the grading of sand to be incorporated in the mix. The general guideline is obtained from the figure 45 of SP: 23-1982, which is based on maximum size of coarse aggregates and the required slump value targeted. It is to be noted that concrete with super plasticizers will have different percentage of sand than concrete without super plasticizer for the same w/c ratio.

Apart from the guidelines given in the figure 45 of the SP: 23-1982 for the calculation of the percentage of sand in total aggregates, percentage of fine aggregates is also seen in relation to the ratio of total fine contents (cement plus fly ash plus fine aggregates) to total coarse aggregate content per m^3 of mature. If it was not found in the specified range then the percentage is adjusted accordingly. The ratio of total fines to aggregates is a very important factor which influence the quality of concrete very much, varies with the water-cement ratio of concrete for a given slump range values.

It is noted that that the water-cement ratio 0.5, 0.45 and 0.5 was kept for the production of M20, M30 and M40 respectively.

Step 7: Determination of fine and coarse aggregates

With the quantities of cement, fly ash, water and percentage of sand in total aggregates already determined, the content of fine aggregates and coarse aggregates is calculated from the following equations:

$V = [W + C/S_c + F/S_p + (1 / p) * (f_a / S_{fa})] \times 1/1000$ -(2) for FA

$V = [W + C/S_c + F/S_p + \{1 /(1- p)\} * (C_a / S_{ca})] \times 1/1000$ -(3) for CA.

Where V = absolute volume of fresh concrete i.e. gross volume (1 m^3) minus the volume of entrapped air,

W = mass of water (kg) per m^3 of the concrete,

C = mass of cement (kg) per m^3 of the concrete,

S_c = specific gravity of cement,

F = mass of fly ash (kg) per m^3 of the concrete,

Sp = specific gravity of fly ash (2.16)

P = ratio of fine aggregate to total aggregates by absolute volume

fa = total mass of fine aggregates (kg) per m^3 of the concrete,

S_{fa} = specific gravity of saturated surface dry fine aggregates,

Ca = total mass of coarse aggregates (kg) per m^3 of the concrete,

S_{ca} = specific gravity of saturated surface dry coarse aggregates.

Step 8: Adjustment of the trial mixture proportions

The trial mixture proportions were adjusted according to the following guidelines to achieve targeted slump (as a measure of workability).

(A) Moisture content – as a part of quality control during production of concrete. It is necessary to provide moisture content correction to dry batching. In this project work sand and coarse aggregate are dried in room temperature after sufficient amount of water sprinkled on the aggregate to avoid further absorption of water from the estimated mixing water quantity. The same quality control was maintained for each batch of concrete produced.

(B) Initial slump- If initial slump is not achieved in the desired range, then the mixing water is adjusted so as to maintain water – cement ratio same. With a change in mixing water quantity, sand quantity is also adjusted accordingly.

Step 9: Selection of Optimum mixture proportions

Once trial mixes have adjusted, test specimens i.e. 150 mm cubes are cast from the concrete produced and finally from the strength tests result of the specimens, optimum of proportioning of mixture is suggested.

For the concrete mixtures of grade M20, ratio used was **1:1.5:3**
For the concrete mixtures of grade M30, ratio used was **1:1.22:2.73**
For the concrete mixtures of grade M40, ratio used was **1:1.2:3.03**

4. EXPERIMENTS AND THEIR PROCEDURES

4.1 INTRODUCTION

This Chapter presents the details of development of the process of making low calcium (ASTM Class F) fly ash-based concrete.

In order to develop the fly ash-based concrete technology, therefore, a rigorous trail-and-error process was used. The focus of the study was to identify the salient parameters that influence the mixture proportions and the properties of low calcium fly ash-based concrete.

As far as possible, the current practice used in the manufacture and testing of ordinary Portland cement (OPC) concrete was followed. The aim of this action was to ease the promotion of this 'new' material to the concrete construction industry.
In order to simplify the development process, the compressive strength was selected as the benchmark parameter.

4.2 PRELIMINARY LABORATORY WORK

In the beginning, numerous trial mixtures of geopolymer concrete were manufactured, and test specimens in the form cubes. A mobile rotating drum concrete mixer available in the concrete laboratory for making OPC concrete was used to manufacture the fly ash based concrete.

The main objectives of the preliminary laboratory work were:
1. To familiarize with the making of fly ash-based geopolymer concrete.
2. To understand the effect of the sequence of adding the alkaline liquid to the solids constituents in the mixture.
3. To observe the behavior of the fresh fly ash-based geopolymer concrete.
4. To develop the process of mixing and the curing regime.
5. To understand the basic mixture proportioning of fly ash-based geopolymer concrete.

4.3 TESTS DONE ON CEMENT

Proponents of fly ash claim that replacing Portland cement with fly ash reduces the greenhouse gas "footprint" of concrete, as the production of one ton of Portland cement generates approximately one ton of CO_2, compared to no CO_2 generated with fly ash. Various tests were conducted on cement and the results are shown in the APPENDIX and the graphs plotted are shown in the next chapter.

4.3.1 Normal Consistency of Cement

The percentage of water by weight of cement which produces a consistency which permits plunger having diameter 10 mm to penetrate up to depth of 5 to 7 mm above the bottom of mould is called the normal consistency of cement paste. Normal Consistency can be found out with the use of Vicat's needle apparatus.

APPARATUS

1. Vicat needle apparatus with plunger of 10 mm dia.
2. Trowel
3. Balance etc.

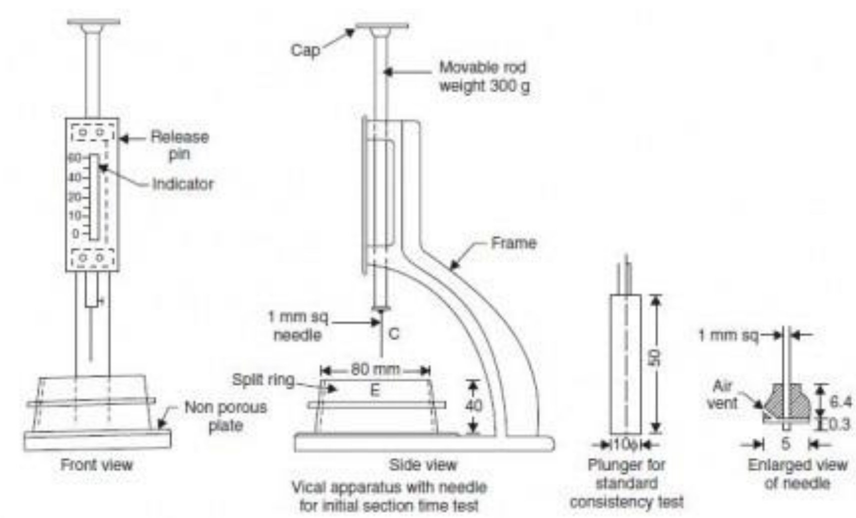


Fig: 4.1:Vicat's Apparatus

PROCEDURE:

1. Take 400 gm of cement.
2. Add 25 % of water in dry cement and mix it. The gauging time should not be less than 3 minutes and not more than 5 minutes. The gauging time is time consumed from adding of water in dry cement to commencing to fill the mould.
3. After mixing properly, fill the vicat mould with this paste.
4. Level the surface of cement with top of mould.
5. A standard plunger, 10mm diameter and 50mm long is attached and brought down to touch the surface of the paste in the test block.
6. Release the plunger and allow it to penetrate by its own weight and note down the reading.
7. If the penetration is less than the desired one then make another trial sample by increasing water content and find the penetration.
8. Repeat the steps until the desired penetration is obtained, i.e. penetration up to 5 to 7 mm. above the bottom is achieved.

4.3.2 Initial and Final Setting Time of Cement

Initial setting time is the time elapsed between the moments that the water added to the cement, to the time that the paste starts losing its plasticity.

Final setting time is time elapsed between the moment that the water added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure. IST AND FST can be found out with the use of Vicat's needle apparatus.

APPARATUS

1. Vicat's needle apparatus
2. Balance
3. Stop watch etc.
4. Triple Beam Balance
5. Mixing Bowl
6. Glass Plate
7. Graduated Cylinder
8. Stop Watch
9. Rubber Gloves
10. Scrapper
11. Mortar Mixer

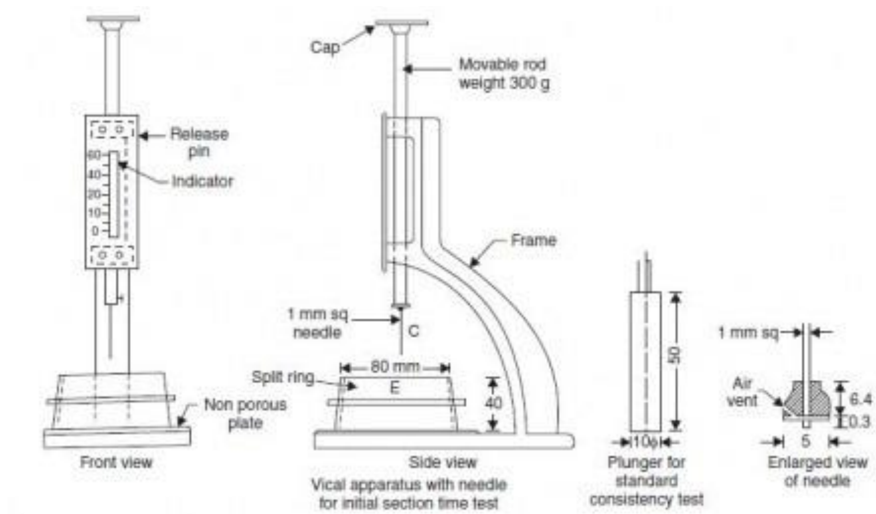


Fig. 4.2: Vicat's Apparatus

PROCEDURE**:**

1. Weigh 400 gm of cement.
2. Add 0.85 P % water by weight of cement and mix it thoroughly, where P is the normal consistency of cement.
3. Fill the mould with the cement paste and level off the cement surface with top of mould. The gauging time should not be less than 3 minutes and should not be more than 5 minutes.
4. Place the mould on the non-porous plate under the needle ($1mm^2$) of apparatus.
5. Bring the needle in contact with the cement surface and release it.
6. The needle completely pierces through the test block. But after some time when the paste starts losing its plasticity, the needle unable to penetrate.
7. Repeat the step (5) until the needle fails to pierce the sample for about 5 mm measured from the bottom of the mould note down this time. It is **initial setting time**
8. Replace the needle by needle with an annular attachment.
9. Bring the needle with attachment near the surface of cement and release it.
10. the cement shall be considered as finally set when, lowering the attachment gently cover the test block, the centre needle makes an impression, while the circular cutting age of the attachment fails to do so.
11. Repeat the step (8) until the surface so hard that the centre needle does not pierce through the paste more than 0.5mm
12. Note down this time also, this is **final setting time**.

4.3.3 Tensile Strength of Cement

Tensile strength of cement is the measure of ability of cement mortar specimen to withstand in tensile load. Although PCC is not nearly as strong in tension as it is in compression, PCC tensile strength is important in pavement applications. Tensile strength is typically used as a PCC performance measure for pavements because it best simulates tensile stresses at the bottom of the PCC surface course as it is subjected to loading. Tensile strength of cement can be checked by making briquette's and testing them.

APPARATUS**:**

1. Briquette testing machine
2. Balance
3. Mould assembly

PROCEDURE**:**

1. Weigh 250 gm of cement, 750gm of sand and mix them properly.
2. Take (p/5 + 2.5) % water of the total weight of sand and cement and mix them properly.
3. Interior surface of the mould be greased.
4. Place the whole quantity of mortar in briquette by compacting it with tempering rod.
5. Put the mould at temp $27 \pm 2^{o}C$ and relative humidity 90% for 24 hrs. then place them in water.
6. Test the briquette for 3 and 7 days.

Fig. 4.3: Briquette Testing Machine

4.3.4 Soundness of Cement

Soundness of cement is the property of hardened cement paste undergoing large change in volume after setting without delayed destructive expansion. This destructive expansion is caused by excessive amounts of free lime or magnesia. This change in volume may cause crack and disintegration of concrete. Soundness of cement can be checked by using Le-Chateliers apparatus.

APPARATUS**:**

1. Le Chatelier apparatus
2. Measuring scale

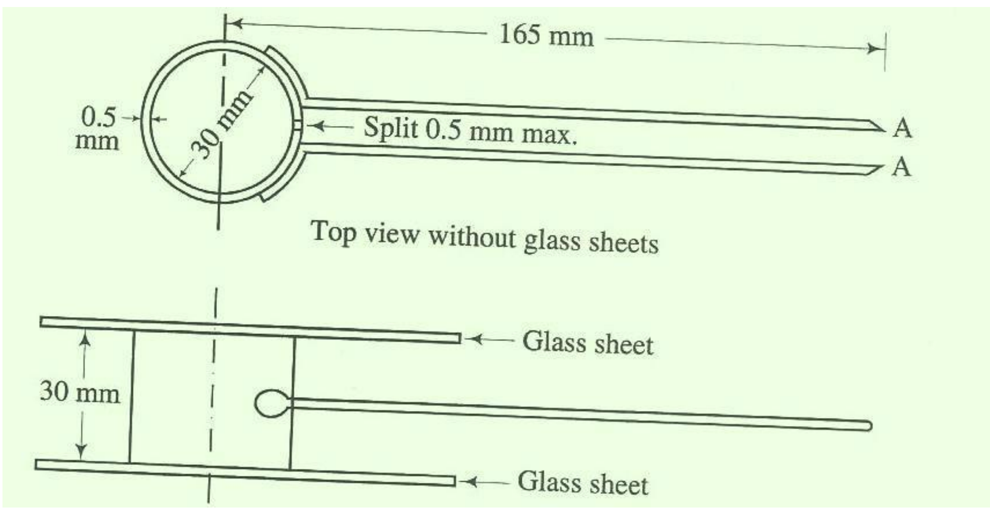


Fig. 4.4: Le Chatelier apparatus

PROCEDURE:

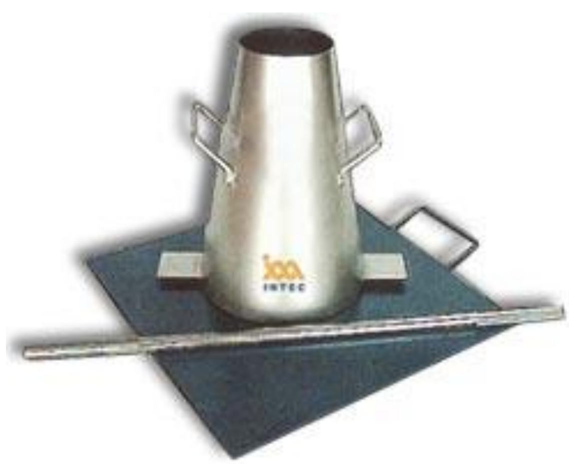
1. Place the mould on a glass sheet and fill it with cement paste formed by gauging cement with 0.78 times the water required for standard consistency.
2. The paste if gauged taking care to keep the edges of the mould gently together.
3. Cover the mould with another sheet of glass.
4. Place a small weight on the covering glass sheet and then placed the whole assembly in water and kept for 24 hr.
5. Measure the distance between the indicator points.

6. Submerge the mould again in water.
7. Then heat the water and bring to boiling point in 25-30 minutes and kept boiling for 3 hr.
8. Remove the mould from water and allow it to cool.
9. Measure the distance between the indicator points. Difference between the two measurements represents the expansion of cement.

4.4 TESTS DONE ON CONCRETE

4.4.1 Workability by Slump Test

Concrete is said to be workable if it can be easily mixed and easily placed, compacted and finished, etc., the ease with which concrete mix flows to the remote corner of the form work. The apparatus for conducting the slump test is of metallic mould in the form of frustum of cone having dimension:



Bottom diameter: 20cm

Top diameter : 10cm

Height : 30cm

Fig 4.5: Slump Cone

PROCEDURE

1. The internal surface of the mould is thoroughly cleaned and applied with a light coat of oil.
2. The mould is placed on a smooth, horizontal, rigid and nonabsorbent surface.
3. The mould is then filled in four layers with freshly mixed concrete, each approximately to one-fourth of the height of the mould.

4. Each layer is tamped 25 times by the rounded end of the tamping rod (strokes are distributed evenly over the cross section).
5. After the top layer is rodded, the concrete is struck off the level with a trowel.
6. The mould is removed from the concrete immediately by raising it slowly in the vertical direction.
7. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured.
8. This difference in height in mm is the slump of the concrete.

4.4.2 Compressive Strength of Concrete

The compressive strength of concrete is the most useful and important properties of concrete. In most of the structural applications concrete is employed primarily to resist compressive stresses. Cubes are casted and tested for the determinations of the compressive strength of harden concrete.

APPARATUS**:**

1. Compressive testing machine.
2. Mould.
3. Tamping rod.
4. Equipment to mix- Concrete mixer.

PROCEDURE**:**

1. Calculate the quantities of cement, coarse aggregate, fine aggregate, and water required for making 6 cubes of each desired grade of concrete.
2. Place the concrete mix in cube and vibrate it. After vibration, level the top surface of cube by removing excess concrete.
3. Put the cube $27 \pm 2^{o}C$ for 24 hrs.
4. Remove the concrete cubes from the mould and put them in water for curing.
5. Put the cubes in compression testing machine after 7, 14 and 28 days of curing and obtain the values.

Fig. 4.6: Compression Testing Machine

4.5 CONCLUDING REMARKS

In this chapter we mentioned the various tests to be done on cement, fresh concrete and the hardened concrete and the different procedures to do those tests. The results are shown in the form of graphs in the next chapter.

5. EXPERIMENTAL RESULTS AND DISCUSSION

5.1 INTRODUCTION

In this Chapter, the experimental results are presented and discussed. Each of the compressive strength test data plotted in figures or given tables corresponds to the mean value of the compressive strengths of two concrete cubes casted in series.

5.2 TESTS DONE ON CEMENT

5.2.1 Normal Consistency of Cement

The amount of water content that brings the cement paste to a standard condition of wetness is called Normal Consistency. The variation of normal consistency of cement using different percentage of fly ash as partial replacement by weight is shown in the figure.

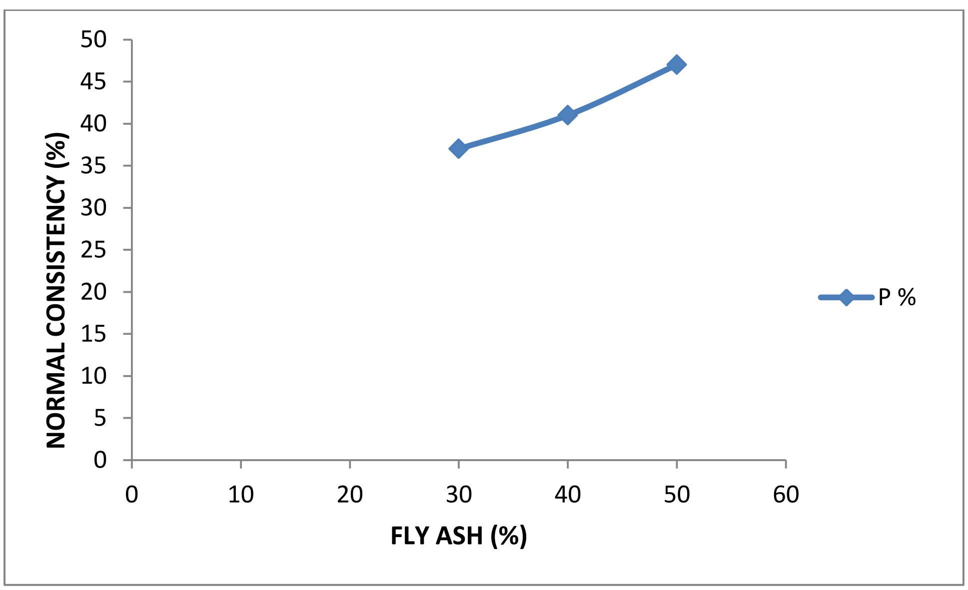


Fig: 5.1 Normal Consistency vs. Fly Ash

The plot indicates that with the increase of fly ash in cement, the normal consistency increased because more water is required for wetting the particles, as the total surface area of the particle increases.

5.2.2 Initial and Final Setting Time of Cement

Initial setting time is the time elapsed between the moments that the water added to the cement, to the time that the paste starts losing its plasticity.

Final setting time is time elapsed between the moment that the water added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure.

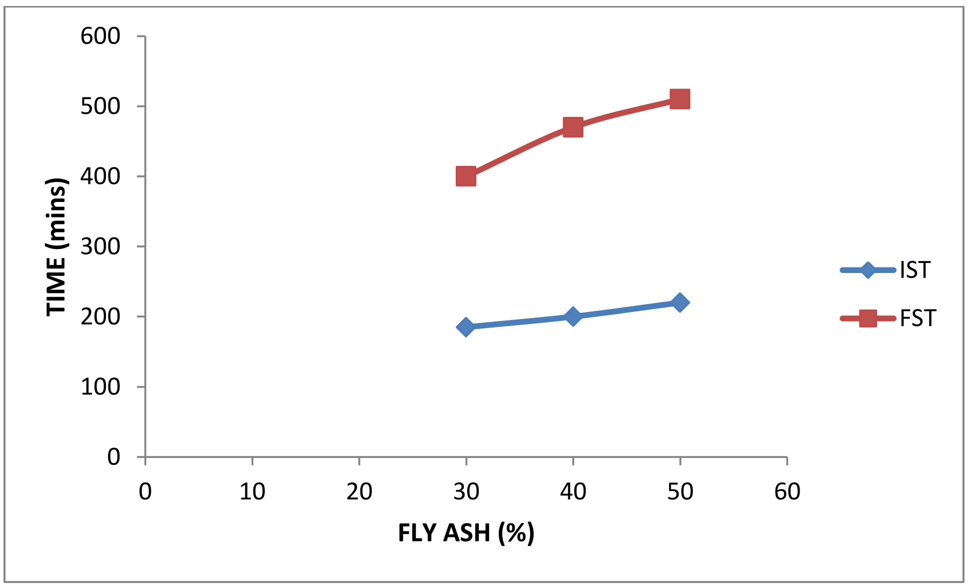


Fig. 5.2: Setting Times vs. Fly Ash

It is seen that with the addition of fly ash to cement, the IST and FST increased considerably. Final setting time increases with inclusion of fly ash, the increase is of lesser magnitude as compared to the increase of initial setting time.

5.2.3 Tensile Strength of Cement

Tensile strength of cement is the measure of ability of cement mortar specimen to withstand in tensile load. Although PCC is not nearly as strong in tension as it is in compression, PCC tensile strength is important in pavement applications.

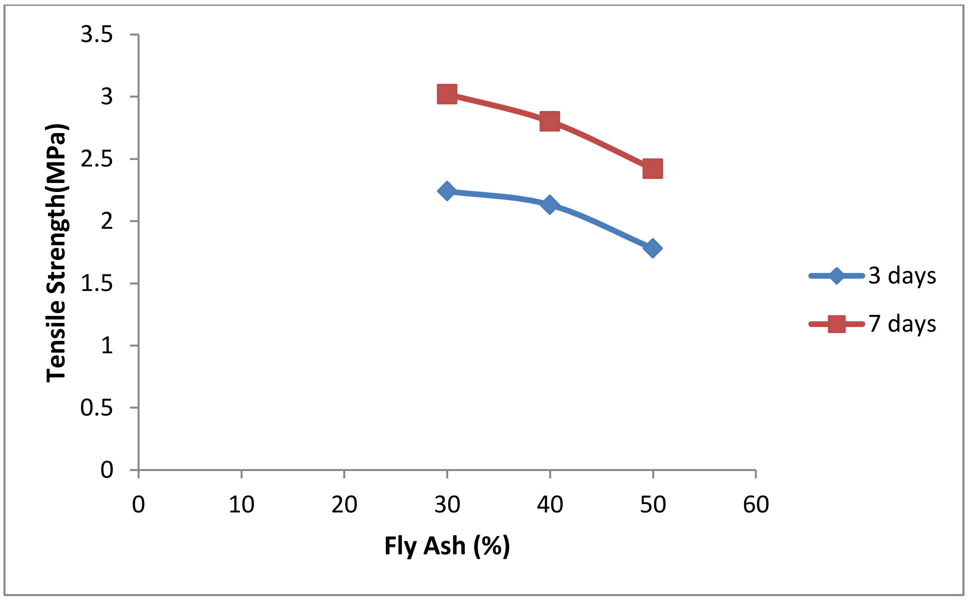


Fig. 5.3: Tensile strength vs. Fly Ash

With the increase in percentage of fly ash present in cement, the tensile strength of cement decreases. Concrete has relatively high compressive strength, but much lower tensile strength. For this reason it is usually reinforced with materials that are strong in tension (often steel).

5.2.4 Soundness of Cement

Soundness of cement is the property of hardened cement paste undergoing large change in volume after setting without delayed destructive expansion. This destructive expansion is caused by excessive amounts of free lime or magnesia. Expansion test were performed as per specification and the Le-Chatelier's expansion is measured. The variation with fly ash contents are shown in fig. below.

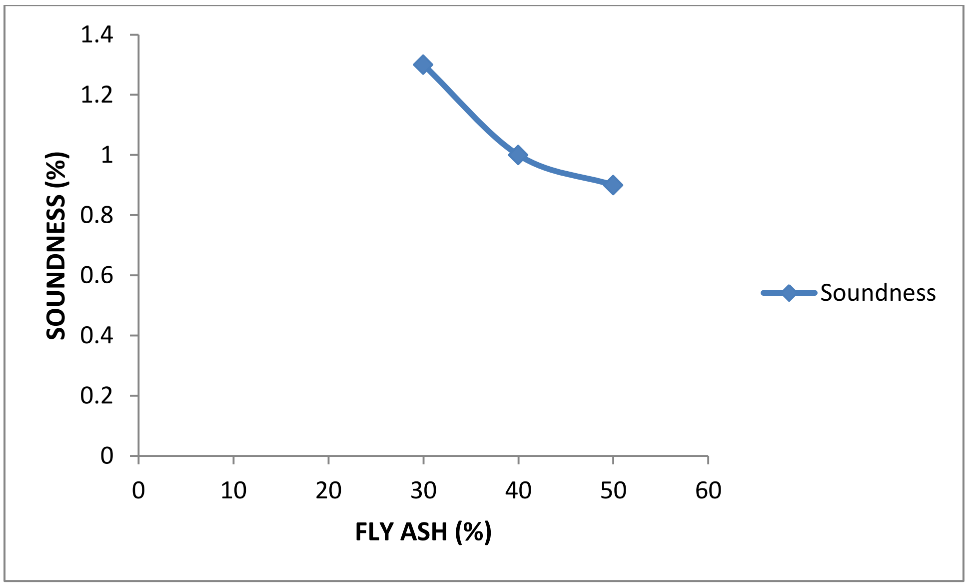


Fig. 5.4: Soundness vs. Fly Ash

Inclusion of fly ash increases the soundness of mixtures or decreases the Le-Chatelier's expansion because of decrease in carbon and increase in silica content.

5.3 TESTS DONE ON CONCRETE

5.3.1 Workability by Slump Test

Concrete is said to be workable if it can be easily mixed and easily placed, compacted and finished, etc., or the ease with which concrete mix flows to the remote corner of the form work.

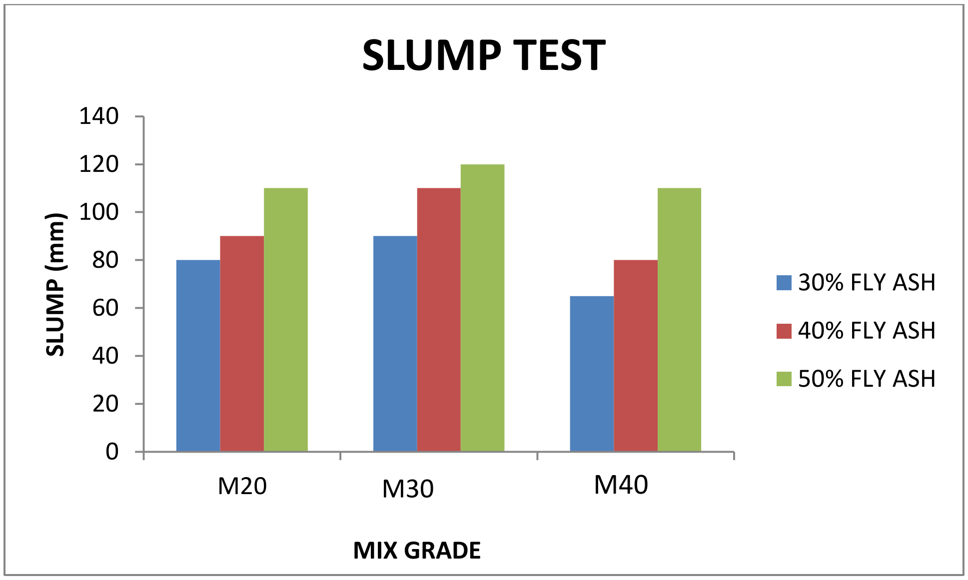


Fig. 5.5: Slump vs. Fly Ash

Fly ash gets absorbed on the surface of oppositely charged cement particles and prevents them from flocculation, releasing large amounts of water, thereby reducing the water-demand for a given workability. The replacement of cement (by mass) with three percentage of fly ash (30%, 40%, 50%) increased the workability. This is due to the ball bearing action of the spherical particles of fly ash.

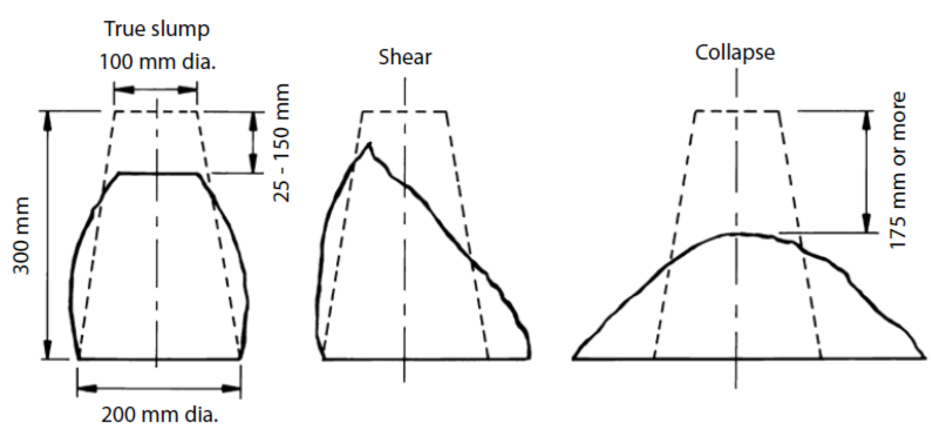


Fig. 5.6 Different Types of Slump

5.3.2 Compressive Strength of Concrete

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. Cubes were casted and were tested on the Universal Testing Machine, the results are plotted below and the exact values can be found out in the tables in Appendix.

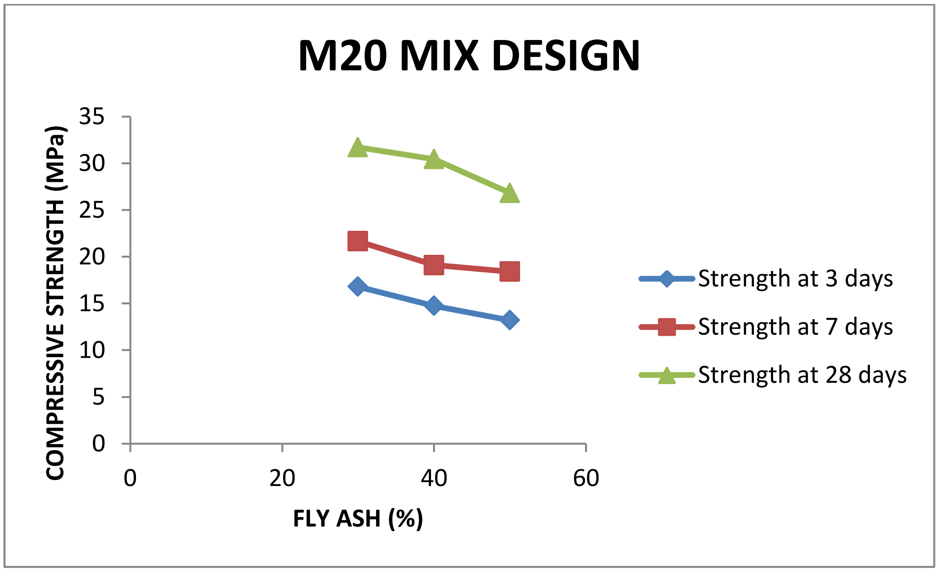


Fig. 5.7: Compressive Strength vs. Fly Ash – M20 Mix Design

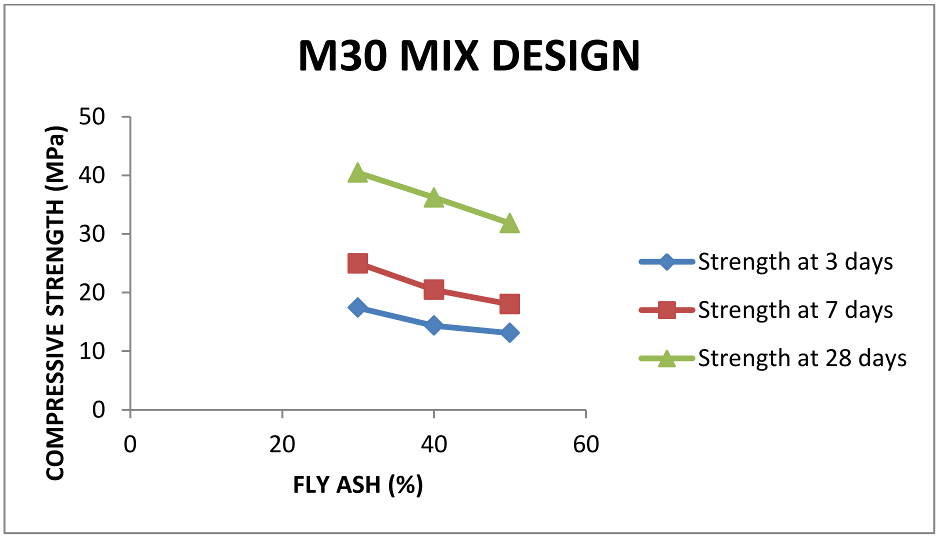


Fig. 5.8: Compressive Strength vs. Fly Ash- M30 Mix Design

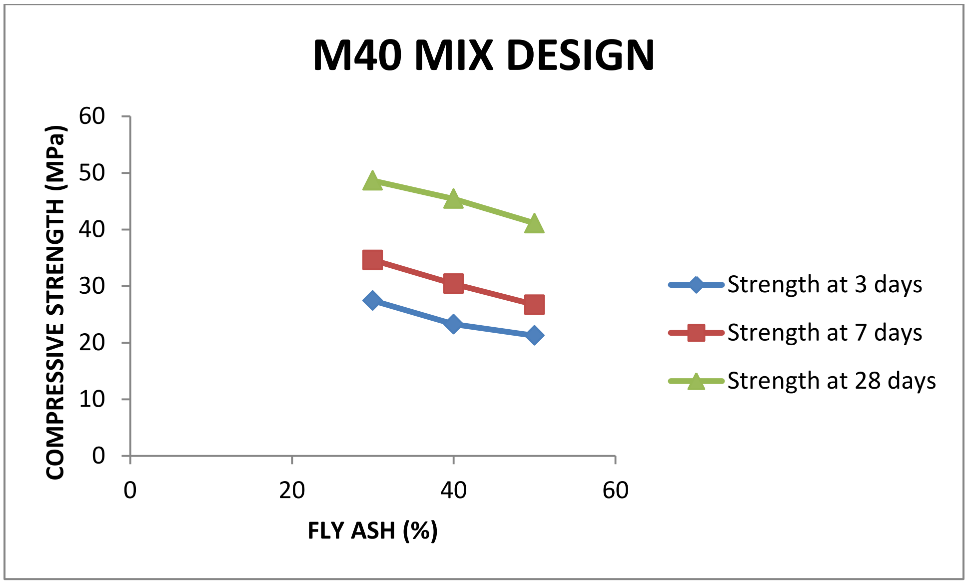


Fig. 5.9: Compressive Strength vs. Fly Ash- M40 Mix Design

Concrete cubes of 150 mm size for finding compressive strength, were cast. After casting, test specimens were un-moulded after 24 hours and were kept in the curing tanks until the time of test. The cubes were air dried for 6 hours before the test. The each test result is the average test result of two cubes.

Compressive Strength of M20, M30 and M40 grade concrete made with PPC of different percentages of fly ash. The compressive strength was seen to decrease with the increase of fly ash percentage.

6. CONCLUSIONS

From the experimental work carried out and the analysis of the results following conclusions seem to be valid with respect to the utilization of fly ash.

1. Normal consistency increases with increase in the fly ash content in cement.
2. Setting time and soundness decreases with the increase in grade of cement.
3. Use of fly ash improves the workability of concrete and workability increases with the decreases in the grade of cement.
4. As the fly ash contents increases in OPC there is reduction in the strength of concrete.
5. For the concretes in which fly ash is used at the same rate instead of cement, compressive and splitting tensile strength of the produced concretes increase as fineness of fly ash increases, but the tensile strength of the cement decreases.
6. The slump value of the fresh fly-ash based geopolymer concrete increases with the increase of extra water added to the mixture.
7. There 10-30% reductions in cost with the addition of 50% fly ash in concrete.
8. The optimum fly ash content is observed to be 40% of cement. Fly ash mortars with 40% cement replacement shows around 14% higher compressive strength than OPC mortar. The corresponding increase in tensile strength is reported to be around 8%.
9. Use of high volume fly ash in any construction work as a replacement of cement, provides lower impact on environment (reduce CO_2 emission) and judicious use of resources (energy conservation, use of by-product).
10. Use of fly ash reduces the amount of cement content as well as heat of hydration in a mortar mix. Thus, the construction work with fly ash concrete becomes environmentally safe and also economical.

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APPENDIX

OBSERVATION TABLES

1. Grading Of Fine Aggregates

We did the grading of fine aggregates and our values of the weight passing falls under ZONE III, which is required to calculate the mix design.

Table 1: Grading Limits of Fine Aggregates IS: 383-1970

IS Sieve Designation	Grading-1	Grading-11	Grading-111	Grading-1V
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

2. Normal Consistency of Cement

Table 2: Consistency for ppc - (30% of fly ash)

Water % of Cement	**Cement(Kg)**	**Fly Ash(Kg)**	**Fly Ash %**	**Distance from bottom, mm**
35	0.4	0.12	30	7.9
40	0.4	0.12	30	5.1
37	0.4	0.12	30	6

Therefore consistency came out to be 37%

Table 3: Consistency for PPC - (40% of fly ash)

Water % of Cement	Cement(Kg)	Fly Ash(Kg)	Fly Ash %	Distance from bottom, mm
45	0.4	0.16	40	5.2
38	0.4	0.16	40	8.3
41	0.4	0.16	40	6.1

Therefore consistency came out to be 41%

Table 4: Consistency for PPC - (50% of fly ash)

Water % of Cement	Cement(Kg)	Fly Ash(Kg)	Fly Ash %	Distance from bottom, mm
50	0.4	0.2	50	5.4
45	0.4	0.2	50	8.3
47	0.4	0.2	50	6.0

Therefore consistency came out to be 47%

3. Initial And Final Setting Time Of Cement

Table 5: IST and FST

Water %, 0.85P	Cement(Kg)	Fly Ash(Kg)	Fly Ash %	Initial Setting Time, mins	Final Setting Time, mins
32	0.4	0.12	30	185	400
35	0.4	0.16	40	200	470
41	0.4	0.2	50	220	510

4. Tensile Strength Of Cement

Table 6: Tensile Strength at 3 & 7 days.

W/C Ratio	Water, (ml)	Cement, (Kg)	Fly Ash, (Kg)	Total Cementicous Material, (Kg)	Fly Ash %	Tensile Strength, MPa At 3 days	Tensile Strength, MPa At 7 days
0.55	940	0.175	0.075	0.25	30	2.24	3.02
0.55	940	0.15	0.1	0.25	40	2.13	2.8
0.55	940	0.125	0.125	0.25	50	1.78	2.42

5. Soundness Of Cement

Table 7: Soundness of cement

Water, (ml) 0.78P	Cement, (mg)	Fly Ash, (mg)	Fly Ash, %	Soundness, %
29	50	15	30	1.3
32	50	20	40	1
37	50	50	50	0.9

6. Compressive Strength Of Concrete

Table 8: Compressive strength of M20 Grade Concrete

W/C Ratio	Water (ml)	Cement (Kg)	Fly Ash(Kg)	Fly Ash %	Compressive Strength, MPa at 3 day	At 7 days	At 28 days
0.50	850	1.19	0.51	30	16.80	21.65	31.72
0.50	850	1.02	0.68	40	14.75	19.10	30.45
0.50	850	0.85	0.85	50	13.20	18.40	26.82

Table 9: Compressive strength of M30 Grade Concrete

W/C Ratio	Water (ml)	Cement (Kg)	Fly Ash(Kg)	Fly Ash %	Compressive Strength, MPa at 3 day	At 7 days	At 28 days
0.45	855	1.36	0.54	30	17.40	24.96	40.43
0.45	855	1.14	0.76	40	14.36	20.45	36.2
0.45	855	0.95	0.95	50	13.1	18	31.83

Table 10: Compressive strength of M40 Grade Concrete

W/C Ratio	Water (ml)	Cement (Kg)	Fly Ash(Kg)	Fly Ash %	Compressive Strength, MPa at 3 day	At 7 days	At 28 days
0.50	925	1.3	0.555	30	27.43	34.6	48.64
0.50	925	1.11	0.740	40	23.26	30.4	45.41
0.50	925	0.925	0.925	50	21.24	26.70	41.09

7. Workability –Slump Test

Table 11: Slump cone test – M20 grade concrete

W/C Ratio	Water(ml)	Cement(Kg)	Fly Ash(Kg)	Aggregate(Kg)	Fly Ash %	Slump (mm)
0.50	850	1.19	0.51	5.1	30	80
0.50	850	1.02	0.68	5.1	40	90
0.50	850	0.85	0.85	5.1	50	110

Table 12: Slump cone test – M30 grade concrete

W/C Ratio	Water(ml)	Cement(Kg)	Fly Ash(Kg)	Aggregate(Kg)	Fly Ash %	Slump (mm)
0.45	855	1.36	0.54	5.190	30	90
0.45	855	1.14	0.76	5.190	40	110
0.45	855	0.95	0.95	5.190	50	120

Table 13: Slump cone test – M40 grade concrete

W/C Ratio	Water(ml)	Cement(Kg)	Fly Ash(Kg)	Aggregate(Kg)	Fly Ash %	Slump (mm)
0.50	925	1.3	0.555	5.620	30	65
0.50	925	1.11	0.740	5.620	40	80
0.50	925	0.925	0.925	5.620	50	110