



STRENGTH AND DURABILITY PROPERTIES OF CONCRETE BY PARTIAL REPLACEMENT OF CEMENT WITH SILICA FUME AND ALCCOFINE

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Abstract: The cement industry is one of the main producers of carbon dioxide (CO₂).for production of one ton of cement approximately one ton of CO₂ is released into the atmosphere. To reduce the cement content different supplementary Cementitious materials (SCM's) like fly ash, silica fume, alccofine, metakaolin, rice husk ash, ground granulated blast furnace slag were used. In the present investigation SCM's like silica fume and alccofine were used, In the first stage, cement is partially replaced by silica fume at various percentages such as 5%, 7.5%, and 10% by weight of cement to produce an optimum content of percentage of silica fume.

In the second stage, by keeping this optimum percentage of silica fume as constant further cement is replaced by alccofine at 5%, 10% and 15% by weight of cement. The mechanical tests, compressive strength, split tensile strength and flexural strength were studied, besides the durability properties sorptivity, rapid chloride penetration test were studied. The obtained results were compared with conventional concrete.

Keywords - Silica Fume, Alccofine, Compressive Strength, Split Tensile Strength, Flexural Strength, Sorptivity, Rapid Chloride Permeability Test.

I. INTRODUCTION

Nowadays cement has become a dominant raw material in the manufacture of concrete. The demand for cement is increasing worldwide with a consumption rate of nearly 4.3 billion tonnes per year. For the production of cement, a large amount of energy is consumed and it is one of the largest sources of CO₂ gas emission. About 13500 million tonnes of CO₂ gas is released during the production of cement. Cement production is one of the major causes of environmental pollution due to the release of large amounts of carbon dioxide into the atmosphere from cement production plants. There is a need to limit the use of cement in concrete manufacturing due to a number of issues such as emissions of toxic gases during the cement manufacturing process, continuous depletion of raw materials for cement production, and the rising cost of cement production. The reduction in consumption of large quantity of cement in the manufacturing of concrete can be achieved by use of supplementary cementitious materials (SCMs) as a partial or full replacement to cement [1]. The use of SCMs is indeed a revolutionary step in the field of civil engineering. Due to the pozzolanic properties of SCMs, the combination of SCMs with cement can produce various strengths and durable concretes. Thus, using SCMs as an alternative or partial replacement to cement can reduce the use of cement in concrete manufacturing and reduce environmental pollution [2].

There are different types of SCMs such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, pond ash, limestone fines, rice husk ash, metakaolin, etcThe SCMs are obtained by processing discharged waste materials from factories and industries. Otherwise, dumping of all these waste materials into the environment is also a cause of environmental problems and the spread of diseases. All the waste materials are reusable in the construction field after suitable changes are made to them so that these waste materials are converted into useful SCMs. Recycling waste materials from industries and factories have economic, technical, and environmental benefits [3]. Globally, the application of SCMs-based concretes is increasing widely due to its eco-friendly

nature, good performance, and energy-conserving reasons. So far, SCMs have been playing a major role in the development of sustainable concrete and will continue to do so in the future.

The SCMs were used either as mineral admixture or partial replacement to cement in the production of sustainable concrete. The use of SCMs in the development of concrete will reduce the use of consumption of cement and leads to a reduction in the emission of carbon dioxide from the cement production plants and limiting the excavation of raw materials used in the manufacture of cement, and also provide a solution for safe disposal of industrial waste [4]. There are several number of SCMs are used in construction industry now we are partially replacing cement with silica fume and alccofine.

SILICA FUME

Silica fume is a by-product of the silicon and ferrosilicon alloy production industry. It is a highly reactive and fine-grained material that is used as a supplementary cementitious material in concrete to improve its strength, durability, and other properties [5].

• **Characteristics and Properties of Silica Fume:**

Silica fume, also known as micro silica or condensed silica fume, is a highly reactive and pozzolanic material. It is produced by reducing high-purity quartz with coal in an electric arc furnace at temperatures of 2,200 to 2,400°C. The resulting gas is then collected and condensed, forming a fine, amorphous, and highly reactive silica fume powder [6]. Silica fume is a very fine-grained material, with an average particle size of 0.1 to 0.3 microns, which is about 100 times smaller than the average size of cement particles. Its high surface area, typically in the range of 15,000 to 30,000 m²/kg, and its highly reactive nature make it an ideal material for improving the performance of concrete [7].

Silica fume is also known for its high pozzolanic activity, which means it reacts with calcium hydroxide and other compounds in the presence of water to form additional cementitious materials, such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H). This reaction leads to the densification of concrete, reducing its permeability and improving its strength and durability.

• **Applications of Silica Fume in Concrete:**

Silica fume is primarily used as a supplementary cementitious material in concrete, where it is typically added in small quantities, ranging from 5% to 10% by weight of cement [8]. The addition of silica fume can significantly improve the properties of concrete, such as its strength, durability, and resistance to chemical and environmental attacks.

One of the primary benefits of using silica fume in concrete is its ability to improve the strength of concrete, especially its compressive strength. This is achieved by increasing the packing density of concrete and reducing its porosity, which leads to improved bonding between cement particles and reduced cracking and shrinkage.

Silica fume can also improve the durability of concrete by reducing its permeability to water, chloride ions, and other harmful substances [9]. This can help to protect concrete from corrosion, sulphate attack, and other types of chemical and environmental damage, thereby increasing its service life.

Silica fume can also improve the workability of concrete, making it easier to place, compact, and finish. However, its high reactivity can also make it challenging to handle and transport, as it tends to clump together and form lumps when exposed to moisture.

• **Challenges and Limitations of Silica Fume:**

Despite its many benefits, silica fume also has some challenges and limitations that must be taken into consideration when using it in concrete. One of the primary challenges is its high cost, which can be several times higher than that of regular cement. This can limit its use to high-performance concrete applications, where the benefits of silica fume justify the additional cost [10].

Another challenge of using silica fume is its highly reactive nature, which can make it challenging to handle and transport. It tends to form lumps and clumps when exposed to moisture, which can lead to difficulties in batching, mixing, and placing concrete.

ALCCOFINE

Alccofine is a type of supplementary cementitious material (SCM) that is used in the production of concrete to enhance its properties and performance [11]. It is a fine-grained material that is produced by the controlled calcination of a blend of ground granulated

blast furnace slag (GGBS) and high-purity quicklime [12]. The resulting material is a highly reactive and pozzolanic material that can be used in a variety of applications, including high-performance concrete, marine structures, and mass concrete constructions [13].

Alcofine was first developed in India by Ambuja Cements Ltd. in collaboration with Geocycle, a subsidiary of the global cement manufacturer LafargeHolcim [14]. The material was first introduced in 2006 and has since gained popularity as an eco-friendly alternative to traditional SCM materials, such as fly ash and silica fume. One of the main advantages of using alcofine in concrete is its high reactivity, which can help to improve the strength, durability, and other properties of concrete [15]. The material also has a low carbon footprint, as it is produced from industrial waste materials and does not require additional energy inputs. This makes it a sustainable and environmentally friendly choice for the construction industry.

Alcofine is typically added to concrete in small quantities, typically between 5% to 15% by weight of cement. The material can also be used in combination with other SCM materials, such as fly ash and silica fume, to further enhance the properties of concrete [16]. Alcofine is a highly reactive and eco-friendly supplementary cementitious material that is used in the production of concrete to improve its properties and performance [17]. Its sustainable and environmentally friendly nature has made it a popular choice in the construction industry, and it is expected to play a growing role in the development of high-performance and sustainable concrete constructions in the future [18].

Alcofine is a type of supplementary cementitious material (SCM) that is available in different grades or types. The type of alcofine used in concrete can have a significant impact on the properties and performance of the resulting concrete [19]. Some of the common types of alcofine SCMs are:

1. Alcofine 1101: This is the most commonly used type of alcofine SCM. It is a high-reactivity material that is produced by the controlled calcination of a blend of GGBS and high-purity quicklime. It is suitable for use in a wide range of applications, including high-strength concrete, marine structures, and mass concrete constructions.
2. Alcofine 1203: This type of alcofine SCM is designed for use in high-performance concrete applications, where a high level of strength and durability is required. It is a finely ground material that is produced by the controlled calcination of GGBS and quicklime, with a higher percentage of quicklime than Alcofine 1101.
3. Alcofine 1201: This is a type of alcofine SCM that is specifically designed for use in mass concrete constructions, such as dams and bridges. It is a high-reactivity material that is produced by the controlled calcination of a blend of GGBS and quicklime, with a higher percentage of GGBS than Alcofine 1203.
4. Alcofine 1108: This type of alcofine SCM is designed for use in low-heat concrete applications, where the risk of thermal cracking is a concern. It is a finely ground material that is produced by the controlled calcination of GGBS and quicklime, with a lower percentage of quicklime than Alcofine 1101.

We are adopting alcofine 1203 as SCMs

Blended concrete is a type of concrete that is made by replacing a portion of the Portland cement with supplementary cementitious materials (SCMs) such as fly ash, slag cement, silica fume, and alcofine. This approach can improve the properties and performance of concrete, while reducing its carbon footprint and environmental impact. In particular, the use of silica fume and alcofine as partial replacements for Portland cement has been shown to be an effective way to produce high-performance concrete with enhanced durability and strength.

Silica fume is a by-product of the silicon and ferrosilicon alloy manufacturing process. It is a highly reactive pozzolanic material that, when added to concrete, can improve its strength, durability, and resistance to chemical attack. Silica fume has a very high surface area and a unique particle shape, which makes it an ideal SCM for use in high-strength and high-performance concrete applications.

Alcofine is another type of SCM that is produced by the controlled calcination of a blend of GGBS and quicklime. Like silica fume, alcofine is a highly reactive material that can improve the properties of concrete [20]. When used in concrete, alcofine can improve its workability, strength, and durability.

When silica fume and alcofine are used together as partial replacements for Portland cement in blended concrete, the resulting concrete can exhibit a range of desirable properties, including increased strength, durability, and resistance to chemical attack [21].

In addition, the use of these SCMs can also reduce the amount of Portland cement required, which can help to reduce the carbon footprint of construction projects.

Overall, the use of blended concrete with silica fume and alccofine as partial replacements for Portland cement is a promising approach to producing high-performance and sustainable concrete structures [22]. By leveraging the unique properties of these SCMs, it is possible to produce concrete that is not only strong and durable but also environmentally friendly and sustainable.

II. MATERIALS

1.Silica Fume

Silica fume is used as an artificial pozzolanic admixture. Silica fume is very fine pozzolanic material composed of ultrafine, amorphous glassy sphere of silica dioxide produced during the manufacture of silicon or ferro-silicon by electric arc furnaces at temperature of over 2000°C. Silica when it is used in concrete acts as a filler and a cementitious material. The micro silica particles fill spaces between cement particles and between the cement and aggregate particles. Micro silica has been added to concrete to 10 percent by weight of cement, although the normal proportion is 5 to 10 percent. If 15 percent is added there is a possibility for the concrete to become very strong and brittle, which will increase the water demand in a concrete mix as the dosage rates are less than 5 percent, then they will not require a water reducer. Only in case of high replacement rates use of high range water reducers are required.

Table: 1 Properties of silica fume

S.No	Particulars	Properties
1	Specific gravity	2.2
3	Density	576 kg/m
4	Colour	Light to dark grey

2.Alccofine

Alccofine is a processed product based on slag of high glass content with high reactivity obtained through granulation process. The raw materials are primarily contain low calcium silicates. Controlled particle size distribution is achieved by the choice of selective ingredients. Alccofine increases the workability of concrete. Alccofine -1203 is a new generation supplementary cementitious material (SCM) with a built-in hightech content. It has high fineness, even then it does not increase water demand if the dosage ranges from 5 to 15 percent of normal Ordinary Portland Cement. Infact the concrete slump is seen to be improved, which is because of the dense packing of cementitious material, which results in very low void content.

Table: 2 Properties of Alccofine

S.No	Physical Properties	Test result
1	Specific gravity	2.86
2	Colour	White

3.Concrete mix proportions

Table: 3 Mix Design

Cement	Fine aggregate	Coarse aggregate	Water
376Kg/m ³	647Kg/m ³	1223Kg/m ³	160Kg/m ³
1	1.72	3.25	0.45

Table: 4 Concrete Mix proportion

S.NO	MIX	CEMENT (Kg/m ³)	SILICA FUME (Kg/m ³)	ALCCOFINE (Kg/m ³)	FINE AGGREGATE (Kg/m ³)	COARSE AGGREGATE (Kg/m ³)	WATER (Kg/m ³)
1	OPC	376	0	0	647	1223	160
2	SF 5%	357.2	18.8	0	647	1223	160
3	SF 7.5%	347.8	28.2	0	647	1223	160

4	SF 10%	338.4	37.6	0	647	1223	160
5	SF 7.5% AF 5%	329	28.2	18.8	647	1223	160
6	SF 7.5% AF 10%	310.2	28.2	37.6	647	1223	160
7	SF 7.5% AF 15%	291.4	28.2	56.4	647	1223	160

III. METHODOLOGY

The methods adopted to find the different properties of binary blended concrete mixes as per IS/ASTM standards were presented. The properties include workability, CS, FS, STS, WS and RCP.

1. **Workability:** The slump test is used to find the workability of concrete. As specified in IS1159: 1959, it is an inverted cone of 300 mm in height, and its top & bottom diameters are 100 & 200 mm. The platform is set on a smooth surface, and the container is filled in three layers with the concrete. The mold is then carefully removed vertically; the level difference between the mold and the highest point is used to calculate the slump of concrete.

2. **Compressive strength:** To test CS, concrete cubes 150 150 150 mm in size are produced. The cubes are placed in a manner to transmit load on opposite faces, as defined in IS 516–1959. The applied load is axial without any disruption, as stated in IS 516–1959. To compute the CS, the highest load applied to the specimen was recorded.

3. **Flexural strength:** To test the FS, concrete prisms with a dimension of 100 100 50 mm are casted. The specimen is positioned in the system so that the load is imparted to the highest surface of the mold in two axes 133 mm apart. As a result, the maximum load borne by the specimen is recorded in accordance with IS 516.

4. **Split tensile strength:** to test the STS, concrete cylinders with a dimension of 300×150mm are casted. The specimen is positioned in the system so that the load is applied on the cylinder radially on the surface which cause a formation on a vertical crack in the specimen along its diameter. The maximum load borne by the specimen is recorded in accordance with IS: 516.

5. **Water sorptivity:** According to ASTM C 1585, water sorptivity is a test used to measure the rate of absorption of water through capillary action. The specimens were dried at 105°C until constant weight, and then the wax was applied to three sides of the specimen, with one side allowing water to transfer from the bottom portion. Rods were positioned at bottom of the tray for support of the specimen, and water is filled in the tray to achieve a level of 1 to 3 mm on top of these supporting rods. Specimens were removed from the tray after 5, 10, 30, 60, and 120 minutes, and their weights were recorded. To get the sorptivity coefficient (S), the cumulative amount of water absorbed per unit cross-sectional area (i) was plotted against the square root of time \sqrt{t} . The slope of the best-fit line is then used to calculate S ($Y = a + bX$) using least-squares linear regression analysis.

Where i (g/mm^2) denotes the cumulative amount of water absorbed per unit cross-sectional area of concrete specimen. S ($\text{g}/\text{mm}^2/\text{min}^{1/2}$) represents the sorptivity coefficient, and t is the time in minutes.

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Rate of chloride penetrability: ASTM 1202 specifies the casting of cylindrical specimens with a diameter of 100 mm and a thickness of 50 mm. The specimens were placed in the cells and left for 6 hours at 60 V. One compartment had 3 percent NaCl and the other 0.3 mol/L NaOH. The concrete cylinder's electrical current was measured, and the total charge passed (in coulombs) was utilised to indicate the concrete's resistance to chloride ion penetration.

IV. RESULTS AND DISCUSSION

1. Slump test

Seven Mixes of concrete cubes of size 150 x150x 150mm are prepared. These mixes are prepared with different percentage replacement of silica fume i.e., 0%, 5%, 7.5%, 10% and further replacement of alccofine i.e., 0%, 5%, 10%, 15%.

workability of the two mixes Mix is gradually decreased with increase in percentage of silica fume. Workability with different % silica fume and alccofine

Graphs was plotted to understand the behaviour of replacement materials in concrete for the slump test results and are shown in Fig. 1.

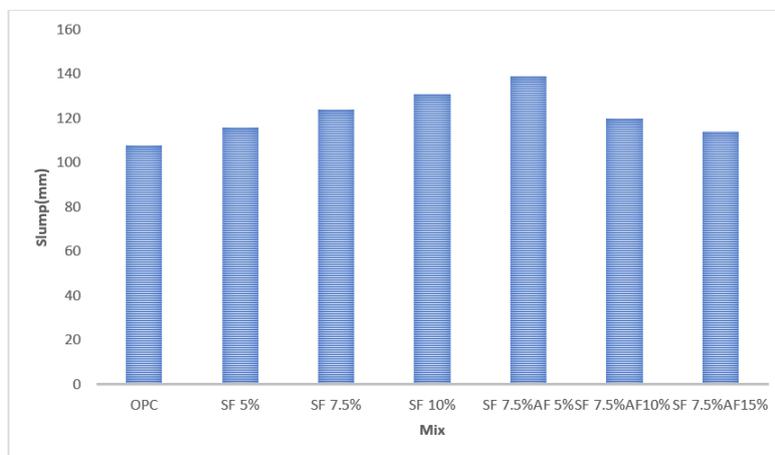


Figure 1. Slump Test Result

2. Compressive strength test

The experimental results obtained after the curing of 7 days and 28 days are shown in the table. The compressive strength of the mix containing 7.5% silica fume and 10% alccofine was increased by **34.63%** when compared to conventional concrete

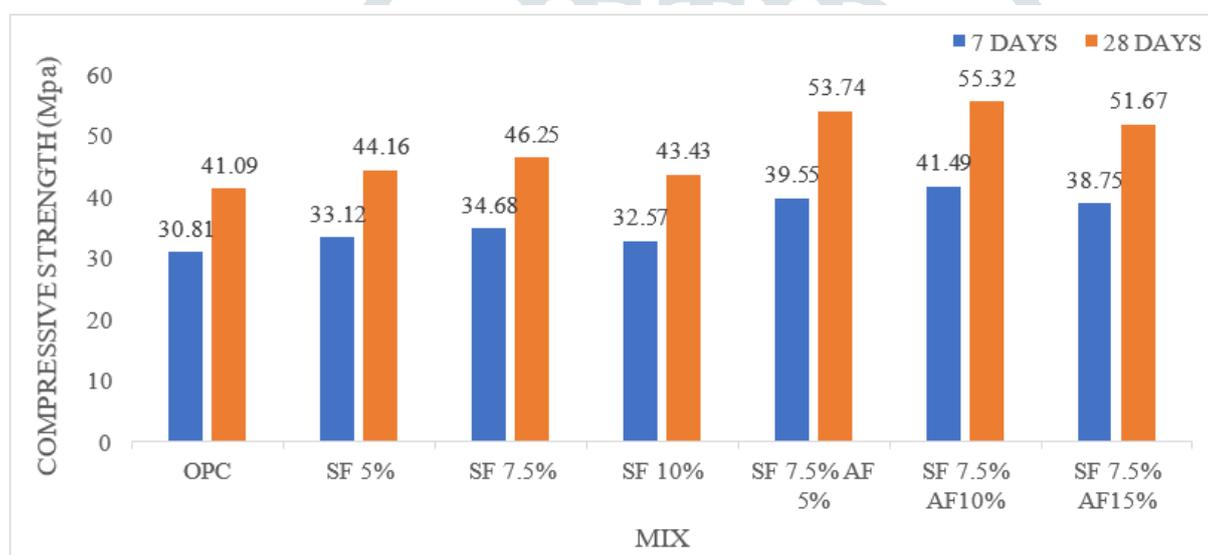


Figure 2. Compressive strength at 7&28 days

3. Split Tensile Strength

The split tensile strength of the mix containing 7.5% silica fume and 10% alccofine was increased by **16.05%** when compared to conventional concrete.

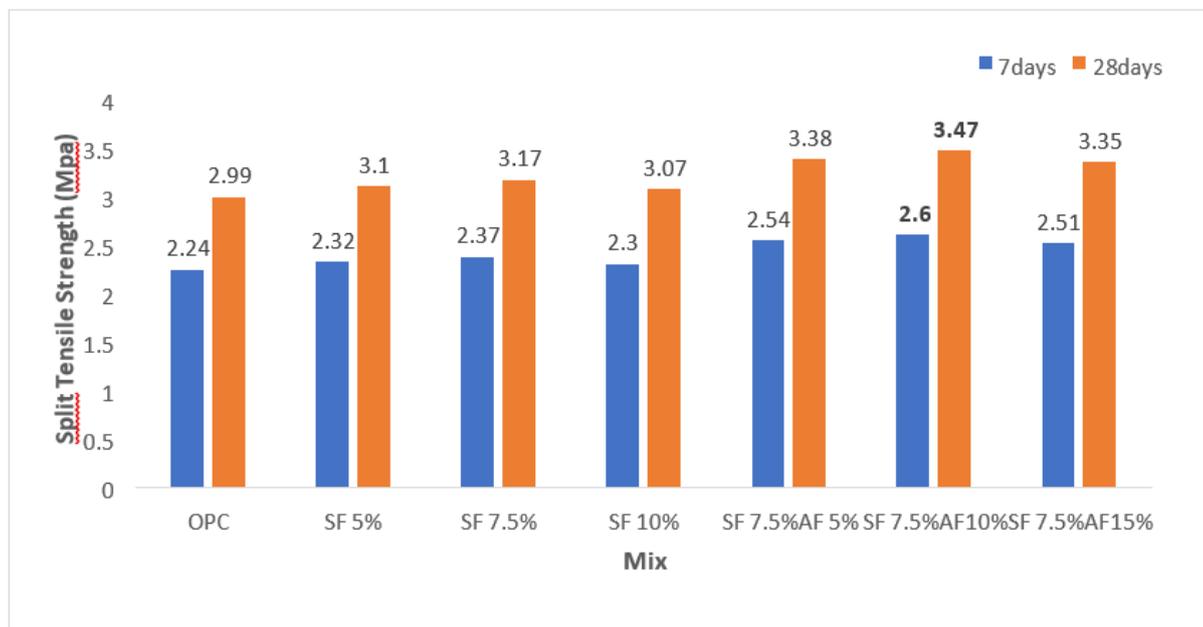


Figure 3. Split Tensile Strength at 7&28 days

4. Flexural Strength

The flexural strength of the mix containing 7.5% silica fume and 10% alcofine was increased by **16.08%** when compared to conventional concrete.

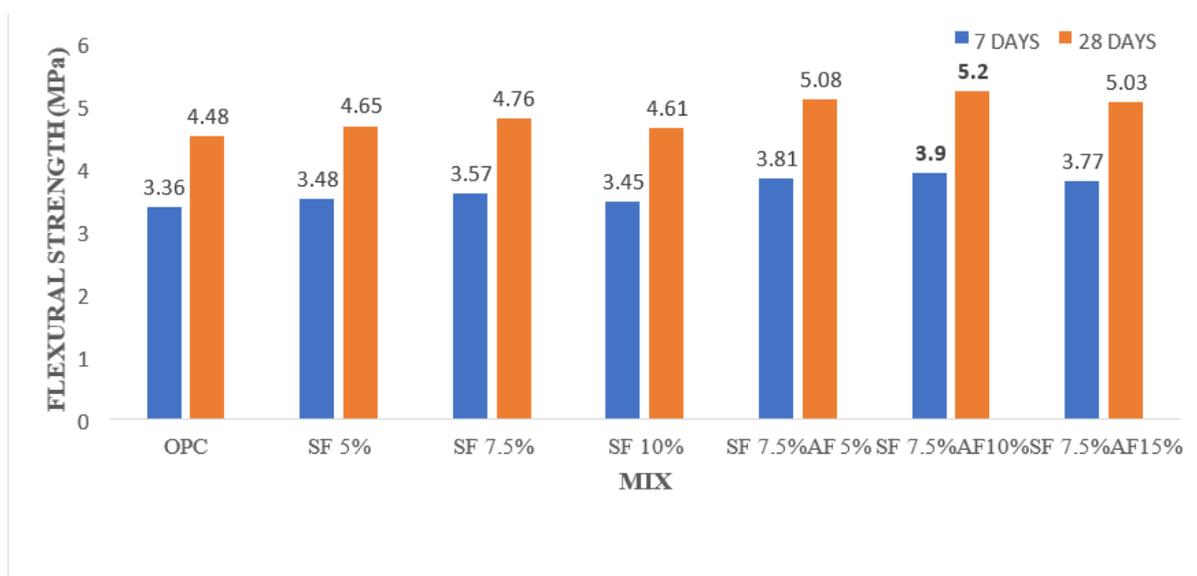


Figure 4. Flexural Strength at 7&28 days.

5. Sorptivity Test

Water sorptivity is one of the measure of durability of concrete. The cumulative amount of water absorbed per unit cross-sectional area with time is shown in Table 5. The sorptivity coefficient is the measure of WS. From graph 4, sorptivity coefficients are calculated by using least-squares linear regression analysis. graph 5 displays the calculated sorptivity coefficients

Table: 5 Cumulative Water Absorption Results

Mix	5min	10min	30min	60min	120min
OPC	2.71	3.42	4.85	6.23	7.65
SF 5%	2.39	2.92	3.84	4.69	6.07
SF 7.5%	2.41	3.05	4.41	5.44	6.42
SF 10%	2.56	3.37	4.72	6.06	7.11
SF 7.5% AF 5%	2.25	2.89	3.85	4.46	5.84

SF7.5% AF10%	2.12	2.78	3.71	4.36	5.47
SF7.5% AF15%	2.06	2.71	3.68	4.28	5.28

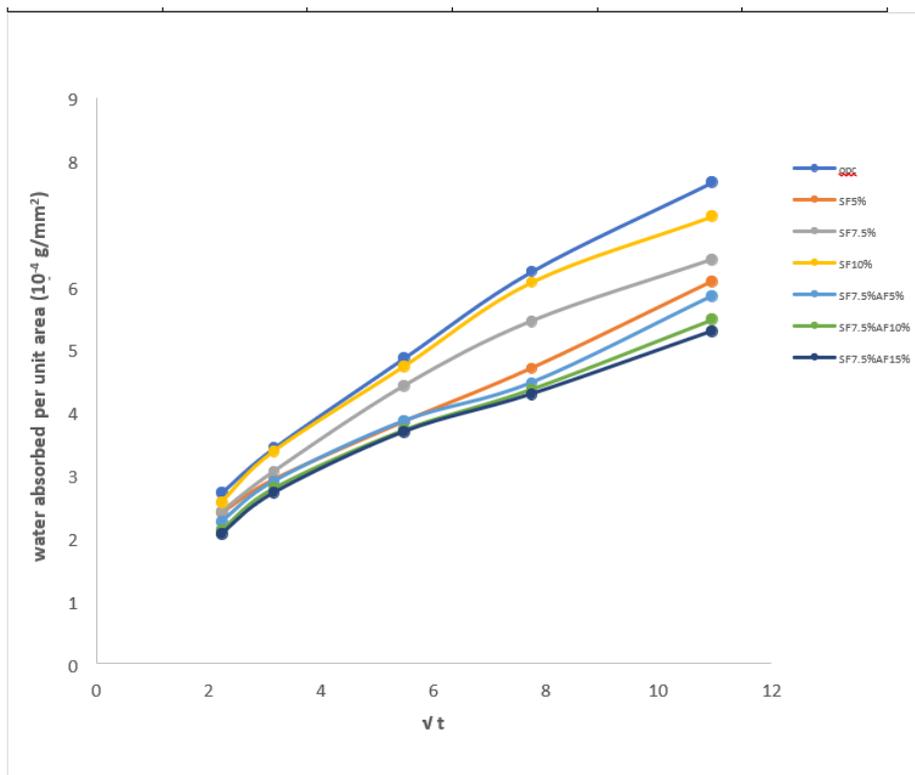


Fig 5: water absorption VS \sqrt{t}

From graph 4 it is observed that SF7.5%AF10% shows satisfactory results

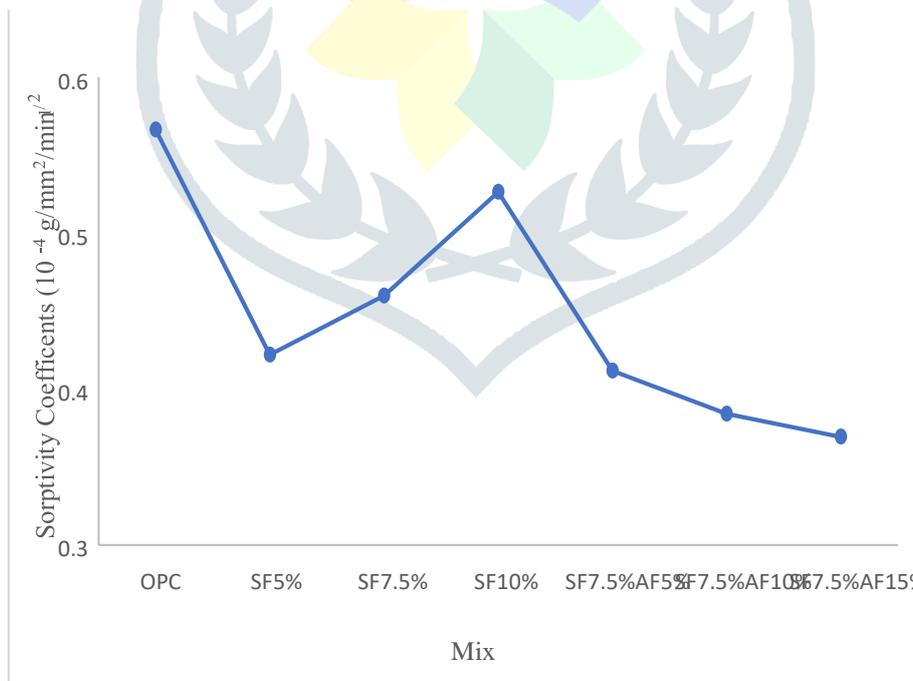


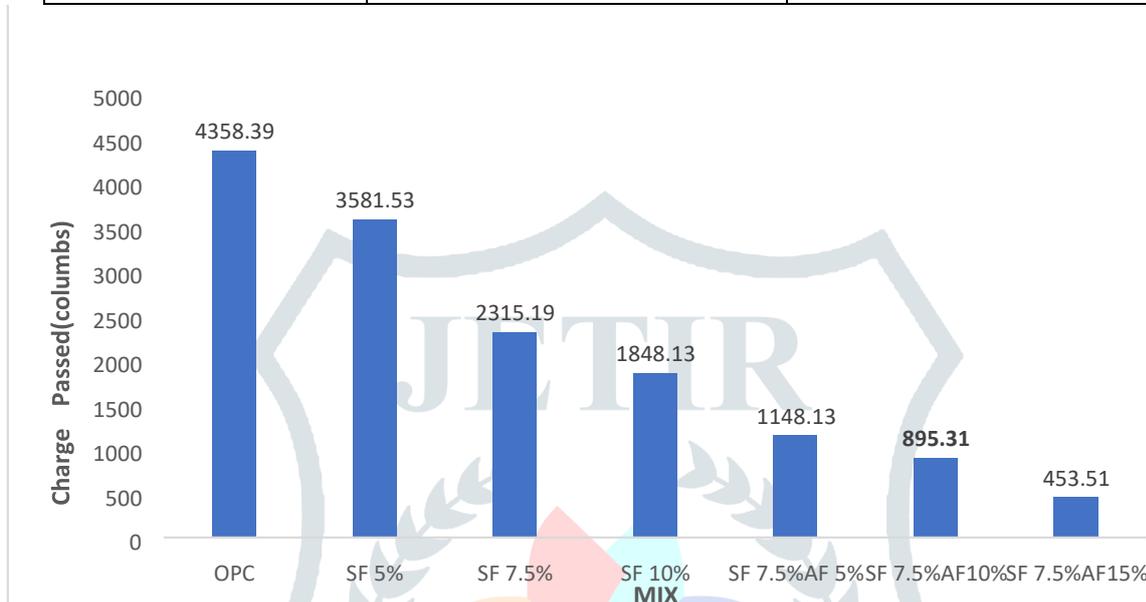
Fig 6: Sorptivity Coefficient Results

6.Rapid Chloride Permeability Test

RCP test is used to measure one of the durability properties, i.e., penetrability. The charge passed is the measure of penetrability expressed as RCP. Graph 6 depicts the charge passed of SF and AF mixes at all ages 28 days. SF mix with 7.5 percent and AF mix with 10% exhibited a significantly lower RCP. The rate of chloride penetration decreased with age for all mixes. The rate of chloride penetration decreased with the increase in SF and AF. Hence it can be concluded that SF 7.5% and AF 10% mixes exhibited lower RCP.

Table: 6 Rapid chloride permeability test

Mix	Charge passed (Columbs)	Chloride Penetration
OPC	4358.39	High
SF 5%	3581.53	Moderate
SF 7.5%	2315.19	Moderate
SF 10%	1848.13	Low
SF 7.5%AF 5%	1148.13	Low
SF 7.5%AF10%	895.31	Very low
SF 7.5%AF15%	453.51	Very low

**Fig 7: Rapid Chloride Permeability Test**

V.CONCLUSIONS

1. The workability of concrete mixes with silica fume and alccofine showed on significant improvement in workability when compared to conventional concrete.
2. The compressive strength of the mix containing 7.5% silica fume and 10% alccofine was increased by **34.63%** when compared to conventional concrete.
3. The flexural and split tensile strength of the mix containing 7.5% silica fume and 10% alccofine was increased by **16.08%** and **16.05%** when compared to conventional concrete.
4. The mix with 7.5% silica fume and 10% alccofine exhibited lesser sorptivity when compared to conventional concrete.

The chloride penetration for the mix containing 7.5% silica fume and 10% alccofine displayed lower when compared to conventional concrete

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