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STRENGTH AND DURABILITY PROPERTIES OF CONCRETE BY PARTIAL REPLACEMENT OF CEMENT WITH FLY ASH AND ALCCOFINE

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Abstract : The cement industry is one of the main producers of carbon dioxide (CO_2) for production of one ton of cement approximately one ton of CO_2 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 (GGBS) were used. In the present investigation SCM's like fly ash and alccofine were used, In the first stage, cement is partially replaced by fly ash at various percentages such as 20%, 30%, and 40% by weight of cement to produce an optimum content of percentage of fly ash.

In the second stage, by keeping this optimum percentage of Fly ash (FA) as constant further cement is replaced by Alccofine (AF) at 5%, 10% and 15% by weight of cement. The mechanical tests like compressive strength (CS), split tensile strength (STS) and flexural strength (FS) were studied, beside this the durability properties like sorptivity, rapid chloride penetrability test (RCP) were studied. The obtained results showed that the combination containing 30% fly ash and 10% alccofine exhibited superior results when compared with conventional concrete.

Keywords: **Fly ash, Alccofine, compressive strength, split tensile strength, flexural strength, water sorptivity and rapid chloride permeability test.**

1 INTRODUCTION

Concrete is one of the most widely used building materials in the world due to its versatility, durability, and low cost. However, the production of cement [1], which is the main component of concrete, is associated with high carbon emissions. According to the International Energy Agency (IEA), the cement industry is responsible for about 7% of global carbon dioxide (CO_2) emissions. This has prompted the development of sustainable alternatives to traditional concrete production [2,3].

One of the most promising solutions is the partial replacement of cement with supplementary cementitious materials (SCMs) such as fly ash and alccofine. Fly ash is a by-product of coal-fired power plants and is composed of small, spherical particles that can be used as a substitute for cement in concrete production [4]. Alccofine is a supplementary cementitious material produced by burning and grinding finely powdered limestone and clay. It has similar properties to cement and can be used to partially replace cement in concrete.

The use of fly ash and alccofine as partial replacements for cement has been shown to have several benefits. First, it reduces the amount of cement used in concrete, which in turn reduces the carbon footprint of the construction industry [5]. Second, it helps to conserve natural resources by using waste materials as a resource for construction. Finally, it improves the strength and durability of concrete.

The strength and durability of concrete are critical factors in determining its performance over time. The strength of concrete is its ability to withstand loads without breaking, while durability refers to its ability to resist weathering and deterioration over time [6]. The use of fly ash and alccofine can improve the strength and durability of concrete by reducing the permeability of the concrete, making it more resistant to water and chemical attack.

In this study, we investigate the strength and durability properties of concrete by partially replacing cement with fly ash and alccofine. We prepared six different concrete mixes with different percentages of cement replaced by fly ash and alccofine. The compressive strength and split tensile strength of the specimens were tested after 7 and 28 days of curing [7,8]. The results of this study will provide valuable insights into the use of fly ash and alccofine as partial replacements for cement in concrete production.

2 MATERIALS, MIX PROPORTIONS AND METHODOLOGY

2.1 MATERIALS

FLY ASH

Fly ash is a byproduct of coal-fired power plants that has been used as a cement replacement in concrete for several decades. It is a highly pozzolanic material that reacts with calcium hydroxide in the presence of water to form calcium silicate hydrate gel, which contributes to the strength and durability of concrete [9].

Firstly, fly ash has a high pozzolanic activity, which means that it reacts with calcium hydroxide to form calcium silicate hydrate gel. This gel contributes significantly to the strength and durability of concrete. Additionally, fly ash has a lower water demand than cement, which means that it requires less water to achieve the desired workability. This, in turn, can lead to a denser concrete with a lower water-cement ratio, which is more durable and resistant to cracking [10]. contributes significantly to the strength and durability of concrete. Additionally, fly ash has a lower water demand than cement, which means that it requires less water to achieve the desired workability. This, in turn, can lead to a denser concrete with a lower water-cement ratio, which is more durable and resistant to cracking.

Secondly, the use of fly ash as a cement replacement can significantly reduce the carbon footprint of concrete. Traditional cement production is a significant contributor to greenhouse gas emissions, with the production of one tonne of cement releasing approximately one tonne of CO_2 into the atmosphere [11]. Fly ash, on the other hand, is a waste material produced by coal-fired power plants and requires no additional energy to produce. Therefore, the use of fly ash in concrete can significantly reduce its carbon footprint.

Furthermore, the use of fly ash in concrete can also improve its workability and reduce the heat of hydration. Fly ash particles are much finer than cement particles, which allows for better hydration and more efficient use of water. This, in turn, leads to a more workable concrete that requires less water to achieve the desired slump. Additionally, fly ash has a lower heat of hydration than cement, which can reduce the risk of thermal cracking in concrete.

Finally, the use of fly ash in concrete can improve its durability. Fly ash has been found to improve the resistance of concrete to sulfate attack and chloride ion penetration, which are major causes of concrete deterioration. This is because the calcium silicate hydrate gel formed by the reaction of fly ash with calcium hydroxide is denser and less permeable than the gel formed by cement alone [12]. Additionally, the use of fly ash in concrete can reduce the risk of alkali-silica reaction (ASR), which is another common cause of concrete deterioration.

In conclusion, fly ash is a highly pozzolanic material that has numerous benefits when used as a cement replacement in concrete. It has been found to increase the strength and durability of concrete, reduce its carbon footprint, improve workability, and enhance its resistance to sulfate attack, chloride ion penetration, and ASR. The use of fly ash in concrete can, therefore, lead to more sustainable and durable concrete structures [13], which is particularly important given the increasing demand for infrastructure and the need to reduce the carbon footprint of construction. Table 1 gives physical properties of fly ash.

Table 1: Physical properties of Fly Ash

S.No	Properties	Proportions
1	Specific Gravity	2.07
2	Colour	Light Gray

ALCCOFINE

Alccofine is a type of mineral admixture that has gained significant attention as a cement replacement in recent years. It is a highly reactive, pozzolanic material produced from the combustion of rice husk [14]. Alccofine has been found to have numerous benefits when used as a replacement for cement in concrete, including increased strength, durability, and sustainability [15].

Firstly, alccofine is a highly reactive pozzolanic material, meaning that it reacts with calcium hydroxide in the presence of water to form calcium silicate hydrate gel. This gel contributes significantly to the strength and durability of concrete. Alccofine also has a much higher fineness than cement, which leads to a more densely packed microstructure and, therefore, a stronger and more durable concrete [16,17].

Secondly, the use of alccofine as a cement replacement can significantly reduce the carbon footprint of concrete. Traditional cement production is a significant contributor to greenhouse gas emissions, with the production of one tonne of cement releasing approximately one tonne of CO_2 into the atmosphere. Alccofine, on the other hand, is produced from a waste material (rice husk) and requires much less energy to produce than cement [18]. Therefore, the use of alccofine in concrete can significantly reduce its carbon footprint.

Furthermore, the use of alccofine in concrete can also improve its workability and reduce the water-cement ratio. This is because alccofine particles are much finer than cement particles, and they have a higher surface area, which allows for better hydration and more efficient use of water [19]. This, in turn, leads to a more workable concrete that requires less water to achieve the desired slump.

Finally, alccofine has been found to improve the durability of concrete. Concrete containing alccofine has been shown to have better resistance to chloride ion penetration, which is a major cause of concrete deterioration [20]. This is because the calcium silicate hydrate gel formed by the reaction of alccofine with calcium hydroxide is denser and less permeable than the gel formed by cement alone. Additionally, the use of alccofine in concrete can reduce the risk of alkali-silica reaction (ASR), which is another common cause of concrete deterioration [21,22].

In conclusion, alccofine is a highly reactive, pozzolanic material that has numerous benefits when used as a cement replacement in concrete. It has been found to increase the strength and durability of concrete, reduce its carbon footprint, improve workability, and enhance its resistance to chloride ion penetration and ASR [23]. The use of alccofine in concrete can, therefore, lead to more sustainable and durable concrete structures [24], which is particularly important given the increasing demand for infrastructure and the need to reduce the carbon footprint of construction. Table 2 shows the physical properties of alccofine.

Table 2: Physical properties of Alccofine

S.No	Properties	Proportions
1	Specific Gravity	2.86
2	Colour	White

2.2 CONCRETE MIX PROPORTIONS

The mix proportion for M30 grade concrete is presented in Table 3, while Table 4 displays the mix proportions for concrete compositions that include fly ash and alccofine.

Table 3: Materials Quantity

Cement	Fine Aggregate	Coarse Aggregate	Water
376 Kg/m^3	647 Kg/m^3	1223 Kg/m^3	160 liters
1	1.72	3.25	0.46

Table 4: Concrete Mix Proportions in Kg/m^3

Mix	Cement	FA	AF
OPC	376	0	0
FA20	300.8	75.2	0
FA30	263.2	112.8	0
FA40	225.6	150.4	0
FA30 AF5	244.4	112.8	18.8
FA30 AF10	225.6	112.8	37.6
FA30 AF15	206.8	112.8	56.4

2.3 METHODOLOGIES

The following methods are commonly used to determine various properties of concrete mixes as per IS/ASTM standards:

I. Workability: The workability of concrete can be determined using the slump test. As per IS1159: 1959, an inverted cone-shaped mold with a height of 300 mm, and top and bottom diameters of 100 and 200 mm, respectively, is used. The mold is filled with concrete in three layers and then carefully removed vertically. The difference in level between the mold and the highest point is used to calculate the slump of the concrete.

II. Compressive strength: The compressive strength (CS) of concrete is determined by casting cubes of size 150X150X150 mm. The cubes are placed in a manner to transmit load on opposite faces, as per IS 516–1959. The load is applied axially without any disruption, and the maximum load applied to the specimen is recorded to calculate the CS.

III. Split tensile strength: The split tensile strength (STS) of concrete can be determined using cylindrical specimens with a diameter of 150 mm and height of 300 mm. The test is performed as per ASTM C496, where a force is applied radially on the surface of the specimen, which causes the formation of a vertical crack along its diameter. STS is an indirect way of evaluating the tensile strength of concrete.

IV. Flexural strength: The flexural strength (FS) of concrete is determined by casting prisms of size 100X100X50 mm. 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, and the maximum load borne by the specimen is recorded as per IS 516.

V. Water sorptivity: Water sorptivity of concrete is measured using the ASTM C1585 test, which determines the rate of absorption of water through capillary action. The specimens are dried at 1050C until constant weight, and then wax is applied to three sides of the specimen, with one side allowing water to transfer from the bottom portion. Rods are positioned at the 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. The sorptivity coefficient (S) is calculated using least-squares linear regression analysis based on the cumulative amount of water absorbed per unit cross-sectional area (i) plotted against the square root of time $\sqrt{t}$.

VI. Rate of chloride penetrability: The rate of chloride penetrability is determined using the ASTM 1202 test, which involves casting cylindrical specimens with a diameter of 100 mm and a thickness of 50 mm. The specimens are placed in cells and left for 6 hours at 60 V, with one compartment containing 3 percent NaCl and the other 0.3 mol/L NaOH. The concrete cylinder's electrical current is measured, and the total charge passed (in coulombs) is used to indicate the concrete's resistance to chloride ion penetration.

3 RESULTS AND DISCUSSIONS

3.1 SLUMP RESULTS

Workability of the two mixes Mix is gradually decreased with increase in percentage of fly ash. Workability with different % fly ash and alccofine (in slump value) is shown in figure 1, and table shows the workability for nominal mix.

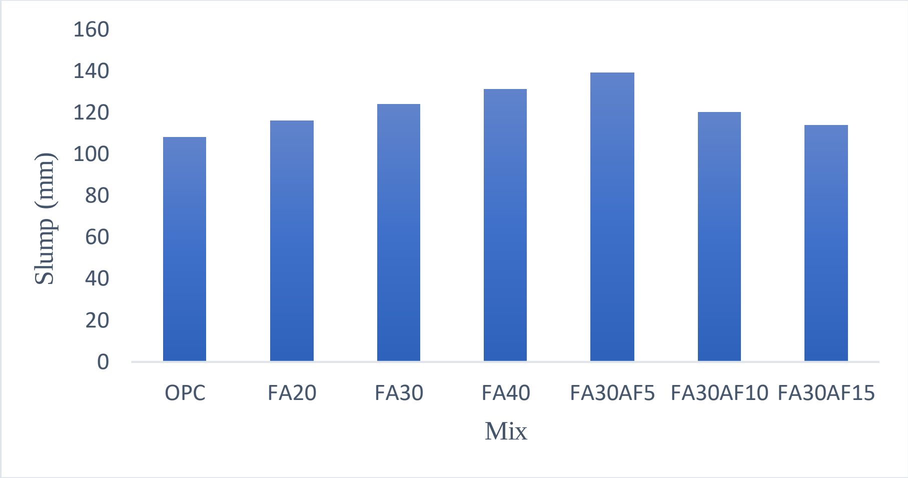


Figure 1: Comparison of slump values for binary & OPC mixes

3.2 COMPRESSIVE STRENGTH

The experimental results obtained after the curing of 7 days and 28 days are presented in Table 5, which depict the compressive strength for 7 and 28 days using fly ash and Alccofine. The figure display the combined compressive strength values for concrete mixes containing fly ash with 20%, 30%, and 40% after achieving the optimum strength of concrete at 30% fly ash with 12.09%. In addition, the cement was replaced with Alccofine at 5%, 10%, and 15% while maintaining a constant fly ash content of 30%. The maximum strength was observed at 30% fly ash and 10% Alccofine with a value of 23.35%. The graphical representation of the compressive strength test results is illustrated in figure 2.

Table 5: Compressive strength test results

MIX	7 DAYS	28 DAYS
OPC	28.85	41.09
FA 20	29.28	42.12
FA 30	32.25	46.74
FA 40	28.26	41.12
FA 30AF 5	34.31	49.37
FA 30AF10	**36.46**	**53.61**
FA 30AF15	33.72	48.87

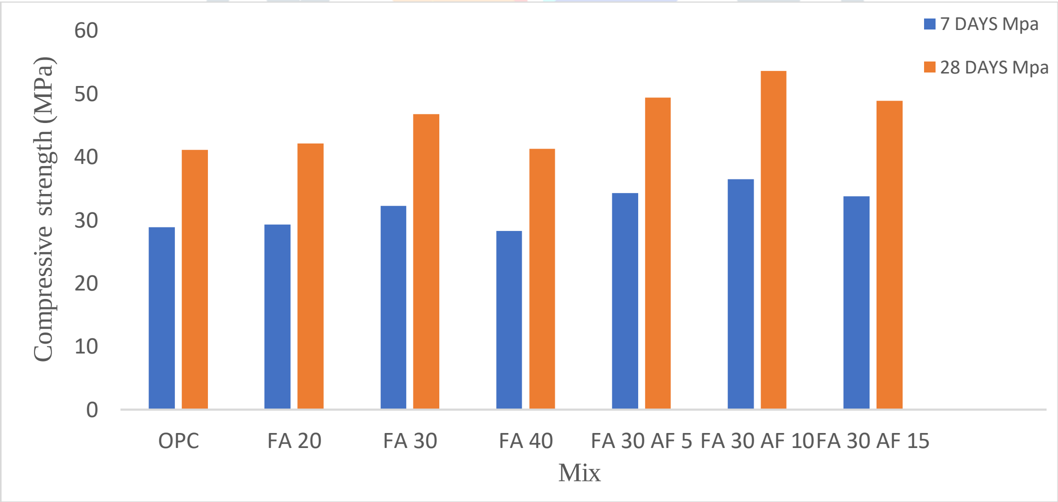


Figure 2: Compressive strength of concrete mixes after 7 and 28 days curing

3.3 SPLIT TENSILE STRENGTH

The experimental results obtained after the curing of 7 days and 28 days are presented in Table 6, which depict the split tensile strength for 7 and 28days using fly ash and Alccofine. The figures display the combined split tensile strength values for concrete mixes containing fly ash with 20%, 30%, and 40% after achieving the optimum strength of concrete at 30% fly ash with 12.09%. In addition, the cement was replaced with Alccofine at 5%, 10%, and 15% while maintaining a constant fly ash content of 30%. The maximum strength was observed at 30% fly ash and 10% Alccofine with a value of 23.35%. The graphical representation of the split tensile strength test results is illustrated in figure 3.

Table 6: Split tensile strength test results

MIX	7 DAYS	28 DAYS
OPC	1.99	2.94
FA 20	2.08	3.03

FA 30	2.13	3.09
FA 40	1.78	2.91
FA 30AF 5	2.27	3.29
FA 30AF10	**2.31**	**3.39**
FA 30AF15	2.19	3.21

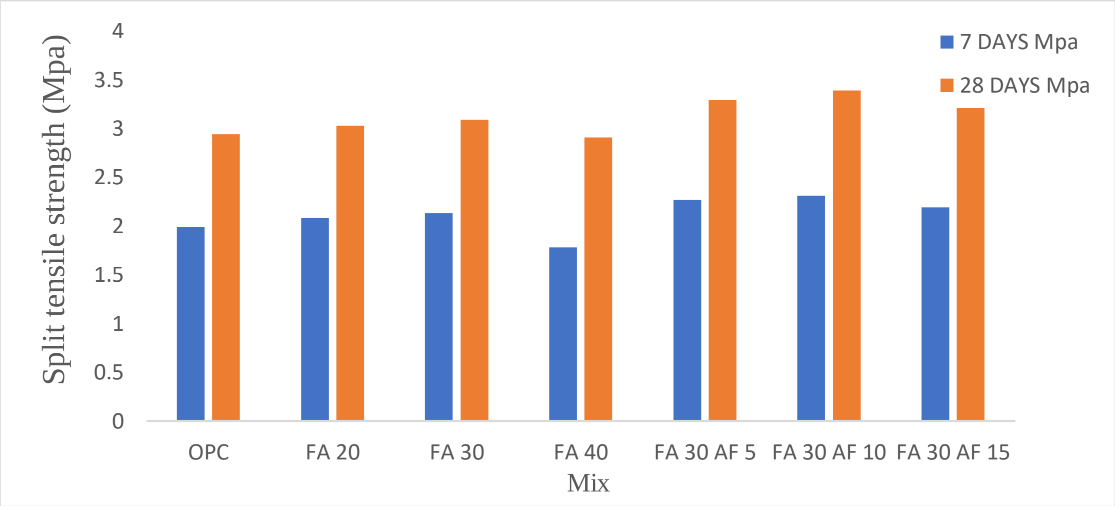


Figure 3: Split tensile strength of concrete mixes after 7 and 28 days curing

3.4 FLEXURAL STRENGTH

The experimental results obtained after the curing of 7 days and 28 days are presented in Table 7, which depict the flexural strength for 7 and 28 days using fly ash and Alccofine. The figures display the combined flexural strength values for concrete mixes containing fly ash with 20%, 30%, and 40% after achieving the optimum strength of concrete at 30% fly ash with 12.09%. In addition, the cement was replaced with Alccofine at 5%, 10%, and 15% while maintaining a constant fly ash content of 30%. The maximum strength was observed at 30% fly ash and 10% Alccofine with a value of 23.35%. The graphical representation of the flexural strength test results is illustrated in figure 4.

Table 7: Flexural strength test results

MIX	7 DAYS	28 DAYS
OPC	3.03	4.43
FA 20	3.12	4.52
FA 30	3.24	4.76
FA 40	3.10	4.50
FA 30AF 5	3.34	4.88
FA 30AF10	**3.51**	**5.09**
FA 30AF15	3.33	4.87

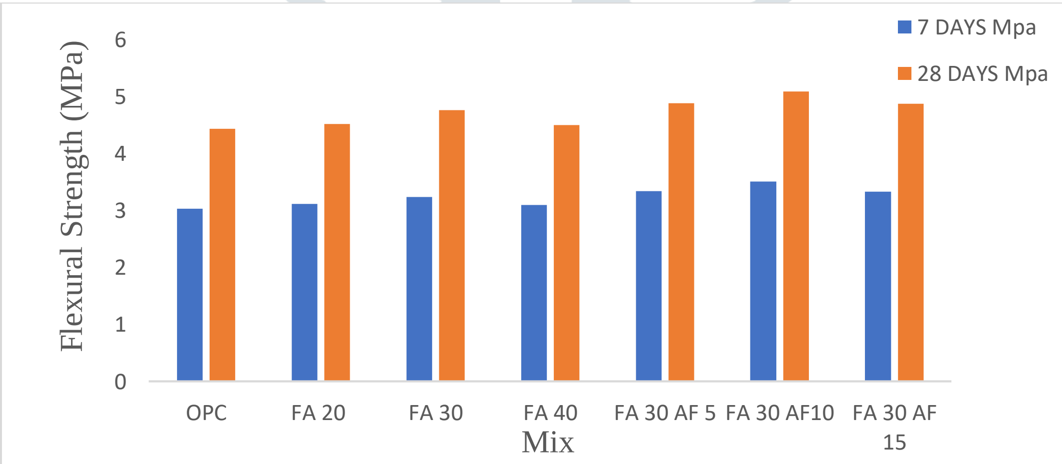


Figure 4: Flexural strength of concrete mixes after 7 and 28 days curing

3.5 WATER SORPTIVITY

The water sorptivity test is a method employed to determine the rate of water absorption in a given material, particularly concrete mixes, at different time intervals. The water sorptivity value is obtained by utilizing the equation $I = S * t^{0.5}$. Table 8 displays the results of the water sorptivity test, while figure 5 depicts a graphical representation of water absorption per unit area versus $\sqrt{t}$. Furthermore, figure 6 illustrates the coefficients of water sorptivity values.

Table 8: Water Sorptivity test results

MIX	i, 10^{-4} g/mm^2				
	5 min	10 min	30 min	60 min	120 min
OPC	2.63	3.25	4.51	6.03	7.32
FA 20	2.32	2.85	3.72	5.01	6.01
FA 30	2.37	2.99	4.11	5.58	6.31
FA 40	2.48	3.04	4.33	5.79	6.85
FA 30 AF 5	2.15	2.68	3.61	4.89	5.71
FA 30 AF10	**2.08**	**2.51**	**3.38**	**4.73**	**5.34**
FA 30 AF 15	2.01	2.42	3.21	4.51	5.1

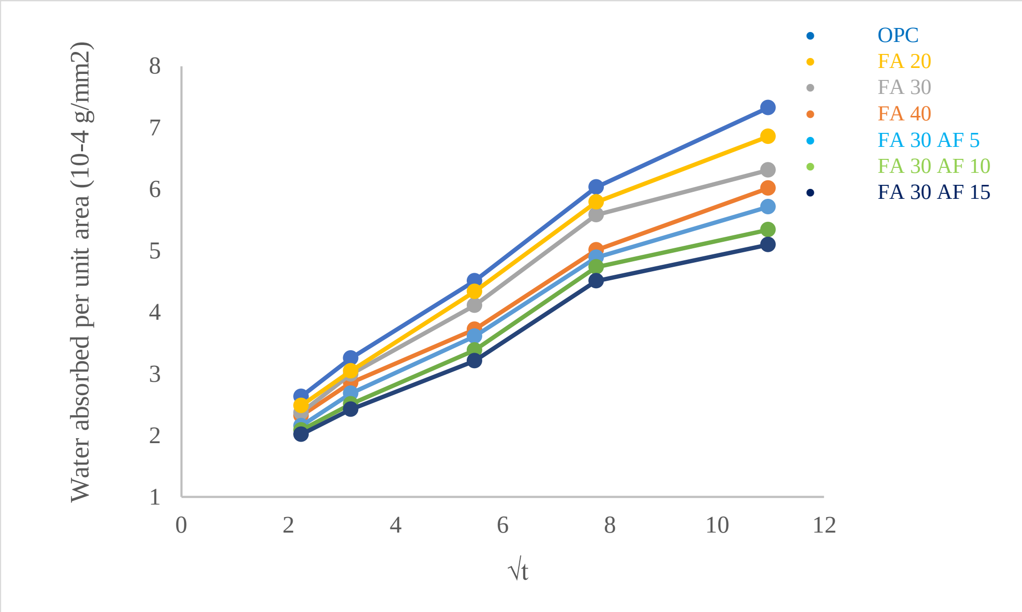


Figure 5: Water absorption vs √t

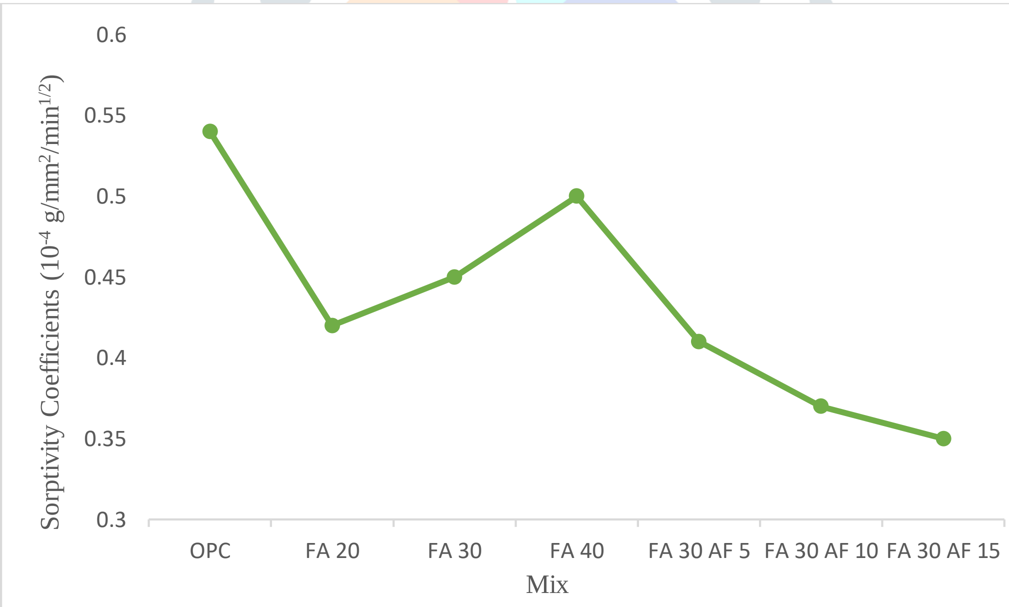


Figure 6: Sorptivity coefficient results

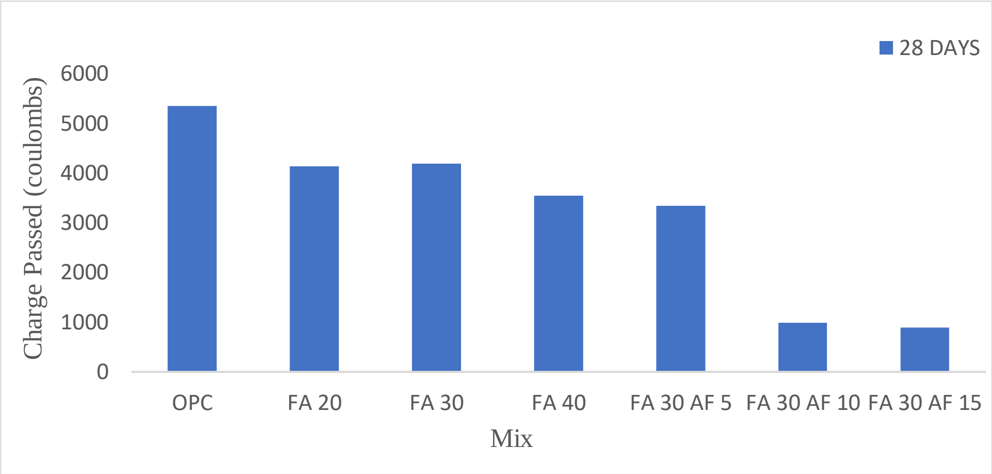
3.6 RAPID CHLORIDE PERMIABILITY

According to the results presented in Table 9 and Figure7, the rapid chloride permeability test (RCPT) is a commonly used method for evaluating the durability and resistance of concrete to chloride ion penetration. The test was performed on different concrete mixes at various time intervals for a duration of 6 hours. The chloride ion permeability was calculated using the equation $P = Q/(A*t)$. The findings indicate that the mixes with fly ash 30% and alccofine 10% and fly ash 30% and alccofine 15% had low chloride permeability. However, based on the results, it can be concluded that the mix with fly ash 30% and alccofine 10% exhibited the optimum permeability.

Table 9: Rapid chloride permeability test results

MIX	Charge passed (Coulombs)	Chloride penetration
OPC	5349.38	High
FA 20	4132.18	High
FA 30	4191.42	High

FA 40	3545.31	Moderate
FA 30 AF 5	3341.13	Moderate
FA 30 AF 10	**983.32**	**Very Low**
FA 30 AF 15	892.14	Very Low



Graph 6.6: Rapid chloride permeability test for concrete mixes after 28 days curing

4 CONCLUSIONS

The Workability of concrete mixes with Fly ash and Alccofine showed on significant improvement in workability when compared to conventional concrete.

The compressive strength of the mix containing 30% fly ash and 10% alccofine was increased by 30.46 %when compared to conventional concrete.

The flexural and split tensile strength of the mix containing 30% fly ash and 10% alccofine was increased by 14.89% and 15.30% when compared to conventional concrete.

The mix with 30% fly ash and 10% alccofine exhibited lesser sorptivity when compared to conventional concrete.

The chloride penetration for the mix containing 30% fly ash and 10% alccofine displayed lower when compared to conventional concrete.

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