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EXPERIMENTAL INVESTIGATION ON CONCRETE USING FLY ASH AND GBFS AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

Concrete is mainly classified into three types based on the density. Concrete containing natural sand and gravel or crushed- rock aggregate and water, when placed in the skeleton of form and allowed to cure, becomes hard like stone. Generally weighing about 2400kg/m^3 is called "normal-weight concrete" and it is the most commonly used concrete for structural purposes. For applications where a higher strength-to-weight ratio is desired, it is possible to reduce the unit weight of concrete by using natural aggregate with lower bulk density. The term lightweight concrete is used for concrete that weightless than 1800 kg/m^3. Heavy weight concrete used for radiation shielding, is a concrete produced from high density aggregate and generally weigh more than 3200kg/m^3.

Our aim it is to study the properties of concrete by partially replacing cement by fly ash and fine aggregate (sand) by granulated blast furnace slag.

In this study, Cement was partially replaced by Fly Ash and Fine aggregate were partially replaced by Granulated Blast Furnace Slag in concrete. A mix design was done for M_{20} grade of concrete by using IS method. The utilization of fly-ash and blast furnace slag in concrete as partial replacement of cement and fine aggregate (sand) is gaining immense importance in today's concrete works, mainly on account of the improvement in long term durability along with ecological benefits. Three grades of ordinary port land cement (OPC) namely: 33, 43 and 53 as classified by bureau of Indian Standard (BIS) or commonly used in construction industry**.** Now in this project only 53 grade of cement is used. This paper reports comparative study on effects of concrete properties by partially replacement of OPC of 53 grades with fly ash and sand were partially replaced by blast furnace slag. The main variable investigated in the study of variation of fly ash dosage of 10% and slag dosage of 10%, 20%, 30%, fly ash dosage of 20% and slag dosage of 10%, 20, 30%, fly ash dosage of 30% and slag dosage of 10%, 20%, and 30%. The compressive strength and split tensile strength & acid attack of concrete were mainly studied. Test results shows that, inclusion of fly ash and GBFS generally improves the concrete properties up-to certain percentage of replacement in53 grade of cement.

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I. INTRODUCTION

1.1 GENERAL

Concrete is a widely used construction material for various types of structures due to its structural stability and strength. The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. Regrettably, production of cement involves emission of large amounts of carbon dioxide gas into the atmosphere, a major contributor for green house effect and the global warming. Hence it is inevitable either to search for another material or partly put back it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact.

In this thesis, the different admixtures were used to study their sole and combined effects on the resistance of concrete in addition to their effects on mechanical and stability properties by the replacement of cement by 10% fly ash and sand replacement 10%, 20%, 30% of slag, cement by 20% fly ash and sand replacement 10%, 20, 30% of slag, cement replacement of 30%fly ash and sand replacement 10%, 20%, 30% of slag.

The secondary materials used in our project are pozzolanic materials. The term pozzolana is a siliceous or a siliceous and aluminous material which itself possesses no cementitious value but in presence of water, chemically react with calcium hydroxide to form compounds possessing cementitious properties .The material which having the pozzolanic property known as pozzolanic material. The pozzolanic materials that are used in our project are

1. Fly ash
2. Granulated Blast Furnace Slag

1.1.1 Fly Ash: Fly ash also known as flue-ash is one of the residues generated in combustion coal and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes considerable amounts of silicon dioxide (SiO_2) and calcium oxide (CaO).

In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release. In the US, fly ash is generally stored at coal power plants or placed in landfills. About 43% is recycled, often used to increase Portland cement because fly ash is an low-cost replacement for Portland cement used in concrete, while it actually improves strength, separation, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills. This waste is causing problems to human health and environmental pollution.

1.1.2Granulated Blast Furnace Slag: Granulated Blast Furnace Slag is a by-product of the steel industry. Granulated Blast furnace slag is defined as "the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace." In the production of iron, blast furnaces are loaded with iron ore, fluxing agents, and coke. When the iron ore, which is made up of iron oxides, silica, and alumina, comes together with the fluxing agents, molten slag and iron are produced. The molten slag then goes through a particular process depending on what type of slag it will become. Air-cooled slag has a rough finish and larger surface area when compared to aggregates of that volume which allows it to bind well with Portland cements as well as asphalt mixtures. GBFS is produced when molten slag is quenched rapidly using water jets, which produces a granular glassy aggregate. This glassy aggregate with little fines used as sand replacement in the present investigation.

So to reduce the environmental pollution we used fly ash waste as a cement replacement and slag as a sand replacement in different percentages and we have determined the compressive strength of concrete.

1.2 EFFECTS OF DISPOSAL OF FLY ASH WASTE

Since coal contains trace levels of arsenic, barium, beryllium, boron, cadmium, chromium, thallium, selenium, molybdenum and mercury, its ash will continue to contain these traces and therefore cannot be dumped or stored where rainwater can leach the metals and move them to aquifers.

Fly ash contains trace concentrations of heavy metals and other substances that are known to be detrimental to health in sufficient quantities. Potentially toxic trace elements in coal include arsenic, beryllium, cadmium, barium, chromium, copper, lead, mercury, molybdenum, nickel, radium, selenium, thorium, uranium, vanadium, and zinc.

1.3 SCOPE AND OBJECTIVES

This research mainly focusing on studying the effect of fly ash and Slag on the properties of concrete mixtures as a partially replacement of cement and sand.The scope of this study, the main goal is to improve compressive and split tensile strength of concrete at different percentage of replacement of fly ash and slag.

Fly ash and slag is the cheapest materials of all concrete constituents and is much less expensive than natural aggregate and sand as possible to save money. The main aim of the research is to study the effect of partially replacement of fly ash and slag in to the concrete. The main objectives are study in this theory is

- ❖ To study normal consistency, initial and final setting times, soundness and fineness of cement.
- ❖ To study specific gravity, water absorption of coarse aggregate.
- ❖ To study specific gravity, water absorption of fine aggregate of river sand and slag.
- ❖ To study the compressive strength of normal concrete and partially replacement of cement by fly ash and sand by GBFS.
- ❖ To study split tensile strength of normal concrete and partially replacement of cement by fly ash and sand by GBFS.

1.4 RESEARCH METHODOLOGY

The following are to be carried out in order to achieve the research objectives.

- To collect the fly ash from thermal power plant RTPP and collect the blast furnace slag from steel plant.
- Sieve the slag by using of 4.75mm sieve.
- To study about the fly ash and slag.
- To study about the strength of replacement of fly ash and slag in concrete.
- Study on acid attack in concrete
- Analysis of experimental results to draw conclusions.

II. REVIEW OF LITERATURE

2.1 GENERAL

Extensive research work both at national and international level has been done on the use of various admixtures in mortars and concretes with common goal. The main objectives are:

- o To combat the environmental hazards from the industrial wastes.
- o To modify the properties of traditional concrete to the desired level suitable to the specific circumstances.
- o To conserve the natural resources used in the production of construction materials.
- o To bring down the increasing cost economics of cement, building blocks and high strength concretes.

In the last decades many experiments and researches have been done to investigate the effects of concrete influenced by the acidic attacks and the impact of chemicals on cementization. Literature relating to blended cements in concrete and the effect of curing regimes on this concrete are numerous. In this chapter, only literature concerning those aspects related to this particular research i. e. the mechanical and durability properties of hardened concrete incorporating fly ash and slag as a mineral admixtures added to concrete made with the Portland cement are discussed. This survey also includes the effect of curing conditions on the various properties of concrete.

2.2 MINERAL ADMIXTURES

Mineral admixtures refer to the finely divided materials which are added to obtain specific engineering properties of cement mortar and concrete. The other, equally important, objectives for using mineral admixtures in cement concrete include economic benefits and environmentally safe recycling of industrial and other waste by-products. Unlike chemical admixtures, they are used in relatively large amounts as replacement of cement and/or of fine aggregate in concrete. In the past, natural pozzolans such as volcanic earths, tuffs, trass, clays, and shales, in raw or calcined form, have been successfully used in building various types of structures such as aqueducts, monuments and water retaining structures. Natural pozzolans are still used in some parts of the world. However, in recent years, many industrial waste by-products such as fly ash, slag, silica fume, red mud, and rice husk ash and highly reactive metakaolin has recently become available as a very active pozzolanic material for use in concrete. Unlike fly ash, slag, or silica fume, this material is not a byproduct but is manufactured from a high-purity kaolin clay by calcination at temperatures in the region of 700 to 800°C are rapidly becoming the main source of mineral admixtures for use in cement and concrete.

2.3 TYPES OF MINERAL ADMIXTURE

Mineral admixtures can be classified in two groups: Pozzolanic materials and inert filler materials. Pozzolanic materials are mineral admixture contains reactive silica which when added to cement reacts with calcium hydroxide to form C-S-H such as volcanic ash, burnt clay, and fly ash. Using pozzolans lower the heat of hydration, increase later strength, and increase durability. Inert materials are mineral admixtures which do not affect the strength of concrete and used as workability aids such as hydrated lime, dust of normal weight aggregates, and colouring pigments.

2.4 REVIEWS ON FLY ASH

2.4.1What is fly ash: Fly ash is one of the residues generated in coal combustion facilities, and comprises the fine particles that rise with the flue gases.

2.4.2 Where does fly ash come from: Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately gets ignites, generates heat and produces a molten mineral residue. Boiler tubes extract heat from the boiler, cool the flue gases and cause the molten mineral residue to harden and form ash. Coarse ash particles, called as bottom ash or slag, fall to the bottom of the combustion chamber, and the lighter fine ash particles, termed as fly ash, remain suspended in the flue gas. Before exhausting the flue gas, fly ash is removed by particulate emission control devices, such as filter fabric bag houses or electrostatic precipitators

2.4.3 Production of fly ash: Fly ash is produced from the combustion of pulverized coal in industrial boilers or electric utility boilers. There are four types of coal-fired boilers: (i) pulverized coal (PC), (ii) stoker-fired, (iii) cyclone, and (iv) fluidized-bed combustion (FBC) boilers. The PC boiler type is the most widely used, especially for generating large electric units. The other boilers are more commonly used in industrial or cogeneration facilities. Fly ash is collected from the flue gases by using electrostatic precipitators (ESP) or in filter fabric collectors. The physical and chemical characteristics of fly ash depend on (i) combustion methods, (ii) coal source, and (iii) particle shape.

Types of boilers: In general, there are three types of coal-fired boilers used in electric utility industry. They are as follows:

- Dry - bottom boilers
- Wet – bottom boilers
- Cyclone furnaces
- When pulverized or powdered coal is combusted in a dry–ash, dry-bottom boiler, about 80% of all the ash leaves the furnace as fly ash, entrained in the flue gas.
- When pulverized coal is combusted in a wet bottom (or slag-trap) furnace, about 50% of the ash is retained in the furnace, and the other 50% being entrained in the flue gas.
- In a cyclone furnace, crushed coal is used as a fuel. 20 to 30 % leaves the furnace as dry ash and rest 70 to 80% of the ash is retained as boiler slag.

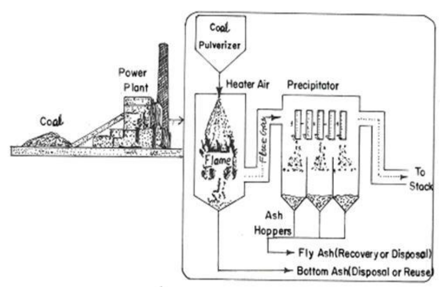

Fig 2.1: general flow diagram of fly ash production in a dry-bottom coal-fired utility boiler operation

2.4.4 Fly ash classification: There are basically two classes of fly ash as defined by ASTM C618 as:-

- Class F Fly ash
- Class C Fly ash

Differences between these two classes are based on the amount of Calcium, Silicon, Aluminium, & Iron content in ash. Chemical property is largely influenced by the chemical content of fly ash. All fly ash don't meet ASTM C618 construction standard, but no such standard for environment has been established so far.

Class F Fly ash: The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% 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 additions of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer.

Properties:

- Most effectively checks heat gain during concrete curing and is therefore considered an ideal cementitious material in mass concrete and high strength mixes. For the same reason, class f is the solution to a wide range of summer concreting problems.
- Provides sulphide and sulphate resistance equal or superior to type v cement. Class f fly ash is often recommended for use where concrete may be exposed to sulphate ions in soil and ground water.

Figure2.2 Example of fly ash

Class C Fly ash: Class C fly ash is produced normally from lignite and sub-bituminous coals and usually contains significant amount of Calcium Hydroxide (Cao) or lime (Cockrell et. al., 1970). This class of fly ash, in addition to having pozzolanic properties, also has some cementitious properties (ASTM C 618-99).

Properties:

- Most useful in "performance" mixes, pre-stressed applications, and other situations where higher early strengths are important.
- Especially useful in soil stabilization since class c may not require the addition of lime.

2.4.5 Transportation of fly ash: Fly ash can be supplied in four forms:

Dry fly ash: This is the most commonly used method for supplying fly ash. Dry fly ash is handled in the same manner as Portland cement is handled. It is stored in sealed silos with the associated filtration and desiccation equipment or in bags.

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

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

Lagoon fly ash: Some power stations pump fly ash as slurry to large Lagoons. These are then drained and when the moisture content of that deposited fly ash has reached to a safe level then it may be recovered. Lagoon fly ash can be used in similar applications as stockpiled & conditioned fly ash.

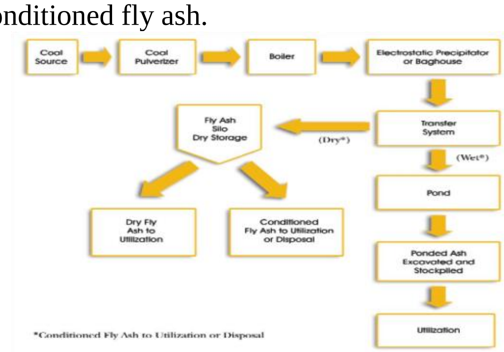

Figure2.3 Method of fly ash transfer

Agricultural application of fly ash

Fly ash as herbicide: Finest fraction of the ash has also been used either as a herbicide or carrier of pesticide with encouraging results. Dusting of domestic kitchen ash over plants (including Tulsi) and vegetable crops (such as brinjal) drives away insects, is a common sight in rural homes of India. Such kitchen ash with high proportion of anhydrous oxides of alkalis and alkaline earth, such as Na2O, K2O, Cao and Mgo, dehydrates (dehydrolyse) animals eating away the plant parts. Classified fly ash can similarly be used for the same purpose. Besides, 80% of the ash being glass, the fine splinters of glass on leaf surface when chewed is likely to damage the oral cavity and mandible of the chewing species, starving them to death. Even when swallowed, the splinters would damage food channel and destroy the insect in due course of time. Therefore alkali rich fly ash after suitable classification can be used as a herbicide. Thus with proper understanding of the various properties of fly ash and suitable modifications, fly ash can find extensive use in agricultural practices and ease the burden of accumulation in the backyard of coal based thermal power plants. Dusting of domestic kitchen ash over swampy and damp area during rainy season is also a common sight in rural homes and cow sheds of India. Such kitchen ash with high proportion of anhydrous oxides of alkalis and alkaline earth, such as Na_2O, K_2O, Cao and Mgo, dehydrates the damp, swampy and marshy area and keeps, the area free from water so that men and animals can feel comfortable because the insects, flies and mosquitoes cannot breed in those area and many diseases because of their bite can be eliminated. Classified fly ash can similarly be used for the same purpose.

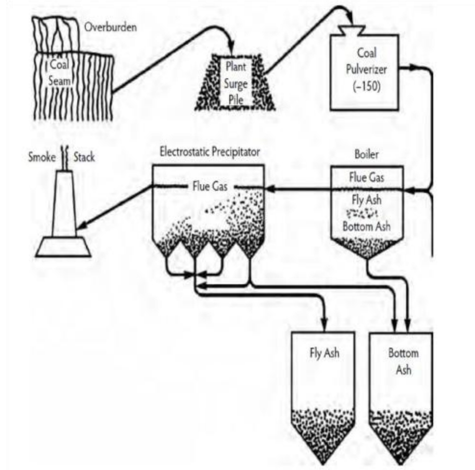

Figure 2.4: Schematic of fossil fuel plant

Chemical composition: In general, which contains more than 60% SiO_2, and 28% Al_2O_3 by mass and source of fly ash influence its mineralogical composition. Due to the rapid cooling of burned coal in the power plant, fly ashes consist of non-crystalline particles (≤90%), or glass and a small amount of crystalline material. Depending on the system of burning, some unburned coal may be collected with ash particles. In addition to a substantial amount of glassy material, each fly ash may contain one or more of the four major crystalline phases: quartz, mullite, magnetite, and hematite. In sub bituminous fly ashes, the crystalline phases may include C_3A, C_4A_3S, calcium sulphate, and alkali sulphates. The below table shows the chemical composition of some selected fly ashes. The reactivity of fly ashes is related to the non-crystalline phase or glass. The reasons for the high reactivity of high-calcium fly ashes may lie partially in the chemical composition of the glass.

Table 1: Chemical Composition and Classification of Fly Ash

Component	Bituminous	Sub bituminous	Lignite
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	5-35	20-30	20-25
Fe_2O_3 (%)	10-40	4-10	4-15
Cao (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

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Table 2: Normal ranges of chemical compositions for fly ash produced from different coal types (expressed as % by wt).

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

2.5 REVIEWS ON GRANULATED BLAST FURNACE SLAG

Slag is primarily made up of Cao (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and Mgo (1-18%). Other elements like manganese, iron, sulfur, and trace amounts of other elements make up about other 5% of slag. The exact concentrations of elements vary slightly depending on where and how the slag is produced. In general increasing the Cao content of the slag results in raised slag basicity and an increase in strength. The Mgo and Al_2O_3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. The glass content of slag suitable for blending with Portland cement typically varies between 90-100% and depends on the cooling method and the temperature at which cooling is initiated. In order to obtain a suitable reactivity, the obtained fragments are ground to reach the same fineness as Portland cement.

Table 3: Chemical Composition of Slag

Composition	Percentage
SiO_2 (%)	32.6
Al_2O_3 (%)	12.8
Fe_2O_3 (%)	1.30
Cao (%)	41.0
Mgo (%)	7.2
SO_3	30.03
P_2O_5	0.05

GBFS has a positive effect on both the flexural and compressive strength of concrete after 28 days. In the first 7 days the compressive strength is generally slightly lower than pure 100% Portland cement mixtures. In the 7 to 14 day range, the compressive strength is about equal to the strength of concrete without slag. The real gain in strength is noticed after the 28 days. A 1992 study which showed that the flexural strength of concrete mixes with different slag replacement percentages was between 6.0-6.8 Mpa at 14 days. The long term strength of slag cement depends on many factors such as the amount of slag and Portland cement, and water to cement ratio. Blast furnace slag comprise of mainly of Cao, SiO_2, Al_2O_3, Mgo, it contains less than 1%crystalline silica, and contains less than 1ppm water soluble chromium IV. It has the same main chemical constituents as ordinary Portland cement, but in different proportions.

Figure 2.5: Example of GBFS

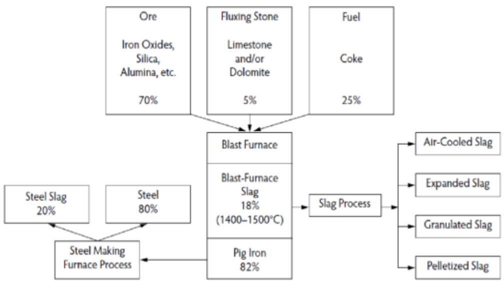

Figure 2.6: shows Flowchart showing production of pig iron and blast-furnace slag

III. MATERIALS AND METHODS

3.1 MATERIALS:

The materials used in this present investigation are Ordinary Portland cement (53 grade), water, coarse aggregates, fine aggregates (sand, sag).In recent years, improvements in concrete properties have been achieved by blending cements with cementitious admixtures such as fly ash (FA),granulated blast furnace slag (GBFS). Incorporation of these materials in concrete mixes improves the durability concrete. The movement of aggressive substances such as chloride ions and carbon dioxide into concrete which are the main causes of deterioration of concrete structures that affect their integrity and long term serviceability life, is thus very much reduced. The deterioration of concrete is not a result of only aggressive agents, but the overall quality of concrete and also play a major role. In view of this problem, a growing number of concrete structures are constructed or under construction with the use of cement replacement materials. Therefore any attempt to alleviate the deterioration-risk implies producing good performance concrete capable of withstanding the harsh environmental conditions.

In this chapter, the materials and methods described together with their properties. In this the tests carried out on different concrete mixes, curing regimes, mix proportions and casting of specimens is discussed.

3.1.1 Fly Ash: The fly ash is collected from local waste scrapers. Fly ash is a pozzolana substance containing aluminous and siliceous material that forms cement in the presence of water. Cement is now partially replaced by its weight by fly ash at varying rates such as 10%, 20%,30%. The specific gravity of fly ash is taken as 2.0.

The physical properties of fly ash are shown in the following table

Table: 4 Physical properties of fly ash

S.NO	DESCRIPTION	
1	Specific Gravity	2.0
2	Physical Form	Powder
3	Color	Dark grey

Table: 5 moisture content of fly ash

Weight of empty crucible(gm)	Weight of fly ash (gm)	Weight of crucible and fly ash before heating (gm)	Weight of crucible and fly ash after heating (gm)	Moisture content (%)	Average moisture Content (%)
1	35.069	36.070	36.044	2.59	

2	40.519	41.523	41.495	2.78	2.78
3	43.852	44.856	44.826	2.98	

3.1.3 AGGREGATES: The material which is combined with cement and water to make concrete is called aggregate. Aggregate makes 60 to 80 percent of concrete volume. It increases the strength of concrete, reducing the shrinking tendencies of cement and is used as economical filler. Aggregates are divided into fine and coarse categories.

3.1.3.1Fine Aggregates

3.1.3.1.1. Sand: Naturally available sand is used as fine aggregate in the present work. The most common constituent of sand is silica, usually in the form of quartz, which is chemical inert and hard. The sand is free from clayey matter, silt and organic impurities etc. Hence used as a fine aggregate in concrete. The size of sand is that passing through 4.75 and retained on 150 micron IS sieve. The specific gravity of Sand is taken as 2.62. Sand is tested for specific gravity, in accordance with IS: 2386-1963.

3.1.3.1.2Grain Size Distribution of Fine Aggregate-Sand

Table 7: Specification of Fine Aggregates Grading

Sieve size	%passing for Grading Zone			
	I	II	III	IV
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
600µm	15-34	35-59	60-79	80-100
300µm	5-2	8-30	12-40	15-50
150µm	0-10	0-10	0-10	0-15

Table 8: Sieve analysis of Fine Aggregate - Sand

S.NO.	Sieve Size	Wt. retained in gm	Percentage wt. retained	Cumulative % wt. retained(F)	Percentage passing (100-F)
1	4.75mm	12	1.2	1.2	98.5
2	2.36mm	103	10.3	11.5	88.5
3	1.18mm	316	31.6	43.1	56.9
4	600µm	205.5	20.5	63.65	36.35
5	300µm	296.5	29.6	93.3	6.7
6	150µm	6.2	0.62	99.5	0.5
7	Pan	2	0.2	100	0

Calculation

Fineness modulus = $\Sigma \frac{F}{100} = \frac{312.25}{100} = 3.12$

Sand is conforming to zone II.

3.1.3.1.3 Slag: Due to scarcity of suitable river sand for use as fine aggregate in construction applications and recent construction boom has led to an drastic increase in price Additionally various government agencies have put some restrictions on sand quarrying to conserve this diminishing natural resources. This has prompted many engineers to look for other alternative material that are cheaper while possessing similar characteristics. One such alternative is “Granulated blast furnace slag” which is a byproduct of steel. Slag waste is used as fine aggregate in RCC construction. The use of slag waste in making concrete or mortar by partial/full replacement of river sand not only provides economy in cost of construction but also solves the problem of disposal of slag waste.

Blast furnace slag is a non-metallic product consisting essentially of calcium silicates and other bases. The exact concentrations of elements vary slightly depending on where and how the slag is produced. The size of slag is that passing through 4.75mm IS sieve is also used as sand up to 30% replacement of sand. The used slag contains sized particles only.

Table 9: Physical properties of slag

S.NO	DESCRIPTION	
1	Specific Gravity	1.71
2	Physical Form	Sized particles
3	Color	Pale white

3.1.3.1.4 Grain Size Distribution of Fine Aggregate –Slag

Table 10: Specification of Fine Aggregates Grading - Slag

Sieve size	%passing for Grading Zone			
	I	II	III	IV
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
600µm	15-34	35-59	60-79	80-100
300µm	5-2	8-30	12-40	15-50
150µm	0-10	0-10	0-10	0-15

Table 11: Sieve analysis of Fine Aggregates Grading - Slag

Calculation

S. No	Sieve Size	Wt. retained in gm	% wt. Retained	Cumulative % wt. retained(F)	% passing (100-F)
1	4.75mm	6.6	0.66	0.66	99.34
2	2.36mm	26.6	2.66	3.32	96.68
3	1.18mm	398.6	39.86	43.18	56.82
4	600µm	246.6	24.66	67.84	32.16
5	300µm	293.2	29.32	97.16	2.84
6	150µm	22.6	2.26	99.42	0.58

Fineness modulus = $\Sigma \frac{F}{100} = \frac{311.58}{100} = 3.11$

Slag is conforming to zone II.

3.1.4 Coarse aggregates: The coarse aggregate is free from clayey matter, silt and organic impurities etc. The specific gravity of Sand is taken as 2.65. Coarse aggregate is tested for specific gravity, in accordance with IS: 2386-1963. The maximum size of 20 mm is used as a coarse aggregate in concrete. For most of building constructions, the coarse aggregate consists of gravel or crushed stone up to 20mm size. However, in massive structures, such as dams, the coarse aggregate may include natural stones or rock.

3.1.4.1 Grain Size Distribution of Coarse Aggregate

Table 12: Sieve Analysis of Coarse Aggregate

S. No	Sieve Size	Wt. retained in kg	% wt. retained	Cumulative % wt. retained(F)	% passing (100-F)
1	20mm	1.908	19.08	19.08	80.92
2	16mm	5.629	56.29	75.37	24.63
3	12.5mm	2.207	22.07	97.44	2.56
4	10mm	0.203	2.03	99.47	0.53
5	4.75mm	0.021	0.21	99.68	0.32

Calculations

Fineness modulus = $\Sigma \frac{F}{100} = \frac{391.04}{100}$ = 3.91

3.2 METHODS

Parameters tested in this study

- Normal consistency,
- Initial setting & Final setting time
- Soundness
- Workability
- Compressive strength
- Split tensile strength

3.2.1 TESTS ON CEMENT

3.2.1.1 Fineness of Cement by Dry Sieving Method: The degree of fineness of cement is a measure of the mean size of grains in cement. The finer cement has quicker action with water and gains early strength through its ultimate strength remains unaffected. However, the shrinkage and cracking cement will increase with the fineness of cement. Apparatus used to determine the sieve analysis are I.S. Sieve No. 9 (90 Microns), Weighing Balance capacity 5 kg as per IS: 4031(part 1)1996.Weigh 100 grams of the given cement and sift it continuously for 15 minutes on IS. Sieve 9 no air set lumps may be broken down by fingers but nothing should be rubbed on the sieves. Find the weight of residue of the sieved after the sifting is over and report the values as a percent of the original sample taken.

3.2.1.2 Normal Consistency: About 400g of cement was initially mixed with 30 percent mixing of water. The paste was filled in the mould of Vicat's apparatus and care was taken such that the cement paste was not pressed forcibly in the mould and the surface of filled paste was smoothened and leveled. A square needle 1mm×1mm of size is to be attached to the plunger and then lowered gently on to the surface of the cement paste and is released quickly. As plunger pierces the cement paste, reading on scale was recorded. The experiment was performed carefully away from vibrators and the other disturbances. The test procedure was repeated by increasing the percentage of mixing water at 0.5% increment until the needle reaches 5 to 7 mm from the bottom of the mould. When this condition is fulfilled, the amount of water added was taken as the correct percentage of water for normal consistency. The entire test was completed within 3 to 5 minutes, if the time taken to complete the experiments exceeds 5 minutes, the sample was rejected and fresh sample was taken and the operation was repeated again. Fresh cement was taken for each repetition of the experiment. The plunger was cleaned each time the experiment is done.

3.2.1.3 Initial and Final Setting Time: Cement paste was prepared by mixing cement with 0.85 times appropriate mixing water required to give a paste of standard consistency. The stop watch was started at the instant the mixing water was added to the cement. After half-a-minute, the paste was thoroughly mixed with fingers for one minute. The mould resting on a nonporous plate was filled completely with cement paste and the surface of filled paste was leveled smooth with the top of the mould. The test was conducted at room temperature of 27 ± 2^0C at a relative humidity of 60%. The mould with the cement paste was placed in the Vicat's apparatus and the needle was lowered gently to make contact with the test block and was then quickly released. The needle thus penetrates the block and the reading on the graduated scale of Vicat's apparatus was recorded. The procedure was repeated until the needle fails to pierce the block by about 5 to 7 mm measured from the bottom of the mould. The stop button of stop watch was pushed down and the time was recorded which give the initial setting time. The cement paste was considered finally set when upon applying the needle gently to the surface of test block, the needle makes an immersion, but fails to penetrate and the time was noted which gives the final setting time. The needle was cleaned after every repetition and also care was taken such that there could not any vibrations.

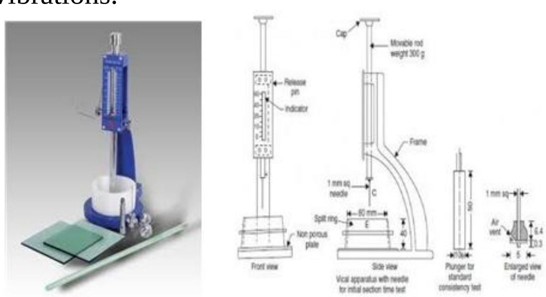

Figure: 3.1: Vicat apparatus with dimensions

3.2.1.4 Soundness: It consists of a small split cylinder of spring brass of 0.5mm thickness, forming a mould with 30mm internal diameter and 30mm high. On either side of the split are attached two indicators are attached with pointed ends AA, the distance from these ends to the Centre of cylinder being 165mm. the mould was placed on a glass sheet and was filled with cement paste formed by gauging 100g of cement with 0.78 times the mixing water required to give a paste of standard consistency. The mould was covered with a glass sheet and a small weight was placed on its top. The mould was then submerged in the water at a temperature of 27 ± 2^0C. After 24hours, the mould was taken out and the distance separating the indicators points was measured. The mould was again submerged in water. Using the water heaters the water was brought to boiling point within 25 to35 minutes and the specimen was kept for 3 hours at a boiling point. The mould was removed from water and was allowed to cool down to 27^0C. The distance between the indicator points was measured again. The difference between the two measurements represents the unsoundness of cement. For each concentration of mixing water, three samples were tested and the mean value was taken as the unsoundness of cement sample.

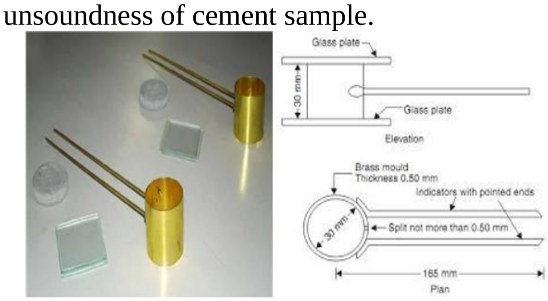

Figure: 3.2: Le Chatelier Apparatus with dimensions

3.2.1.5 Specific Gravity Cement: Specific gravity of cement is defined as, the ratio of dry weight of cement to the weight of equal volume of kerosene added. This test is conducted by Le-Chatliers apparatus this property very important in the mix design. Note down the weight of empty density bottle (W_1). Take a one third of cement in bottle and weigh the bottle (W_2) then fill the bottle with kerosene fully and weigh the bottle with cement and kerosene (W_3). Then clean the bottle and fill the kerosene in the bottle and weigh the bottle with kerosene (W_4).

Note down the readings and determine the specific gravity of cement.

Specific Gravity of Cement $= (W_2-W_1)/((W_2-W_1)-(W_3-W_4))$

Figure 3.3: Specific gravity apparatus (Density bottle)

3.2.2 TESTS ON AGGREGATES

Specific Gravity of Coarse and fine aggregate: Obtain approximately 1000 g of aggregate material passing the (4.75 mm) sieve. Prepare the material. Dry the material until it maintains a constant mass. This indicates that all the water has left the sample. Drying should occur in an oven regulated at 230°F (110°C).Cool the aggregate to a comfortable handling temperature. Immerse the aggregate in water at room temperature for a period of 15 to 19 hours. Dry the sample to a saturated surface dry (SSD) condition. Spread sample on a flat, non-absorbent surface and stir it occasionally to assist in homogeneous drying. A current of warm air may be used to assist drying procedure .The air current (typically from a blow dryer) should not blow the sample off the non-absorbent surface. Throughout this drying process, the aggregate should be repeatedly tested for a SSD condition using the Cone Test as follows: Fill a cone-shaped metal mould to overflowing with drying aggregate. Lightly tamp the aggregate into the mould with 25 light drops of a small metal tamper Remove loose aggregate from the outside of the mould and carefully lift the mould vertically. If surface moisture is still present, the fine aggregate will retain its moulded shape. When thea ggregate achieves an SSD condition, it will slump slightly. Upon the first test where slumping occurs, record the weight of the aggregate as SSD mass.

Figure 3.5: Specific gravity of fine and coarse aggregates apparatus

3.4 TESTS ON CONCRETE

3.4.1 Compressive Strength Test: Remove the specimen from water after specified curing time and wipe out excess water from the surface. Take the dimension of the specimen to the nearest 0.2m. Clean the bearing surface of the testing machine. Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast. Align the specimen centrally on the base plate of the machine. Rotate the movable portion gently by hand so that it touches the top surface of the specimen. Apply the load gradually without shock and continuously at the rate of 140kg/cm2/minute till the specimen fails. Record the maximum load and note any unusual features in the type of failure.

Minimum three specimens should be tested at each selected age. If strength of any specimen varies by more than 15 per cent of average strength, results of such specimen should be rejected. Average of their specimens gives the crushing strength of concrete.

Figure 3.8: Compressive testing machine

3.4.2 Split Tensile Test: The split tensile test were conducted as per IS 5816:1999. The size of cylinder is 300mm length with 150mm diameter. The specimen were kept in water for curing for 28, 60 and 90 days and on removal were tested in wet condition by wiping water and grit present on the surface. The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder along the vertical diameter. The maximum load applied to the specimen was then recorded and the appearance of the concrete for any unusual features in the type of failure was noted. Average of three values was taken as the representative of batch.

The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder along the vertical diameter.

To find split tensile strength following equation has used. Figure 3 shows the testing of split tensile test.

Split tensile strength = 2P/ (π DL)

Where P=split tensile load, D=diameter of the cylinder

IV. RESULTS AND DISCUSSIONS

4.1 GENERAL

Concrete is the most widely used manufactured material in the construction industry. It's the most important property is durability which relates the performance of the material to its service life under various environmental conditions. The ability of concrete to withstand and satisfactorily and for long periods the effects of load, time, and environment depends very much on how the engineering properties of the material are constituted initially and how they are allowed to develop with age.

The use of cementitious and pozzolanic siliceous industrial by-products as mineral admixtures-in concrete can bring improvements in engineering properties of concrete (strength, impermeability and general durability). Normal pozzolan additives due to their low surface area and reactivity are not generally able to improve the early strength which is crucial to the strength and stability of structural concrete applications and durability of concrete. The problem, though, could be solved by using a mixture of normal (such as fly ash and slag) and a highly reactive pozzolan, to produce a durable concrete which does not suffer from low early strength. Also the durability of concrete during its service life may be significantly affected by the environmental conditions to which it is exposed, and in order to produce a concrete of high quality, the placing of an appropriate mix must be followed by a planned curing system in a suitable environment during the early stages of hardening.

4.2 TESTS FOR WORKABILITY

Workability is the ability of fresh (plastic) concrete mix to fill the form/mould properly with the desired work (vibration) and without reducing the concrete's quality. Workability depends on water content, aggregate (shape and size distribution), cementitious content and age (level of hydration) and can be modified by adding chemical admixtures. Raising the water content or adding chemical admixtures will increase concrete workability. Excessive water will lead to increased bleeding and/or segregation of aggregates (when the cement and aggregates starts to separate), with the resulting concrete having reduced quality. The use of an aggregate with an undesirable gradation can result in a very harsh mix design with a very low slump, which cannot be readily made more workable by addition of reasonable amounts of water.

Workability is measured by performing the following tests:

4.2.1. Slump Cone Test: Slump test is the most commonly method for measuring the consistency of concrete which can be employed either in laboratory or at site of work. The internal surface of the mould is thoroughly cleaned and freed from moisture and adherence of any old set concrete before commencing the test. The mould is placed on a smooth, horizontal, rigid and non-absorbent surface. The mould is then filled in four layers, each approximately ¼ of the height of the mould. Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred as 'slump' of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. The difference in height in 'mm' is taken as slump of concrete.

Fig.4.1 Slump Cone Apparatus

Test results

1. Slump in terms of millimeters to the nearest 5 mm = 49.5mm
2. Shape of the slump: SHEAR
3. Referring to the selection of data, we have a slump value within the Range (60 – 180 mm).

Fig4.2. Measuring Slump Fall

Table 13: Workability of concrete with replacement of fly ash and slag

S.NO	**Details of Material**	**Slump in mm**
1	90%cement +10%FA and 90%sand+10%slag	45
2	90%cement +10%FA and 80%sand+20%slag	47
3	90%cement +10%FA and 70%sand+30%slag	50
4	80%cement +20%FA and 90%sand+10%slag	53
5	80%cement +20%FA and 80%sand+20%slag	56
6	80%cement +20%FA+70%sand30%slag	58
7	70%cement +30%FA and 90%sand+10%slag	54
8	70%cement +30%FA and 80%sand+20%slag	57
9	70%cement +30%FA and 70%sand+30%slag	59

4.3 SOUNDNESS TEST

The expansion of cement specimen was less than 10 mm specified by IS 4031(Part 3)1988. This confirmed that the cement is a good additive material. Table 4.9 shows the values for soundness of 100% OPC

Table 15: Soundness of Ordinary Portland Cement

Test for Physical Requirement	**Zuari O.P.C 53 Grade**	**IS 4031-1988**
Lechatlier Method(mm)	1	<10

Soundness of cement with 10% replacement of fly ash:

Table 16: soundness of cement with 10%replacement of Fly Ash

Test of Physical requirement	ZUARI O.P.C 53 Grade	IS 4032 (part 3) :1987
Le chatlier method(mm)	2	<10mm

Soundness of cement with 20% replacement of fly ash:

Table 17: Soundness of cement with 20%replacement of Fly Ash

Test of Physical requirement	ZUARI O.P.C 53 Grade Cement	IS 4032 (part 3) :1987
Le-chatelier method(mm)	1	<10mm

Soundness of cement with 30% replacement of fly ash:

Table 18: soundness of cement with 30%replacement of Fly Ash

Test of Physical requirement	ZUARI O.P.C 53 Grade Cement	IS 4032 (part 3) :1987
Le-chattier method(mm)	2	<10mm

4.4 TESTS ON CEMENT

4.4.1 Specific Gravity of Cement

Table 19: Specific gravity of cement

Specific gravity of Sample-1 = (W2-W1)/((W2-W1)-(W3-W4))

S.No.	Specifications	Sample-1	Sample-2
1	Weight of empty gravity bottle(W_1)	28	25
2	Weight of empty bottle+ cement(W_2)	38	35
3	Weight of empty bottle+ cement +Kerosene(W_3)	73	74.5
4	Weight of bottle + Kerosene(W_4)	66.2	67.9

= 10/ (10)-(6.8)

= 3.12

Specific gravity of sample-2 = $(W_2-W_1)/ ((W_2-W_1) - (W_3-W_4))$

= 10/ (10)-(6.6)

= 2.94

Specific Gravity of cement = (3.12+2.94)/2

=3.0

4.4.2 Standard Consistency of Cement

Theory: Normal consistency is defined as that percentage water requirement of the cement paste, the viscosity of which will be such that the Vicat's plunger penetrates up to a point 5 to 7 mm from the bottom of the Vicat's mould. The object of conducting this test is to find out the amount of water to be added to the cement to get a paste of normal consistency i.e. a paste of certain standard

Table 20: Normal Consistency of Cement

B	percentage of water to be added	Depth not penetrated(mm)
1	28%	37
2	30%	33
3	32%	12
4	34%	5

Initial reading is the indicator reading when the lower and of the plunger touches the bottom non-porous paste.

Result

Standard consistency of cement = 34%

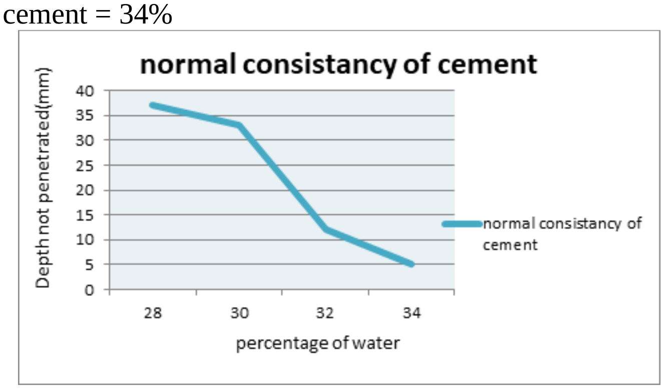

Figure 4.3: shows the normal consistency of cement

4.4.3 Standard Consistency of Cement with Replacement of 10% Fly Ash

Table 21: Normal Consistency of Cement 10% replacement of cement

S.NO.	Percentage of water to be added	Depth not penetrated(mm)
1	30%	29
2	32%	21
3	33%	15
4	34%	6

Initial reading is the indicator reading when the lower and of the plunger touches the bottom non-porous paste.

Result

Standard consistency of cement = 34%

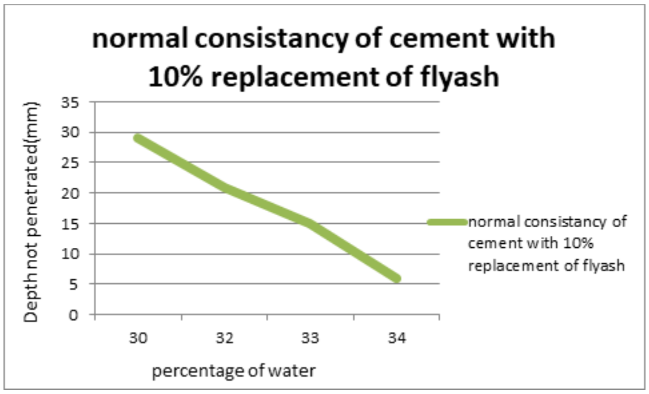

Figure4.4: shows the normal consistency of cement with 10%replacement of Fly Ash

4.4.4 Standard Consistency of Cement with Replacement of 20% Fly Ash

Table 22: Normal Consistency of Cement with20% replacement of fly ash

S.NO.	Percentage of water to be added	Depth not penetrated(mm)
1	30%	30
2	32%	23
3	33%	13
4	34%	5

Initial reading is the indicator reading when the lower and of the plunger touches the bottom non-porous paste.

Result

Standard consistency of cement = 34%

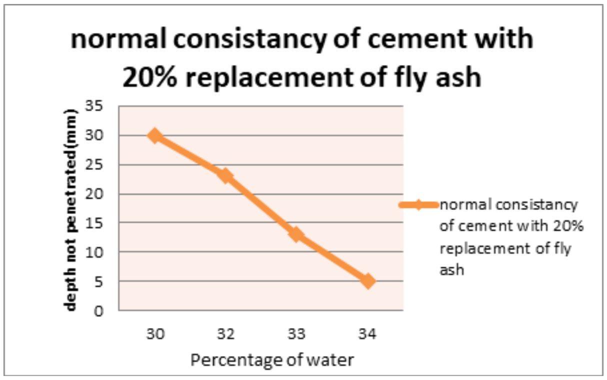

Figure4.5 shows the normal consistency of cement with replacement of 20% Fly Ash

4.4.5 Standard Consistency of Cement with Replacement of 30% of Fly Ash

Table 23: Normal Consistency of Cement with replacement of30% fly ash

S.NO.	Percentage of water to be added	Depth not penetrated (mm)
1	30%	33
2	32%	21
3	33%	17
4	34%	12

5	35%	5

Initial reading is the indicator reading when the lower and of the plunger touches the bottom non-porous paste.

Result

Standard consistency of cement = 35%

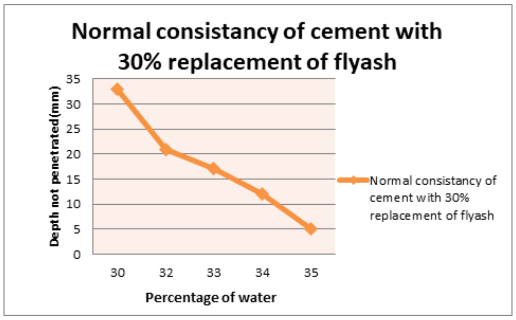

Figure 4.6 shows the normal consistency of cement with 30% replacement of fly ash

V. CONCLUSIONS

Fly Ash and GBFS is used in production of concrete cubes and cylinders replacement cement by fly ash dosage of 10% at replacement sand by slag dosage of 10%, 20%, 30%, replacement cement by fly ash dosage of 20% at replacement of sang by slag dosage of 10%, 20, 30%, replacement of cement by fly ash dosage of 30% at replacement of sand by slag dosage of 10%, 20%,30%.These cubes and cylinders were cured and tested for compressive strength and split tensile strength for 3days, 7days, 14days, 28days, 56days, 90days and results were noted. Based on experimental investigation conducted following conclusions are made.

- ✓ With increasing of fly ash and slag percentages in concrete then the workability should be increased gradually as compared to normal concrete.
- ✓ By using of fly ash and slag in concrete the water absorption quantity should be increased gradually because of slag absorbed more quantity of water.
- ✓ The most interesting finding was that Fly Ash retards the initial setting and accelerates the final setting of concrete mortar.
- ✓ The experimental results show that the pozzolanic activity of fly ash and slag waste increases with increase of time.
- ✓ The physical properties of cement with the replacement of fly ash and slag were found to be increase with the increasing of the percentages of admixtures.
- ✓ Although the soundness of cement was found to be increase after replacement of admixtures.
- ✓ The compressive for
  - 100% cement + 0% replacement mineral admixtures at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 15.82N/mm^2,18.74 N/mm^2,23.54 N/mm^2,29.25 N/mm^2,35.47 N/mm^2 and37.54 N/mm^2.
  - 10%FA+10%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 20.66 N/mm^2,32.66 N/mm^2.33.33 N/mm^2,36.88 N/mm^2,39.77 N/mm^2,42.55 N/mm^2, 10%FA+20%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 20.88 N/mm^2,23.55 N/mm^2,24.22 N/mm^2,25.99 N/mm^2,32.22 N/mm^2,35.55 N/mm^2, 10%FA+30%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 19.33 N/mm^2,20.66 N/mm^2,20.44 N/mm^2,22.88 N/mm^2,25.15 N/mm^2,28.66 N/mm^2.
  - 20%FA+10%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 23.77 N/mm^2,26.22 N/mm^2.26.22 N/mm^2,31.22 N/mm^2,33.11 N/mm^2,35.11 N/mm^2, 20%FA+20%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 18.88 N/mm^2,20.44 N/mm^2,23.77 N/mm^2,29.99 N/mm^2,31.11 N/mm^2,32.66 N/mm^2, 20%FA+30%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 14.22 N/mm^2,19.11 N/mm^2,21.77 N/mm^2,24.88 N/mm^2,26.21 N/mm^2,27.22 N/mm^2.

- 30%FA+10%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 14.44 N/mm^2,20.66 N/mm^2,21.11 N/mm^2,23.33 N/mm^2,28.22 N/mm^2,30.22 N/mm^2, 30%FA+20%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 13.77 N/mm^2,19.77 N/mm^2,20.55 N/mm^2,21.33 N/mm^2,27.55 N/mm^2,29.33 N/mm^2,30%FA+30%GBFS at 3 days, 7 days, 14 days, 28 days, 56 days and 90 days were 111.77N/mm^2,17.22 N/mm^2,18.22 N/mm^2,18.99 N/mm^2,23.55 N/mm^2,27.66 N/mm^2.

- ✓ The Compressive strength of concrete for 10% FA and 10% GBFS is more compared to that for 10% FA and 20% GBFS and 10% FA and 30% GBFS.
- ✓ The Compressive strength of concrete for 20% FA and 10% GBFS is more compared to that for 20% FA and 20% GBFS and 20% FA and 30% GBFS.
- ✓ The Compressive strength of concrete for 30% FA and 10% GBFS is more compared to that for 30% FA and 20% GBFS and 30% FA and 30% GBFS.
- ✓ The maximum strength had attained 39.59% increased at 10 % FA and 10% GBFS replacement when compared to controlled concrete.
- ✓ The split tensile strength values were found to be gradually decreased while the combination of percentage replacement of admixtures is increased.

REFERENCES

1. Text Books

1) N.Krishna Raju, “Design of Concrete Mixes”, Year 2005
2) A.M.Nevile, “Properties of concrete” , ELBS with Longman 1987
3) M.S.Shetty, “Concrete Technology”, Year 2008
4) M.L.Gambhir, “Concrete Manual”, Dhanpat Rai Publications,
5) M.L.Gambhir (2009) , “Concrete Technology, Theory and Practice”, McGraw Hill Publications, Year 2009

2. Journals

1) B. Mather, “Concrete--Year 2000, Revisited”, ACI journal, vol-144, pp 31-40, 1994
2) Taiwan, Concrete International, vol-17, pp 71-76, 1995 etc.
3) International Symposium on “innovative world of concrete”, Vol- II , IWC-98 proceedings.
4) Proceedings of Seventh International Conference on Fly Ash, Silica Fume,Slag and Natural Pozzolans in Concrete, Vol-II Editor, V.M.Malhotra.
5) The Indian Concrete Journal, Vol.80, June 2006.
6) Magazine of Concrete Research, Vol.58, June 2006.

3. IS Codes

1) IS 456-2000 -Code of practice for plain & reinforced cement concrete.
2) IS 12269-1987-Specification for OPC 53 grade.
3) IS 10262-2009-Recommended guide line for concrete mix design.
4) IS 1727-1967-Methods of test for pozzolonic materials.
5) IS 3812-1981-Specifications of fly ash for use as pozzolana & admixtures (First Revision).
6) IS 3812(Part1)-2003-Specifications for pulverized fuel ash for use as cement, cement mortar and concrete (Second Revision).
7) IS 9103-1999-Concrete admixture –Specifications.
8) IS 516-1965-Method of Test for Strength of Concrete.
9) IS 383-1970-Specification for coarse aggregate and fine aggregate from natural sources.
10) IS 650-1966-Specification for standard sand for testing of cement.
11) IS 2386 (Part 3)-Method of test for aggregates for concrete-Specific gravity, density, voids, absorption and bulking.