Comparison between the effect of silica fume and fly ash in high strength concrete using concrete mix design

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Abstract - **Concrete is the most important engineering material with cement as the basic ingredient. Concrete consumption is second only to water in terms of total volume consumed annually. With increase in trend towards the wider use of concrete for pre stressed concrete and high rise buildings there is a growing demand of concrete with higher compressive strength, thus driving up the concrete demand in the construction sector. The present per capita cement consumption is about 190 kg/capita and it will increase up to about 465 kg/capita to 810 kg/capita. Increased production of cement will have a strong impact on the overall energy utilization of the cement industry. More energy input will be required to meet the demand in various processes, which will result in increased fuel consumption leading to higher emissions of CO_2 and other green house gases. Enormous efforts are being made in the cement industries to bring down the carbon dioxide emission during cement production by using cement substitution. Clinker substitution by supplementary cementitious materials like silica fume and fly ash is being used as mineral admixtures to the cement. Both silica fume and fly ash are regarded as waste product produced in the industries. Silica fume is defined as very fine non crystalline silica produced in electric furnaces as a by-product in the production of elemental silicon or alloys containing silicon. Fly ash is defined as the by-product recovered from the gases of burning coal during the production of electricity and also from boilers. The use of these by-products offer environmental advantages by diverting the material from the waste stream, reducing the energy investment in virgin materials, thus reduces the cost of construction and also improving the performance and quality of concrete. The comparative use of silica fume and fly ash as cement replacement and its effect in the production of high strength concrete has been studied in this project. We have used 5%, 10% and 15% by weight of cement as replacement by silica fume and fly ash in concrete.**

keywords - **Cement, High Strength Concrete, Silica fume, Fly ash, Concrete Mix Design, Concrete properties**

I. CONCRETE

1.1 INTRODUCTION

Concrete can be defined as a composite construction material composed primarily of aggregate, cement and water. It is the most widely used man-made construction material in the world. It is obtained by mixing the components and some admixtures along with water in required proportions on the basis of required strength. The aggregate used is generally coarse gravel or crushed rocks, along with a fine aggregate such as sand. The cement, commonly Portland cement, and other cementitious materials, serve as a binder for the aggregate. Various chemical admixtures are also added to achieve varied properties. Water is then mixed with this dry composite, which enables it to be shaped and then solidified and hardened into rock-hard strength through a chemical process called hydration. The water reacts with the cement, which bonds the other components together, eventually creating a robust stone-like material.

1.2 HISTORY

The word concrete comes from the Latin word "concretus" meaning compact or condensed. Concrete has been in use as a construction material since the Roman period and during that period, materials were obtained from quicklime, pozzolana and an aggregate of pumice. Its widespread use in many Roman structures can be termed as a key event in the history of architecture which freed it from the restrictions of stone and brick material and allowed for revolutionary new designs in terms of both structural complexity and dimension. The Pantheon in Rome, Italy is the world's oldest known concrete structure built in about AD 125, which is still standing and is also the world's largest unreinforced concrete dome.

1.3 COMPOSITION

The strength, durability and other characteristics of concrete largely depend upon the properties of the ingredients. The popularity of concrete is due to the fact that from the common ingredients, it is possible to tailor the properties of concrete to meet the demands of any particular situation. The key to producing a strong, durable and uniform concrete lies in the careful control of its basic components. These are the following –

1.3.1 CEMENT

Portland cement is the most common type of cement in general usage and is the basic ingredient of concrete. It consists of a mixture of oxides of calcium, silicon and aluminum. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay and grinding this product (called clinker) with a source of sulfate (most commonly gypsum).

1.3.2 AGGREGATE

Fine and coarse aggregates make up the bulk of a concrete mixture and include sand, natural gravel and crushed stone are used. Recycled aggregates (from construction, demolition and excavation waste) are increasingly being used these days as partial replacements of natural aggregates. The presence of aggregate greatly increases the robustness of concrete above that of cement, which otherwise is a brittle material and makes concrete, a true composite material.

1.3.3 WATER

Water is mixed with a cementitious material to form a cement paste by the process of hydration. This cement paste glues the aggregate together, fills voids within it, and makes it flow more freely. If impure water is used to make concrete, it can cause problems when setting or cause premature failure of the structure. Hydration involves many different reactions, often occurring at the same time. As the reactions proceed, the products of the cement hydration process gradually bond together the individual sand and gravel particles and other components of the concrete, to form a solid mass.

1.3.4 CHEMICAL ADMIXTURES

Chemical admixtures are materials in the form of powder or fluids that are added to the concrete mixture immediately before or during mixing of concrete to reduce the water requirement, accelerate/retard setting or improve the specific durability characteristics. In normal use, admixture dosages are less than 5% by mass of cement and are added to the concrete at the time of batching/mixing.

1.4 PROPERTIES OF CONCRETE:

- Concrete has a considerably high compressive strength compared to most other materials but it has a very low tensile strength, which is about one-tenth of its compressive strength.
- Concrete also has a very low coefficient of thermal expansion and shrinks as it matures. All concrete structures crack to some extent, due to shrinkage and tension.
- The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop.

Among the various properties of concrete, its compressive strength is considered to be the most important and is taken as the index of its overall quality.

1.5 GRADES OF CONCRETE:

Concrete is generally graded according to its compressive strength. The various grades of concrete are designated in IS: 456-2000 and IS: 1343-1980. They are classified into different groups.

Grade Designation	Group
M 10	Ordinary concrete
M 15	
M 20	
M 25	Standard concrete
M 30	
M 35	
M 40	
M 45	
M 50	
M 55	
M 60 AND HIGHER	High strength concrete

In the designation of concrete mix, the letter 'M' refers to the mix and the number refers to the specified characteristic strength of 150mm work cubes at 28 days, expressed in MPa (N/mm^2).

II. HIGH STRENGTH CONCRETE

2.1 INTRODUCTION

Concrete is defined as "high-strength concrete" solely on the basis of its compressive strength measured at a given age. In the 1970's, any concrete mixtures that showed 40 MPa or more compressive strength at 28-days were designed as high-strength concrete. Later, 60-100 MPa concrete mixtures were commercially developed and this mixture of the above mentioned strength is now regarded as high strength concrete.

2.2 COMPOSITION

Manufacture of high-strength concrete involves making optimal use of the basic ingredients that constitute normal-strength concrete. And along with these, some admixtures are also used for making high-strength concrete. Producers of high-strength concrete know what factors affect compressive strength and know how to manipulate those factors to achieve the required strength. The components of high-strength concrete are as follows-

2.2.1 Cement

Ordinary Portland Cement (OPC) of is generally used for production of high-strength concrete. In general, cements with low content of C3A (Tricalcium aluminate) is considered suitable for production of high strength concrete.

2.2.2 Aggregates

Fine aggregates in the form of sand and coarse aggregates in the form of natural gravel and crushed stone are used in the production of high strength concrete. The aggregate plays an important role on the strength of concrete. It is recommended that fine aggregates with higher fineness modulus of around 3.0 should be used in high strength concrete. And the maximum size of coarse aggregates should be about 20-28mm to produce a high strength concrete.

2.2.3 Water

Water is the main component in every possible type of concrete. The quantity of water used for making high strength concrete is less than that required in producing a normal strength concrete. The reason behind using low amount of water is due to the use of coarser fine aggregates which helps in attaining the same workability.

2.2.4 Admixtures

2.2.4.1 Mineral admixtures

Silica fume and Fly Ash are the most commonly used mineral admixtures in high-strength concrete. These admixtures are also called supplementary cementing materials. These materials impart additional strength to the concrete by reacting with Portland cement hydration products to create additional C-S-H gel (Calcium Silicate Hydrate gel), the part of the paste responsible for concrete strength.

2.2.4.2 Chemical admixtures-

It would be difficult to produce high-strength concrete mixtures without using chemical admixtures. Superplasticizer is the most commonly used chemical admixture in high strength concrete. The superplasticizer gives the concrete adequate workability at low water-cement ratios, leading to concrete with greater strength.

2.3 Properties of high strength concrete

The various properties of high strength concrete are listed below-

- It has a higher compressive strength and also higher stiffness.
- It has an improved durability, reduced creep and drying shrinkage.
- It also has a better impact resistance and better resistance to abrasion

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2.4 Difference between high strength concrete and normal strength concrete

- The main difference lies in the strength. High strength concrete has comparatively higher strength than normal strength concrete.
- In normal strength concrete, the micro cracks form when the compressive stress reaches about 40% of the strength. Whereas in high strength concrete, the micro cracks form at about 65% – 70% of the strength.
- High Strength Concrete is less ductile compared to normal strength concrete. Because the stress-strain curve is more linear in case of high strength concrete.
- The cost of high strength concrete is less than normal strength concrete.

2.5 Uses of high strength concrete

- It is mainly used in high-rise buildings.
- It is used in the construction of bridges.
- It is used in making marine structures and underwater structures.
- It is also used in earthquake and wind resistant frame structures. Because the damping of high strength concrete is twice as much as steel.

III. SILICA FUME

3.1 INTRODUCTION

The American Concrete Institute (ACI) defines silica fume as "very fine non crystalline silica produced in electric furnaces as a by-product of the production of elemental silicon or alloys containing silicon". It is usually a gray colored powder, somewhat similar to Portland cement. It is usually categorized as a supplementary cementing material, which is also known as a chemical admixture. Silica fume is frequently referred by other names such as:

- Condensed Silica Fume
- Micro silica
- Volatilized Silica

3.2 PROPERTIES OF SILICA FUME

3.2.1 The primary chemical properties of silica fume are as follows:

- It is an amorphous material.
- It has a very high concentration of silicon dioxide (SiO_2) of about 85%.
- There may be additional trace elements in silica fume. But, these trace elements have no impact on the performance of silica fume in concrete.

3.2.2 The primary physical properties of silica fume are as follows:

- It is odorless and grey in colour.
- Silica fume particles are extremely small with more than 95% of the particles being less than 1 µm (one micrometer).
- The bulk density of silica fume is very low. It is about 130-430 kg/m^3. However, a densified silica fume has a very high bulk density of about 480-720 kg/m^3.
- Silica fume has a specific gravity of 2.2.
- The specific surface of silica fume is very high. It is about 15,000-30,000 m^2/kg, measured with the Blaine's permeability method.

3.3 CONTRIBUTION OF SILICA FUME IN CONCRETE

The benefits seen from adding silica fume are the result of changes to due to the microstructure of concrete. These changes result from two different but equally important processes. The first of these is the physical contribution of silica fume and the other is the chemical contribution of silica fume in concrete. These two contributions are discussed as follows-

- **Physical contribution:**

Adding silica fume brings millions and millions of very fine particles to a concrete mixture. The silica fume fills in the spaces between the cement grains. This phenomenon is referred to as particle filling or micro-filling. Even if silica fume do not react chemically, the micro-filler effect would bring about significant improvements in the nature of concrete.

- **Chemical contributions:**

Because of its very high amorphous silicon dioxide content, silica fume is a very fine reactive pozzolanic in concrete. As the Portland cement in concrete begins to react chemically, hydration occurs which releases calcium hydroxide, which is an unwanted product in concrete. The silica fume reacts with this calcium hydroxide to form additional binder material called calcium-silicate-hydrate(C-S-H) gel, which is very similar to the calcium-silicate-hydrate(C-S-H) gel formed during the hydration of Portland cement. It is largely this additional binder that gives the silica fume concrete, its improved hardened properties.

3.4 EFFECT OF SILICA FUME IN CONCRETE

Silica fume is used in concrete because it significantly improves the properties of fresh and hardened concrete. It is known that silica fume is generally used as a property enhancing material in concrete.

3.4.1 The effect of silica fume in fresh concrete is as follows-

- The concrete has an increased cohesion. Fresh concrete with silica fume is more cohesive than the fresh concrete without silica fume. And therefore the fresh silica fume concrete is less prone to segregation. And hence this type of concrete results in more efficient shotcreting, where a cohesive concrete is more preferred and advantageous.
- Fresh concrete with silica fume has little or no bleeding. Because of very high surface area of the silica fume and the usually very low water content of silica fume concrete, there is little or no bleeding. This therefore leads to non bleed of water channels and no waiting for the bleeding to finish in the concrete. Because of this factor, silica fume concrete more durable and has more efficient finishing.

3.4.2 The effect of silica fume in hardened concrete is as follows-

- The concrete has enhanced mechanical properties. Such as increase in the compressive strength and increase in modulus of elasticity in concrete. Although this type of concrete has been specified to take advantage of improvements in other properties too, but the property of most interest is certainly the compressive strength.
- The permeability of hardened silica fume concrete is very much less compared to the normal concrete. This is due to the higher surface area of the concrete. By reducing the permeability, the time is extended for any aggressive chemical to get into the concrete where it can do its damage. And this leads to the improved durability of the concrete.

IV. FLY ASH

4.1 INTRODUCTION

A fine, glass powder recovered from the gases of burning coal during the production of electricity is fly ash. These micron sized earth elements consist primarily of silica, alumina and iron. The combustion of powdered coal in thermal power plants produces fly ash. The high temperature of burning coal turns the clay minerals present in the coal powder into fused fine particles mainly comprising of aluminum silicate. Fly ash produced, thus possesses both ceramic and pozzolanic properties. When pulverized coal is burnt to generate heat, the residue contains 80 percent fly ash and 20 percent bottom ash. The ash is carried away by flue gas collected at economizer, air pre-heater and ESP hoppers. Clinker type ash collected in the water-impounded hopper below the boilers is called bottom ash.

4.2 TYPES OF FLY ASH

- **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 mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geopolymer.

- **Class C fly ash**

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

4.3 PROPERTIES OF FLY ASH

4.3.1 The primary chemical properties of silica fume are as follows:

- It is generally spherical in shape.
- The concentration of silicon dioxide (SiO_2) in fly ash is about 35%-55%.

4.3.2 The primary physical properties of silica fume are as follows:

- The specific gravity of fly ash is about 2.25.
- The specific surface fly ash is greater than 320 m^2/kg, measured by Blaine's permeability method.

4.4 EFFECT ON FLYASH ON CONCRETE

4.4.1 WORKABILITY

The use of good quality fly ash with a high fineness and low carbon content reduces the water demand of concrete and, consequently, the use of fly ash should permit the concrete to be produced at a lower water content when compared to a Portland cement concrete of the same workability with addition of chemical admixtures.

4.4.2 BLEEDING

Fly ash will reduce the rate and amount of bleeding primarily due to the reduced water demand. High levels of fly ash used in concrete with low water contents can virtually eliminate bleeding. Therefore, the freshly placed concrete should be finished as quickly as possible and immediately protected to prevent plastic shrinkage cracking when the ambient conditions are such that rapid evaporation of surface moisture is likely.

4.4.3 SETTING TIME

The impact of fly ash on the setting behavior of concrete is dependent not only on the composition and quantity of fly ash used, but also on the type and amount of cement, the water-to-cementitious materials ratio (w/cm), the type and amount of chemical admixtures, and the concrete temperature. It is fairly well-established that low-calcium fly ashes extend both the initial and final set of concrete

4.4.4 COMPRESSIVE STRENGTH DEVELOPMENT

This is generally the effect of fly ash in hardened concrete. Compressive strength of fly ash replacing a certain mass of Portland cement with an equal mass of low-calcium (Class F) fly ash and maintaining a constant water-cement ratio. As the level of replacement increases the early-age strength decreases.

V. CONCRETE MIX DESIGN

5.1 INTRODUCTION

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible is termed the concrete mix design. Designing a concrete mix to get the required properties using the available materials is very essential to achieve the durability of concrete and economy to save the cost of structure. The proportioning of ingredient of concrete is governed by the required performance of concrete in two states, namely the fresh and the hardened states. If the fresh concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance. In the hardened state, the compressive strength of concrete is considered as the most important property, which rates the quality of the concrete.

5.2 BASIC CONSIDERATIONS FOR CONCRETE MIX DESIGN

The proportioning of concrete mixes is accomplished by the use of certain empirical relations which afford a reasonably accurate guide to select the best combination of ingredients so as to achieve the desired properties. The design of concrete for medium strength is based on the following assumptions-

- The compressive strength of concrete is governed by its water-cement ratio.
- For the given aggregate characteristics, the workability of concrete is governed by its water content.

For high strength concrete mixes of low workability, considerable interaction occurs between the above criteria and the validity of such assumptions may become limited. Moreover, there are various factors which affect the properties of concrete, e.g. the quality and quantity of cement, water and aggregates, techniques used for batching, mixing, placing, compacting and curing etc. Therefore, the specific relationships used in proportioning of a concrete mix should be considered as a basis for

making an initial guess at the optimum combination of the ingredients and final mix proportion is obtained only on the basis of further trial mixes.

5.3 REQUIREMENTS FOR CONCRETE DESIGN

The requirements which form the basis of selection and proportioning of mix ingredients are -

- The minimum compressive strength required from structural consideration
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-cement ratio and maximum cement content to give adequate durability for the particular site conditions
- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

5.4 TYPES OF MIXES

5.4.1 Nominal Mixes

In the past, the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates required. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed as nominal mixes. These mixes offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients, the nominal concrete for a given workability varies widely in strength.

5.4.2 Standard Mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under-rich or over-rich mix. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

5.4.3 Designed Mixes

In these mixes, the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete. This is the most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically.

5.5 MIX PROPORTION DESIGNATIONS

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For example, a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass.

5.6 CONCRETE MIX DESIGN FOR HIGH STRENGTH CONCRETE

The properties of concrete with a compressive strength of above 50 MPa are highly influenced by the properties of aggregate in addition to the water-cement ratio. To achieve high strength, it is necessary to use the lowest possible water cement ratio with higher cement content which invariably affects the workability of the mix. It should be kept in mind that high cement content may liberate large heat of hydration causing rise in temperature which may affect the setting and may result in excessive shrinkage. Now-a-days, concrete which has a desired 28 day strength over than 60 MPa can be made by suitably proportioning the ingredients and using normal vibration techniques for compacting the mix.

The concrete making materials being essentially variable, results in the production of mixes of variable quality. Therefore in case of high strength concrete, the most rational approach of mix proportioning is to select proportions with specific materials in mind which possess more or less unique characteristics. This will ensure the concrete with the appropriate properties to be produced, most economically.

5.7 PROPERTIES CONSIDERED FOR HIGH STRENGTH CONCRETE

The properties considered for high strength concrete are as follows-

5.7.1 PERFORMANCE REQUIREMENTS

- **Age:**

High strength concrete can gain considerable strength after the normally specified 28-days strength. To take advantage of this characteristic, many specifications for compressive strength have been modified from typical 28 days to 56 days, 91 days or later ages.

- **Strength:**

To meet the specified strength requirements, the concrete must be proportioned in such a manner that not more than a predefined percentage of the average compressive strength results of the field tests shall fall below the specified characteristic strength of concrete, fck. Moreover a high strength concrete mixture in the field generally requires some adjustments in the proportions for the air content.

- **Workability:**

Because of high content of coarse aggregate and cementing material content and a low water-cement {w/(c+p)} ratio, high strength concrete is difficult to place. This is a very important property to be taken care of.

5.7.2 SELECTION OF MATERIALS

Selection of appropriate constituent materials to produce high strength concrete is a critical stage in the process of mixture proportioning for high strength concrete. The optimum proportions are selected considering the characteristics of cement and mineral additives such as fly ash and silica fume, aggregate quality, admixture type and its dosage, and mixing.

- **Cement:**

To produce high strength concrete, use of Ordinary Portland Cement of grade 43 (OPC 43) is generally recommended. The adoption of OPC-43 to OPC-53 is because of the fact that OPC-43 has lower specific surface, lower fineness than OPC-53, thus providing a better consistency. Again compatibility between cement and super plasticizer is one of the major factors affecting the choice of cement and consequently the additives for high strength concrete. The minimum cement content adopted for high strength concrete proportioning is 400 kg/m^3.

- **Coarse Aggregate:**

High strength concrete is produced with nominal weight aggregate which is clean, free from fissures or weak planes, and free from surface coatings. Smaller size aggregates is used for attaining high strength for a given w/(c+p) ratio. A 20 to 10mm nominal maximum size aggregate is used for producing concrete up to 60Mpa or higher. Aggregates also influence the consistency of aggregate. Lime stone aggregates are especially suitable to produce high strength concrete due to the development of epitaxic adherence which increases the strength remarkably.

- **Fine Aggregate:**

The grading and particle shape of fine aggregates significantly influence the mixing water content and compressive strength. The quantity of cement paste required per unit volume of a concrete mixture decreases as the relative volume of versus fine aggregate increases. Fine aggregates with fineness modulus of about 3.0 are preferable for high strength concrete.

- **Fly Ash:**

The use of fly ash in concrete results in a lowered cost of materials in the finished concrete with improved characteristics. It is generally recognized as the replacement of Portland cement by fly ash as percentage of total mass of cementing material. Fly ash mixes can be proportioned by using fly ash quantities in excess of the amount of cement replaced. As a result, fly ash mixes contain a total of Portland cement and amount of fly ash used as replacement. However, the effect of fly ash is different at all percentages of replacement.

- **Silica Fume:**

It contains about 80% - 95% of amorphous silicon dioxide SiO_2 , in the form of microscopic glassy spherical particles. Larger surface area and high content of amorphous silicon dioxide give silica fume super pozzolanic properties. Silica fume is blended with Portland cement as percentage of total mass of cementing material. The cementing efficiency of silica fume is not constant at all percentages of replacement.

- **Super plasticizer:**

In the production of concrete, a reduction in w/(c+p) ratio by decreasing the water content rather than increasing the total cementing materials content will produce higher compressive strength. For this reason, chemical admixtures such as super plasticizers are used for producing high strength concrete. The use of superplasticizers help in dispersing the cement materials, thus reducing the water content and thereby increasing the compressive strength.

5.7.3 WATER-CEMENTING MATERIAL {w/(c+p)} RATIO

The single most important variable in achieving high strength concrete is the water cement ratio. Since most of the high strength concrete mixtures contain cementing materials other than cement, the {w/(c+p)} ratio is to be considered in place of the traditional water-cement (w/c) ratio. The {w/(c+p)} ratio, like the water-cement ratio is calculated on a weight basis. The relationship between water-cement ratio and compressive strength, which has been identified for normal strength concrete mixes is reasonably valid for high strength concrete as well.

5.8 MIX PROPORTIONING PROCEDURE

With reference to IS 10262 : 2009, the mix design is proportioned. The procedure consists of a series of steps, which when completed provide a mixture meeting the strength requirements based on the combined properties of the individually selected and proportioned ingredients. The mix design is proportioned as follows-

5.8.1. Evaluation of target mean strength (f'_{ck}):

Depending upon the level of quality control, the target mean strength is necessary to reach the characteristic strength is determined.

The target mean strength is given as, $f'_{ck} = f_{ck} + (1.65 * s)$

Where,

f'_{ck} = target mean compressive strength at 28 days in N/mm^2

f_{ck} = characteristic compressive strength at 28 days in N/mm^2

s = standard deviation in N/mm^2

5.8.2. Selection of the Water-cementitious ratio w/(c+p):

The maximum water-cement ratio for high strength ratio is about 0.35. so while adopting a water-cement ratio, it should be adopted such that the ratio is less than or equal to 0.35.

5.8.3. Selection of water content:

The water content of concrete is influenced by a number of factors such as aggregate size, aggregate shape, aggregate texture and many other factors. An increase I the aggregate size, a reduction in water-cement ratio and slump, and use of rounded aggregate and water reducing admixtures will reduce the water demand. Om the other hand increased temperature cement content slump, water cement ratio will increase the water demand. The quantity of maximum mixing water per unit volume of concrete is determined from table 2 of IS 10262: 2009. The table is given as follows-

Sl. No.	Nominal maximum size of aggregate (mm)	Maximum water content (kg)
1	10	208
2	20	186
3	40	165

Table 1: Maximum water content per cubic meter of concrete for nominal maximum size of aggregate.

The water content in the table is for angular coarse aggregate and for 25 to 50mm slump. The estimate water content can be reduced by approximately 10 kg for sub-angular aggregates, 20 kg for gravel with some crushed particles and 25 kg for rounded gravel to produce same workability. For the desired workability other than 25 to 50 mm slump range, the required water content may be established by an increase of about 3 percent for every additional 25mm slump. Water educing admixtures or super plasticizers usually decrease the water content by 5 to 10 percent and 20 percent and above respectively at appropriate dosages.

5.8.4. Calculation of cementitous material content:

The cement and supplementary cementitious material content per unit volume of concrete is calculated from the free water-cement ratio {w/(c+p)} and the quantity of water per unit volume of concrete. The cementitious material content so calculated shall be checked against the minimum content for the requirements of durability and the greater of the two is to be adopted. We have assumed as the minimum cement content for high strength concrete is to be about 400 kg/m^3. By knowing the cementitious content, we can estimate the quantity of cement and the quantity of fly ash and silica fume replacement respectively according to their varying percentages.

5.8.5. Estimation of coarse aggregate proportion:

Aggregates of essentially the same nominal maximum size, type and grading will produce concrete of desired workability when a given volume of coarse aggregate per unit volume of total aggregate is used. Approximate values for this aggregate volume is given in table 3 of IS 10262: 2009 for water cement ratio of 0.5 which may be suitably adjusted for other water cement ratios. It can be seen that for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and grading zone of fine aggregates. For more workable concrete mixes which is sometimes required when placement is done by pump, it may be desirable to reduce the estimated coarse aggregate content up to 10 percent.

Sl. No.	Nominal Maximum size of aggregate (mm)	Volume of Coarse Aggregate per Unit Volume of Total Aggregate for different Zones Of Fine Aggregate			
		Zone IV	Zone III	Zone II	Zone I
1	10	0.50	0.48	0.46	0.44
2	20	0.66	0.64	0.62	0.60
3	40	0.75	0.73	0.71	0.69

Table 2: Volume of coarse aggregate per unit total volume of total aggregate for different zones of fine aggregate

5.8.6. Estimation of Fine Aggregate:

The quantities of fine aggregate and coarse aggregate content are determined by finding out the absolute volume of cementitious material, water and the chemical admixture; by dividing their mass by their respective specific gravity, multiplying by 1/1000 and subtracting the result of their summation from unit volume. The values so obtained are divided into coarse and fine aggregate fractions by volume in accordance with coarse aggregate proportion already determined. The coarse and fine aggregates contents are then determined by multiplying with their respective specific gravities and multiplying by 1000.

5.8.7. Mix proportion:

After the mix calculations is done and the quantities of the ingredients required is determined. Finally a mix proportion is prepared for the concrete mix with desired proportions of cementitious material, fine aggregate and coarse aggregate. This mix

proportion is used in producing the concrete along with the other required quantities to test the specified requirements of concrete.

VI. DISCUSSION ON THE EXPERIMENT

The detailed discussion of the test conducted is as follows:

6.1 Materials collected

a. Coarse aggregate with a nominal size of 20mm is collected from the laboratory.
b. Fine aggregate corresponding to Zone-III, having a fineness modulus of 3.05 is collected.
c. Ordinary Portland Cement of grade 43 (OPC-43) is used.
d. Silica Fume.
e. Fly Ash.
f. Sikament, a superplasticizer is used as chemical admixture.

6.2 Test conducted on the materials and results

a. Specific gravity of cement – 3.15
b. Fineness of Cement – 6%
c. Specific Gravity of coarse aggregate – 2.65
d. Specific Gravity of fine aggregate – 2.65
e. Water absorption of coarse aggregate – 0.25%
f. Water absorption of fine aggregate – 0.10%

6.3 Collected information of some materials

a. Specific Gravity of silica fume – 2.2
b. Specific Gravity of fly ash – 2.25
c. Specific Gravity of superplasticizer – 1.2

6.4 Machineries and Equipments used

a. Compression testing machine for determining the compressive strength of concrete.
b. Mixing machine is used for mixing and production of concrete.
c. Steel plates used to make 150mm x 150mm x 150mm mould.
d. Hand tools.

Figure 1: Compression Testing Machine

Figure 2: Mixing Machine

6.5 Proportioning of concrete mix design

The concrete mix design proportioning was done to obtain for determining the relative amounts of ingredients required in concrete for obtaining a workable and a economical mix which will satisfy the required properties of concrete. Based on the codal provisions, design mix proportion was done with the help of MS-Excel. One of the Excel sheet is given below-

MIX PROPORTION FOR FLY ASH REPLACEMENT OF CEMENT BY 5% FLY ASH

PART 1

A. DATA

A1: Design Speculations		
A2: Characteristic compressive strength of concrete (fck)	60	Mpa
A3: Standard Deviation (s)	5	N/mm2
A4: Probability Factor (k)	1.65	
A5: Workability	75	mm
A6: Exposure Condition	Extreme	
A7: Cement	OPC 43	
A8: Fly Ash	Class F	

B. Characteristics of materials

B.1: Specific gravity of Cement	3.15
B.2: Specific gravity of Fly Ash	2.25
B.3: Specific gravity of coarse aggregate	2.65
B.4: Specific gravity of fine aggregate	2.65
B.5: Specific gravity of plasticizer	1.2
B.6: Water absorption for coarse aggregate in %	0.25%

B.7: Water absorption for fine aggregate in %	0.10%	
B.8: Free surface moisture for coarse aggregate in %	0.40%	
B.9: Free surface moisture for fine aggregate in %	0.05%	
B.10: Maximum size of coarse aggregate in mm	20mm	
B.11: Grading Zone of fine aggregate	zone- III	
B.12: Superplasticizer used	Sikament	

PART - II: MIX DESIGN

FIRST TRIAL

1. Target mean strength (ft) = fck + k*s	**68.25**	Mpa
2. Maximum free water-cement ratio	0.35	
3. Water-cement ratio to be adopted	**0.3**	
4. Maximum water content for maximum size of aggregate	186	kg
5. Reduction in water content due to type of aggregate	0	kg
6. New reduced water content	186	kg
7. Increased amount of water content for required slump	5.58	kg
7.1 Estimated water content for required slump	191.58	kg
After addition of plasticizers, Final water content reduces to	**162.84**	kg
8. Calculation of cementitous content	542.81	kg/m3
9. Minimum cement content as per durability consideration	400	kg/m3
10. Cementitious content to be adopted	**542.81**	kg/m3
11. Cement content @95% of cementitous content	**515.67**	kg/m3
12. Fly Ash content @5% of cementitous content	**27.141**	kg/m3
13.Volume of Coarse Aggregate corresponding to maximum size of aggregate and fine aggregate for w/c ratio of 0.5	0.64	
14. Increase/decrease in volume of coarse aggregate	0.04	
15.Corrected Proportion of Volume of Coarse Aggregate for the adopted water cement for this trial	0.68	
16. Reduction in volume of coarse aggregate for pumpable concrete	10%	
17. Final volume of coarse aggregate	0.612	
18. Final volume of fine aggregate	0.388	

PART III- MIX CALCULATIONS

1. Volume of concrete	1	m3
2. Volume of cement	0.1637	m3
3. Volume of microsilica	0.0121	m3
4. Volume of water	0.1628	m3
5. Volume of chemical admixture (Superplasticizer)	0.009	m3
6. Volume of all inn aggregate	0.6523	m3
7. Mass of coarse aggregate (dry)	1058	kg
8. Mass of fine aggregate (dry)	670.74	kg

PART IV- MIX PROPORTIONS

1. Cementitious content	542.81	kg/m3
2. Water	162.84	kg/m3
3. Cement (95%)	515.67	kg/m3
4. Fly Ash Content (5%)	27.141	kg/m3

5. Fine Aggregate	670.74	kg/m3
6. Coarse Aggregate	1058	kg/m3
7. Chemical Admixture	10.856	kg/m3
8. Water-cement ratio	**0.3**	

MIX RATIO **1 : 1.24 : 1.95**

The other mix design proportions for various percentage of replacement by Fly Ash and Silica Fume are given below-

- **For Fly Ash**

Sl. no.	w/(c+p)	Cementitious content	% of replacement of fly ash	Mix design proportions
1	0.3	543	5%	1 : 1.24 : 1.95
2	0.3	543	10%	1 : 1.23 : 1.94
3	0.3	543	15%	1 : 1.22 : 1.93

- **For Silica fume-**

Sl. no.	w/(c+p)	Cementitious content	% of replacement of Silica Fume	Mix design proportions
1	0.3	542.8	5%	1 : 1.24 : 1.95
2	0.3	542.8	10%	1 : 1.23 : 1.94
3	0.3	542.8	15%	1 : 1.22 : 1.93

6.6 PRODUCTION OF CONCRETE

The high strength concrete is produced using silica fume and fly ash in varying percentage as cement replacement. The process of production is different for the concrete mixes using silica fume and fly ash respectively.

6.6.1 Process for production of high strength concrete using Fly Ash

i. Add the coarse aggregates into the mixer.
ii. Add the fine aggregates into the mixer.
iii. Add the cement content slowly into the mixer.
iv. Add the fly ash slowly in the mixer. While adding fly ash, it should be added such that fly ash is spread evenly over the other ingredients in the mixer.
v. Rotate the mixer for about 5 – 7 minutes. The mixer is stopped after getting a good dry mix of the ingredients used.
vi. Add the required water content and the required content of superplasticizer and start the mixer.
vii. Mixing is continued until a desired concrete is formed.

6.6.2 Process for production of high strength concrete using Silica Fume

i. Place 75% of water in the mixing machine.
ii. Add the coarse aggregate in the mixer.
iii. Add silica fume content slowly into the revolving mixer.
iv. Mix the contents for one and a half minutes.
v. Add the cement slowly into the revolving mixer.
vi. Mix it again for on and half minutes.
vii. Add the fine aggregate into the mixer.
viii. Now add the remaining 25% of water and the amount of superplasticizer into the mixer and start mixing.
ix. The mixing process is done by mixing 5 minutes and giving 3 minute rest. This process is repeated for 5 times.

6.7 Casting and compaction of concrete

The fresh concrete produced by the above process is casted into a mould of 15 cm cube. The casting is done along with compaction of concrete. Compaction is done either by vibration or by hand ramming which is done by ramming rod. Compaction of concrete is done in 3 layers. While casting of mould and compaction of concrete, there are precautions which are to be followed. Some precautions are given as follows-

i. While preparing the mould, the mould should be tightly fixed with nut and bolt to make the concrete in its required shape.
ii. The inner faces of the mould should be properly oiled so that the concrete remains in its shape and the surface of the concrete remains smooth.

iii. Compaction should be done in 3 layers and proper compaction is to be done so that the concrete does not possess any layered structure.

6.8 Curing of concrete

After the concrete in the mould has set, the casting is demoulded and the concrete blocks were subjected to curing for 7 days and 28 days. Curing is one of the important process, which is essential for producing a concrete of required strength.

6.9 Testing of concrete

The testing of concrete refers to the testing of compressive strength of concrete, in the form of concrete cube. This test is done in a compression testing machine.

The results of the testing of concrete are as follows-

Figure 3: concrete block

We have, dimension of the cube = 150mm x 150mm x 150mm
And, Cross-sectional area = 150mm × 150 mm

- **For fly ash 5%,**

2 cubes were tested for 7 days.
Compressive strength of Cube 1 = 640KN
Compressive strength of Cube 2 = 620KN
Average 7 day Compressive strength = (640+620)/2
= 630 KN

2 cubes were tested for 28 days.
Compressive strength of Cube 1 = 990KN
Compressive strength of Cube 2 = 970KN
Average 28 day Compressive strength = (990+970)/2
= 980 KN

- **For fly ash replacement of 10%**

2 cubes were tested for 7 days.
Compressive strength of Cube 1 = 530KN
Compressive strength of Cube 2 = 510KN
Average 7 day Compressive strength = (530+510)/2
= 520 KN

2 cubes were tested for 28 days.
Compressive strength of Cube 1 = 820KN
Compressive strength of Cube 2 = 790KN
Average 28 day Compressive strength = (820+790)/2
= 805 KN

- **For fly ash replacement of 15%**

2 cubes were tested for 7 days.
Compressive strength of Cube 1 = 430KN
Compressive strength of Cube 2 = 400KN
Average 7 day Compressive strength = (430+400)/2

= 415 KN

2 cubes were tested for 28 days.
Compressive strength of Cube 1 = 730KN
Compressive strength of Cube 2 = 710KN
Average 28 day Compressive strength = (730+710)/2
= 720 KN

- **For silica replacement of 5%**

2 cubes were tested for 7 days.
Compressive strength of Cube 1 = 350KN
Compressive strength of Cube 2 = 330KN
Average 7 day Compressive strength = (350+330)/2
= 340 KN

2 cubes were tested for 28 days.
Compressive strength of Cube 1 = 980KN
Compressive strength of Cube 2 = 960KN
Average 28 day Compressive strength = (980+960)/2
= 970 KN

- **For silica fume replacement of 10%**

2 cubes were tested for 7 days.
Compressive strength of Cube 1 = 1000KN
Compressive strength of Cube 2 = 1030KN
Average 7 day Compressive strength = (1000+1030)/2
= 1015 KN

2 cubes were tested for 28 days.
Compressive strength of Cube 1 = 1610KN
Compressive strength of Cube 2 = 1590N
Average 28 day Compressive strength = (1610+1590)/2
= 1600 KN

- **For silica fume replacement of 15%**

2 cubes were tested for 7 days.
Compressive strength of Cube 1 = 380KN
Compressive strength of Cube 2 = 370KN
Average 7 day Compressive strength = (380+370)/2
= 375 KN

2 cubes were tested for 28 days.
Compressive strength of Cube 1 = 890KN
Compressive strength of Cube 2 = 870KN
Average 28 day Compressive strength = (890+870)/2
= 880 KN

Now,

- **For fly ash replacement of 5%,**

7 day compressive strength in N/mm^2 = (630*1000)/(150*150)
= 28 N/mm^2
28 day compressive strength in N/mm^2 = (980*1000)/(150*150)
= 43.56 N/mm^2

- **For fly ash replacement of 10%,**

7 day compressive strength in N/mm^2 = (520*1000)/(150*150)
= 23.11 N/mm^2
28 day compressive strength in N/mm^2 = (805*1000)/(150*150)
= 35.78 N/mm^2

- **For fly ash replacement of 15%,**

7 day compressive strength in N/mm^2 = (415*1000)/(150*150)
= 18.44 N/mm^2
28 day compressive strength in N/mm^2 = (720*1000)/(150*150)
= 32 N/mm^2

- **For silica fume replacement of 5%,**

7 day compressive strength in N/mm^2 = (340*1000)/(150*150)
= 15.11 N/mm^2
28 day compressive strength in N/mm^2 = (970*1000)/(150*150)
= 43.11 N/mm^2

- **For silica fume replacement of 10%,**

7 day compressive strength in N/mm^2 = (1015*1000)/(150*150)
= 45.11 N/mm^2

28 day compressive strength in N/mm^2 = (1600*1000)/(150*150)
= 71.11 N/mm^2

- **For silica fume replacement of 15%,**

7 day compressive strength in N/mm^2 = (375*1000)/(150*150)
= 16.67 N/mm^2
28 day compressive strength in N/mm^2 = (880*1000)/(150*150)
= 39.11 N/mm^2

The results are shown in the tables below-

- **For Fly Ash**

Sl. No.	Fly ash replacement	7 days compressive strength (N/mm^2)	28 days compressive strength (N/mm^2)	Target mean strength in N/mm^2 (based on 28 day compressive strength)	Remarks
1	5%	28	43.56	68.25	Does not exceed target mean strength
2	10%	23.11	35.78	68.25	Does not exceed target mean strength
3	15%	18.44	32	68.25	Does not exceed target mean strength

Table 3: Compressive strength of concrete for varying percentages of fly ash replacement.

- **For Silica Fume**

Sl. No.	Silica Fume replacement	7 days compressive strength (N/mm^2)	28 days compressive strength (N/mm^2)	Target mean strength in N/mm^2 (based on 28 day compressive strength)	Remarks
1	5%	15.11	43.11	68.25	Does not exceed target mean strength
2	10%	45.11	71.11	68.25	Exceeds target mean strength
3	15%	16.67	39.11	68.25	Does not exceed target mean strength

Table 4: Compressive strength of concrete for varying percentages of Silica fume replacement.

VII. RESULTS AND COMPARISON

7.1 RESULTS

The results of the test conducted to evaluate the compressive strength of concrete having fly ash and silica fume as replacement of cement is as follows-

- **For Fly Ash**

Sl. No.	Fly ash replacement	7 days compressive strength (N/mm^2)	28 days compressive strength (N/mm^2)	Target mean strength in N/mm^2 (based on 28 day compressive strength)	Remarks
1	5%	28	43.56	68.25	Does not exceed target mean strength
2	10%	23.11	35.78	68.25	Does not exceed target mean strength
3	15%	18.44	32	68.25	Does not exceed target mean strength

Table 5: Compressive strength of concrete for varying percentages of fly ash replacement.

- **For Silica Fume**

Sl. No.	Silica Fume replacement	7 days compressive strength (N/mm^2)	28 days compressive strength (N/mm^2)	Target mean strength in N/mm^2 (based on 28 day compressive strength)	Remarks
1	5%	15.11	43.11	68.25	Does not exceed target mean strength
2	10%	45.11	71.11	68.25	Exceeds target mean strength
3	15%	16.67	39.11	68.25	Does not exceed target mean strength

Table 6: Compressive strength of concrete for varying percentages of Silica fume replacement.

The results are shown in the charts below-

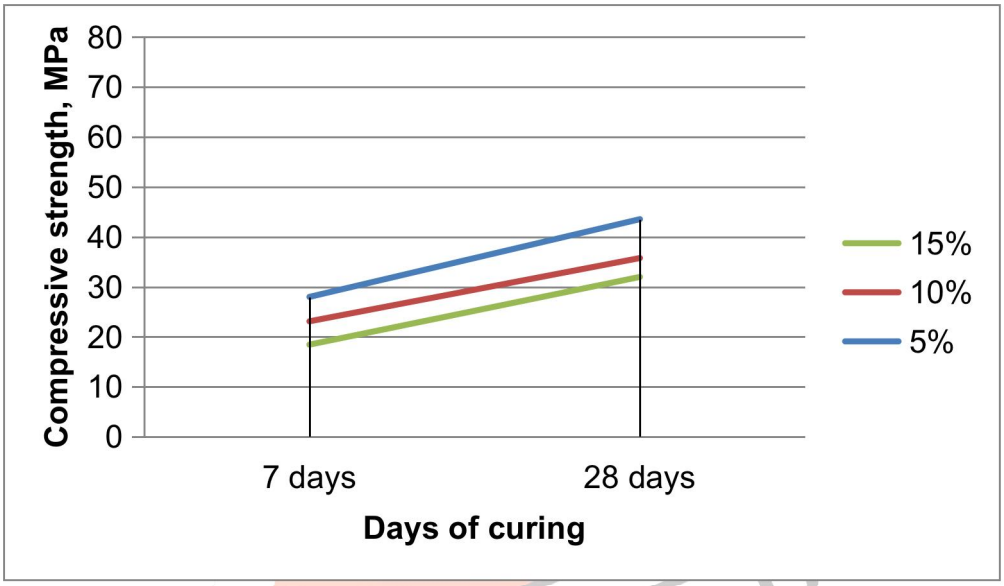

Chart 1: Relation between compressive strength in MPa and days of curing for varying percentage of fly ash content

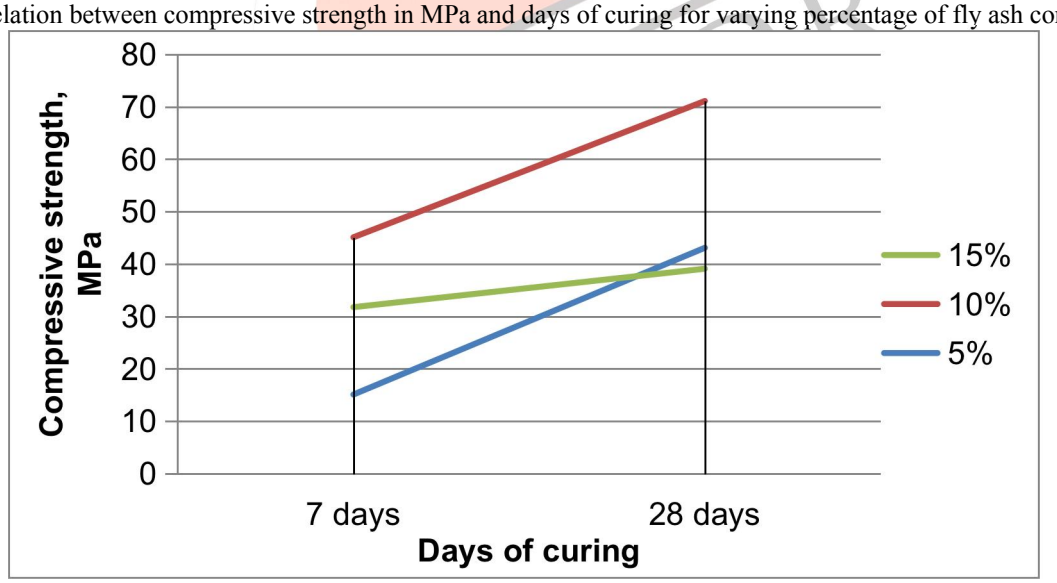

Chart 2: Relation between compressive strength in MPa and days of curing for varying percentage of Silica Fume content

7.2 COMPARISON BETWEEN SILICA FUME AND FLY ASH

Silica Fume and Fly Ash differ from each other in all the physical and chemical properties, and hence they have varied effect in concrete.

7.2.1. Difference between effect of silica fume and fly ash in fresh concrete-

Sl. No.	Characteristics	Fly Ash Concrete	Silica Fume Concrete
1.	Method of production	We have adopted a general procedure for production of concrete.	We have adopted the procedure as per the method given in ACI
2.	Stickiness	It is stickier than silica fume.	It is less sticky in comparison to fly ash
3.	Rate of drying	The rate of drying of fly ash concrete is very fast in comparison to silica fume concrete.	The rate of drying is silica fume concrete is slow in comparison to fly ash concrete.
4.	Setting time	It takes more time for setting of the concrete.	It also takes more time for setting of the concrete but less than the time taken by fly ash concrete

Table 7: Difference between silica fume concrete and fly ash concrete in fresh state

7.2.2 Difference between effect of Silica Fume and Fly Ash in hardened concrete-

The difference in hardened state is mainly dependent on the compressive strength of the concrete as obtained after a specified age. The compressive strength of concrete of various mixes of fly ash and silica fume is given below in the form of graphical representation between compressive strength of concrete versus the various percentage of fly ash and silica fume replacement.

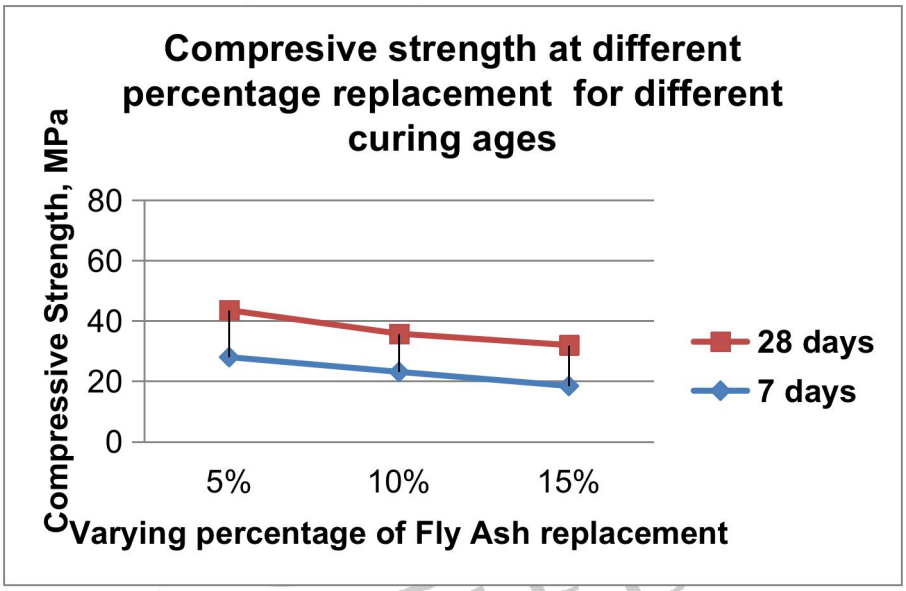

Chart 3: Compressive strength at different percentages of Fly Ash replacement for different curing ages

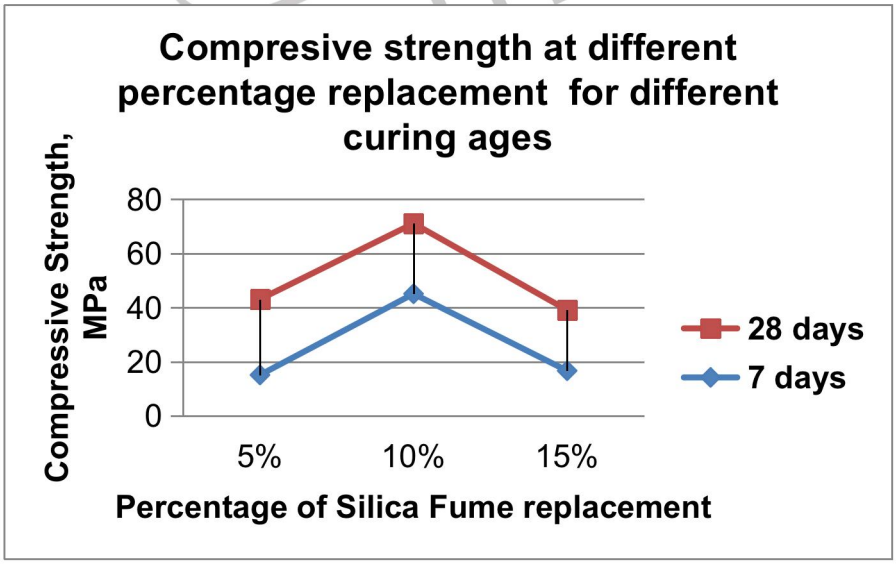

Chart 4: Compressive strength at different percentages of Silica Fume replacement for different curing ages.

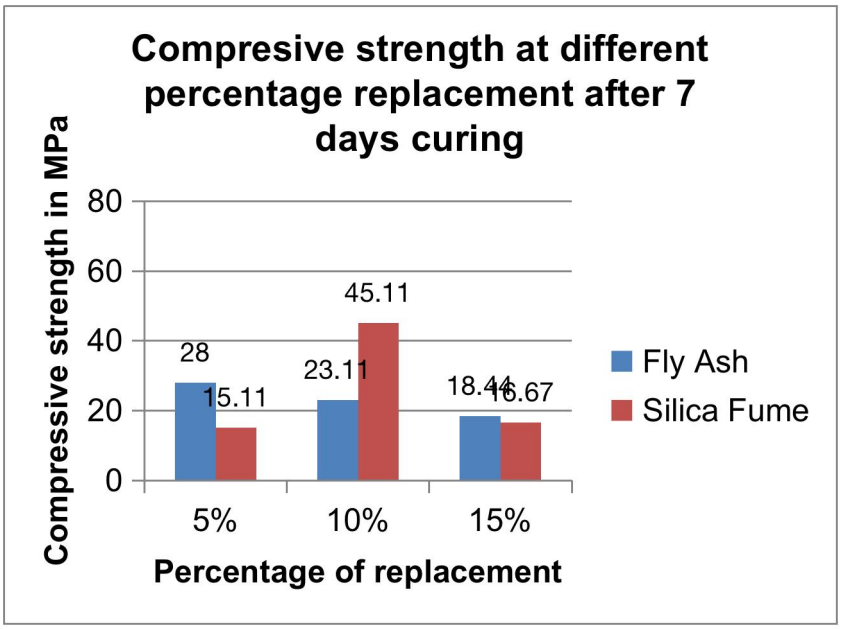

Chart 5: Compressive strength at different percentage of replacement after 7 days curing

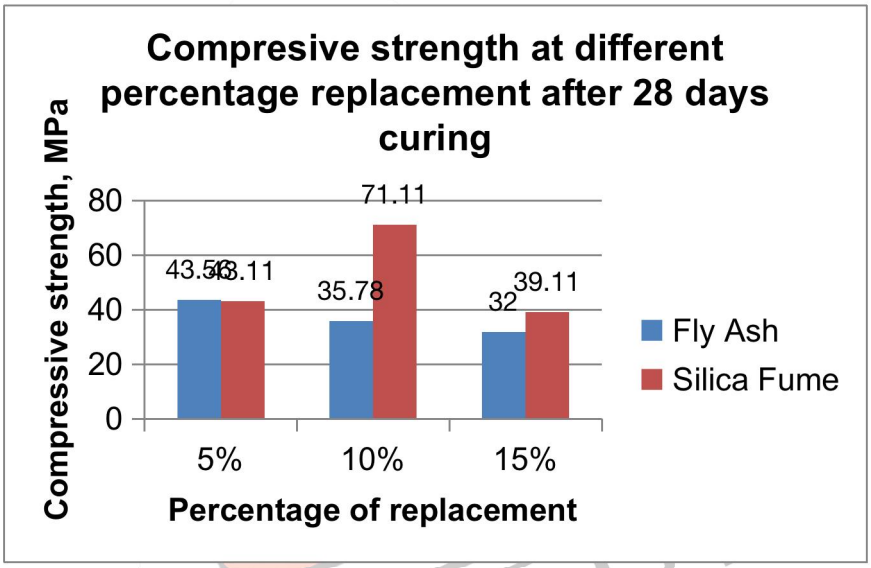

Chart 6: Compressive strength at different percentages of replacement after 28 day curing

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From the obtained results, we see that only the 10% replacement of cement by silica fume exceeds the target mean strength (68.25 MPa).

In case of fly ash, fly ash replacement of 5% shows the highest strength both after 7 days and 28 days of curing and the strength gradually decrease with increase in percentage of replacement of cement by fly ash. The rate of increase in strength from 7 days to 28 days is almost similar for all varying percentages of fly ash replacement. But no percentage of fly ash replacement has exceeded the target mean strength based on 28 days compressive strength.

In case of silica fume, the strength of concrete increase rapidly with increase in silica fume replacement, but this increase is upto a certain extent. And after reaching a certain strength at some proportion of silica fume content, there is a decrease in the strength of the concrete with further increase in silica fume content. The silica fume replacement of 10% gives the highest compressive strength both after 7 days and 28 days of curing. Only the concrete produced by 10% silica fume replacement has exceeded the target mean strength based on 28 days compressive strength, while the other percentage of silica fume replacement does not possess a very high strength.

The development of compressive strength from 7 days of curing to 28 days of curing is high in silica fume in comparison to fly ash concrete. The reason behind this are-

- **High amount of silicon dioxide, SiO_2 :**

The amount of silicon dioxide, SiO_2 is higher in silica fume in comparison to fly ash. Hence there occurs a better and efficient pozzolanic effect in silica fume concrete than in fly ash concrete, which gives rise to more amount of formation of calcium-silicate-hydrate (C-S-H) gel. It is largely this additional C-S-H gel which gives the silica fume concrete its hardened properties, thereby increasing the rate of development of strength in concrete.

- **Specific surface area:**

The specific surface area of silica fume is more than fly ash. This gives rise to a better micro filler effect produced by the silica fume in comparison to fly ash, which result in change in the micro structure of the concrete. This micro filler effect improves the paste-to-aggregate bond, thereby providing rapid development of strength.

VIII. ACKNOWLEDGEMENT

The author would like to thank his laboratory mates and instructors of concrete laboratory of Assam Engineering College.