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Effect of Alccofine on Durability Properties of Engineered Cementitious Composites Containing Mono and Hybrid Synthetic Fibres

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Abstract

Objectives: The study intends to assess the durability behaviour of Engineered Cementitious Composites containing Alccofine and fibres in mono and hybrid formats. **Methods:** The study comprehensively investigates ECC's response to water absorption, density, volume of permeable pores and sorptivity based on ASTM C 642 and 1585, respectively. In addition, ECC specimens were subjected to various environments such as acid, alkaline and sulphate mediums to find the performance mentioned above. **Findings:** The introduction of Alccofine caused a significant effect on both mechanical and durability properties. The results indicated that the inclusion of Alccofine exhibited a decrease of 18.67% of absorption and 25.89% of voids in ECC compared to the control mortar. The density of ECC increased by about 13.42%. After being exposed to acid, alkaline, and sulphate environments, the percentage loss of weight in ECC is 2.93%, 0.56%, and 0.51%, respectively, whereas in the control specimen, it was 3.92%, 0.83%and 1.51%, respectively. Percentage loss of strength also follows the same trend; the values are 14.67%, 3.27% and 11.19% in ECC, whereas in the control specimen, 23.32%, 8.33% and 16.79%, respectively. Alcconfine enhanced microstructure refinement and synthetic fibres crack mitigation behaviour improve ECC's resistance to the deterioration mechanisms. **Novelty:** The article reveals that adding Alccofine and hybridising fibers developed a sustainable material and found superior performance in all harsh environmental conditions. Using concrete with enhanced properties will be beneficial.

Keywords: Engineered Cementitious Composites; Polyvinyl alcoholfibre; Polypropylenefibre; Absorption; Sorptivity

1 Introduction

In recent years, there has been a substantial change in the construction industry towards using modern materials and technologies to improve the performance, durability, and sustainability of concrete structures. A notable development in this direction is using Engineered Cementitious Composites (ECC), which provide a rare combination of high ductility, higher tensile strain capacity, and improved crack management. Due to their potential to further enhance the material's mechanical and durability properties, adding additional cementitious materials and fibres to ECC formulations has drawn much interest. High-performance supplementary cementitious material alccofine has gained popularity as a potential improvement to ECC mixes. Alccofine can modify the microstructure of cementitious matrices due to its pozzolanic and micro-filling properties, which results in higher strength, decreased permeability, and increased resistance to various degradation mechanisms. In addition, synthetic fibres like polypropylene and polyethylene have been extensively used to increase ECC's tensile strength and crack resistance. These fibres especially work in harmony with Alccofine since they not only improve the mechanical qualities of the material but also help reduce cracking and increase durability. This research article's primary goal is to give a thorough durability investigation on Engineered Cementitious Composites made with Alcofine and synthetic fibres. This study offers insightful information about the synergistic effects of Alccofine and synthetic fibres on ECC's long-term performance under various environmental conditions. This is accomplished through a systematic investigation of various durability aspects, including Absorption, Density, Volume of permeable pores, Sulphate attack, Acid attack and Alkaline attack. Through this study, we hope to add to the corpus of knowledge concerning creating and improving ECC mixtures for increased durability, facilitating the implementation of more robust, durable concrete structures in contemporary construction methods.

1.1 Motivation

Since it is an era of materials, many researchers concentrated on new materials by making binary and ternary blended compositions. Adesina et al. used glass as aggregate in making ECC by replacing ultra-fine silica sand (USS) and found it had enhanced the durability properties of the composites. By doing this, utilisation of USS was reduced since it is more expensive, whereas the glass beads used by the above authors. According to the text, the optimal amount of Alccofine and synthetic fibers added to the ECC mixture is 20%. Were commercially available in the market at lower prices. They studied permeability-related durability tests. Inthis present study, along with absorption tests, ECC specimens were kept in different environments, such as acid, alkaline and sulphate tested and observed[(1)]. Sagar et al. reported that the addition of Alccofine in concrete increases its performance in both mechanical and durability parameters. This study attempted to use Alccofine in the ECC and observed the same results[(2)]. Utilisation of industrial by-products effectively in concrete as a supplementary cementitious material is known as sustainable construction; hence, the authors used Alccofine and polypropylene fibre in concrete and found that both compressive strength and flexural strength have increased[(3)]. Adding supplementary cementitious materials in the cement-based grouting field is advantageous and reduces the cost with improved performance. Even though the mechanical properties have been studied on this topic, durability hasyet to be studied much[(4)]. Ranjith et al.reviewed durability studies of ECC with PP fibres, glass fibre, and fly ash as supplementary cementitious material and found enhanced performance. The higher strain capacity of ECC is due to the formation of multiple cracks instead of a continuous increase of a crack opening. Studies have been undertaken using PVA fibre and PE fiber. To formulate a new type of ECC, alccofine was used as a supplementary cementitious material, and PP fiber was used as a micro reinforcement in this study[(5)]. Meenatchi et al. found a ternary blend of cement, Alccofine and flash and found that a 10% addition of Alccofine and 25% fly ash perform better when compared to the other mixes. Its mechanical performance is enhanced still because of the addition of fibers. Tests on Alccofine-based concrete under alkaline and sulphate environment is limited, whereas, under acid environment, it shows minimal loss in weight as well as strength[(6)]. Introducing fibers into the composite increases its toughness and cracking resistance from PVA and PP. PVA performs well but is expensive, whereas pp serves a little lower than PVA but is a relatively cheaper price[(7)]. Using PP fibers, mechanical properties have been enhanced significantly. Studies on mechanical properties are enormous, whereas durability studies are limited[(8)]. Polypropylene fibers used in the composite increase mechanical properties such as compression, tensile and flexural strength based on the fiber bridging action[(9)]. Sai Srinath et al. found that concrete containing Alccofine performs better under different environments such as acid, alkali, and sulphate[(10)]. Since the crack width is limited to 100 μm, external ingression of foreign materials is not possible, which eventually increases the life of the ECC member[(11)]. Incorporating alccofine in green concrete leads to notable improvements in mechanical strength and reduced water absorption properties when compared to conventional concrete mixtures at all stages of development. The strength of green concrete sees a significant increase, up to 20%, with the replacement of cement by alccofine[(12)].

1.2 Research Significance

The mechanical characteristics of Engineered Cementitious Composites (ECC), focusing on improved ductility and fracture control, have been the subject of substantial research in recent years. While numerous studies have looked into the addition of additional cementitious materials and synthetic fibres to ECC mixtures, little focus has been placed on the interaction between

Alccofine and particular types of fibres, like polyvinyl alcohol (PVA) and how this affects the durability performance of ECC. Additionally, the majority of the literature that is currently available places a strong emphasis on mechanical qualities, leaving a sizable research hole in our understanding of the complex interactions between alccofine, PVA fibres, and the durability of ECC in a variety of environmental circumstances. By conducting a thorough analysis of the synergistic effects of Alcofine and PVA fibres on the durability of ECC, this work aims to close this gap.

1.3 Objective

This study's primary goal is to evaluate the material characteristics of Alccofine incorporated cementitious composites containing mono and hybrid Fibres.

2 Methodology

1. Testing of all the constituent materials for their basic properties.
2. Casting and testing of ECC containing alccofine cube specimens to determine compressive strength.
3. Casting and testing of ECC containing alccofineprism specimens for determining the modulus of rupture.
4. Casting and testing of ECC containing Alccofine specimens (cubes and discs) for examining their durability properties such as water absorption, porosity, sorptivity, acid, alkaline and sulphate resistance.

Researchers have worked to attain superior performance by adding Alccofine into ECC to make it more ductile and environmentally friendly by adding two types of synthetic fibers.

2.1 Experimental Programs

Ordinary Portland cement OPC 53grade conforming to IS 12269-1989 was used as a binder. In addition to it, Alccofine 1203 was used. Fine aggregate with a specific gravity of 2.61 and conforming (IS 383:1970) to grading zone 3 was used. The particle size distribution curve for fine aggregate is shown in Figure 1. Potable water is used for mixing and curing the specimens. The properties of polyvinyl alcohol fiber and polypropylene fiber are used in this study and conform to ASTM C 1116 . The properties of both fibersare presented in Table 1. Alccofine is added about 80% by the weight of the cement, designed based on the trial and error method. This work used a cement content of 640.2 kg/m3, 514.8 kg/m3 of Alccofine, and 574 kg/m3 of fine aggregate with a 0.27 w/b ratio. The chemical composition of Alccofine and cement is given in Table 2. Sika Viscocrete, a polycarboxylate-based high range water reducer, was used, and it conforms to ASTM C 494.

Table 1. The properties of fiber

Property	Polyvinyl Alcohol Fiber	Polypropylene Fiber
Specific Gravity	1.3	0.91
Length (mm)	12	12
Diameter (μm)	30	30
Tensile Strength (MPa)	1700	550
Young's Modulus (GPa)	40	5

Table 2. The chemical Analysis of Cement and Alccofine

Chemical composition, %	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	SO_3	Na_2O	LOI
Cement	21.80	63.56	5.12	3.20	0.80	0.75	3.22	0.55	1.00
Alccofine	35.24	31.22	19.41	2.43	7.21	0.24	0.2	0.15	1.00

2.2 Test Specimens and Methods

Cube Specimens of size 70.7 mm were tested according to ASTM C 109 in a compression testing machine of 200-ton capacity. Prism specimens of size (150 x 40 x 30)were tested under four-point bending in a 100 kN capacity universal testing machine. Cube specimens of length 70.7 mm were cast and tested as per ASTM C 642 – 2007. Cylinder specimens 100 mm x 50mm were cast and tested as per ASTM C 1585 – 04. Cubes of 70.7 mm were cast and cured in acid, alkaline and sulphate environments as per ASTM C 1012. The details of the specimens are given in Table 3. Mix proportions used in the study are shown in Table 4.

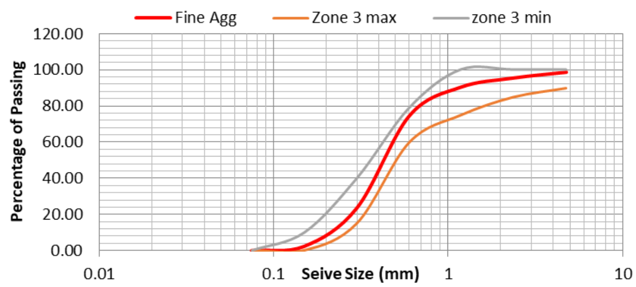

Fig 1. Particle Size DistributionCurve for Fine Aggregate

Table 3. Details of Specimens

Sl No	Specimen	No. of Specimens	Type of Test
1	Cube (70.7mm)	6 x 3 = 18	Compressive Strength as per ASTM C 109
2	Prisms (150 x 40 x 30)	6 x 3 = 18	Four-point bending as per IS 516-1999
3	Cube (70.7mm)	6 x 3 = 18	Water absorption as per ASTM C 642
4	Cube (70.7mm)	6 x 3 =18	Acid Curing
5	Cube (70.7mm)	6 x 3 =18	Alkaline Curing
6	Cube (70.7mm)	6 x 3 =18	Sulphate Curing
7	Cylinder (100mm dia, 50 mm height)	6 x 3 =18	Sorptivity as per ASTM C 1585

Table 4. Mix Proportions

Mix ID	Cement (kg/m^3)	Alccofine (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	Fibers (kg/m^3)		HRWR (kg/m^3)	Compressive Strength (N/mm^2)
					PVA	PP		
CC	527	-	1556	223	-	-	3.16	54.06
M_1	640.2	514.8	574	310	24	-	7.02	76.44
M_2	640.2	514.8	574	310	-	24	7.02	74.14
M_3	640.2	514.8	574	310	12	12	7.02	71.58
M_4	640.2	514.8	574	310	18	6	7.02	72.44
M_5	640.2	514.8	574	310	6	18	7.02	75.32

2.3 Density, Absorption, and Porosity

Eighteen cubes of size 70.7mm (CC, M_1, M_2,M_3,M_4,M_5) were tested for water absorption as per ASTM C 642 (ASTM 2006). Each value represents the average results of three specimens in the same group. To dry the samples to a consistent mass, they were first heated to 110°C for 24 hours in the oven. The specimens were dried, allowed to cool to room temperature before an initial mass was produced, and then submerged in water for three days (or 72 hours) at about 21 °C. After three days of immersion, the specimens were surface dried, and the mass was measured to determine the surface dry mass. The samples were boiled for 5 hours to cool to room temperature, and then another surface dry mass was taken to calculate the volume of permeable voids (i.e., porosity). To calculate the apparent mass of the specimens while submerged, they were further suspended in water. They were using Eqs. (1)–(7), the specimens' density, absorption, and void characteristics were calculated. Here m_1, m_2, ,m_3 and m_4 represent the original mass, surface dry mass, surface dry mass upon boiling, and immersed apparent mass, respectively. Furthermore, ρ_w in equations (1) through (7) denotes the density of water.

1. Absorption after Immersion $= \frac{m_2-m_1}{m_1} \times 100$
2. Absorption after immersion and boiling $= \frac{m_3-m_1}{m_1} \times 100$
3. Bulk Density (ρ_d) = $= \frac{m_1}{m_3-m_4} \times \rho_w$
4. Bulk Density after immersion = $= \frac{m_2}{m_3-m_4} \times \rho_w$
5. Bulk Density after immersion and boiling = $= \frac{m_3}{m_3-m_4} \times \rho_w$
6. Apparent Density (ρ_a) = $= \frac{m_1}{m_1-m_4} \times \rho_w$

7. Volume of permeable pore space (Voids) = = $\frac{\rho_a - \rho_d}{\rho_a} \times 100$

2.4 Sorptivity

Sorption in the concrete member is due to the capillary suction through the pores. Since the capillary suction would not occur in either dry or saturated concrete. Sorptivity test specimens were oven-dried for at least 48 hours after 28 days of water curing to remove all the moisture from the concrete specimens. After removing from the oven, it has tobe covered tightly inside polythene bags for about 15 days. After removing the specimens from the bags, leaving one side exposed to water, all other sides were covered with the electrician insulation tape and placed in the sorptivity setup, keepinga 3 – 5 mm water depth as per ASTM C 1585. This test was performed based on ASTM C 1585. The below-given formulas calculated the sorption,

$$\mathrm{I} = \frac{m_t}{axd} \tag{1}$$

Where m_t = Change in mass of the specimen (gm)
a = Exposure area of the specimen (mm^2)
d = Density of the water (gm/mm^3)

$$\mathrm{S} = \frac{I}{\sqrt{t}} \tag{2}$$

Where S = Sorptivity of the specimen
I = cumulative percentage of water absorbed per unit area
t = time taken

2.5 Acid, Alkaline and Sulphate Resistance

Three nos of 18 cubes sized 70.7mm were tested for acid, alkaline and sulphate resistance. Each value represents the average result of three specimens in the same group. The initial mass of all the specimens was measured. For acid resistance, samples were immersed in 5% H_2SO_4 solution for about 28 days. The alkaline resistance specimens were immersed in a 5% NaOH solution for about 28 days. For Sulphate resistance, specimens were engaged in 5% of $MgSO_4$solution. The samples were taken out after 28 days, surface dried, and their masses determined. All models were tested in compression to assess the strength loss.

3 Results and Discussions

3.1 Mechanical Properties

Durability properties are crucial to the long-term performance of composites in the environment to which they are exposed; corresponding mechanical properties are also equally important. This study reports mechanical characteristics, including their compressive and flexural strengths, in Figure 2.

Figure 2 shows a direct correlation between the mixtures' compressive strength and flexural strength. The ECC combination with PVA fibre as the micro reinforcement has 28 days of compressive and flexural strength, and those results are respectively 76.44 and 10.21 MPa, whereas that with hybrid ECC containing an equal amount of PVA and PP is 71.58 and 8.23 MPa are acceptable. However, a mix containing less PVA and more PP fiber shows lesser flexural strength, about 6.88 MPa, compared to all other combinations. Incorporating alccofine as the supplementary cementitious material resulted in improved mechanical properties, which was attributed to the Alccofine's specific surface area, resulting in a more dense matrix. Adesina et al. observed the formation of the densified matrix as one of the reasons for the improved compressive strength and flexural strength[(1)]. Adding Alccofine increasescompressive and flexural strength in concrete, the same trend found in the composites[(2)]. Alccofine's integration produced a dense matrix structure in the concrete due to the ultrafine particles and unique chemistry[(4)]. Meenatchi et al.show the same trend of enhanced mechanical properties such as compressive and flexure using Alccofine and flyash[(6)]. This enhancement can be attributed to alccofine's high specific surface area and strong pozzolanic activity, which promote the formation of a dense C-S-H gel structure within the concrete. This, in turn, contributes to improved early strength development[(12)].

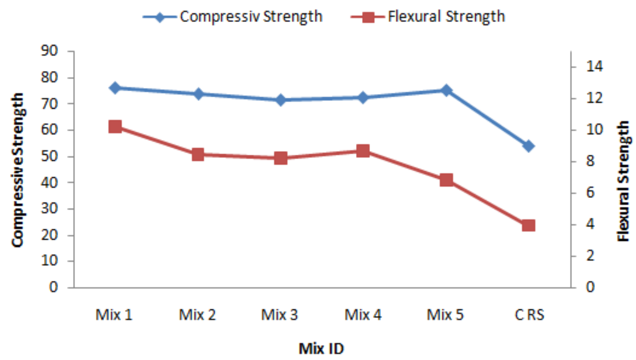

Fig 2. Mechanical properties of ECC mixtures

3.2 Density, Absorption and voids

3.2.1 Density

The dry and apparent density of the ECC and hybrid ECC is shown in Figure 3. The graph shows a decrease in the thickness of hybrid ECC mixes compared to the mono-fibre ECC mixes; this slight variation in the ECC mixes is due to the lack of compatibility of the yarns. Different moduli of fibers lead to the fibres' accumulation and a slight decrease in the density of the mixtures. All ECC and HECC combinations had more than 2,000 kg/m3 densities. Therefore, they can be used in situations that call for regular-density concrete. ECC with glass as an aggregate shows a thickness greater than 2000 $kg/m^{3,}$ which is required for normal-density concrete[1].

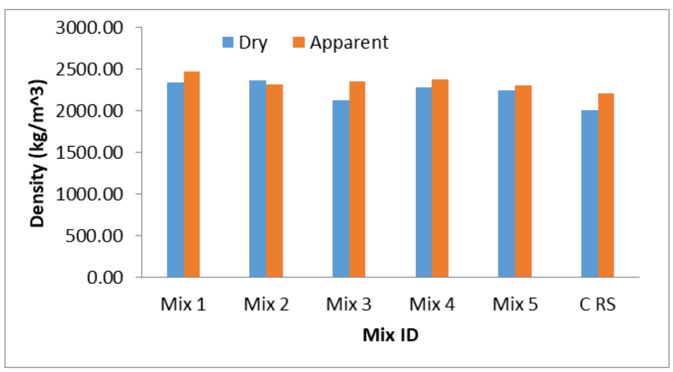

Fig 3. Density of ECC mixtures

3.2.2 Water Absorption

The cementitious composite's water absorption is a reliable indicator of its longevity and integrity. Because they prevent the entry of harmful ions, which are typically conveyed with water into cementitious composites, they are anticipated to have longer service lives. Figure 4 shows the water absorption after immersion at 28 days, whereas Table 5 shows the water absorption after immersion and after immersion and boiling at 28 days. All the ECC mixtures showed lesser water absorption values than the control mortar due to the densification of the ECC matrix. However, mixes containing PVA fiber showed lower water absorption than PP fiber. The type of fibre used altered the tortuosity of the pore system in the mortar,leading to the variation in the absorption pattern in the ECC mixtures. The addition of glass reduces the absorption due to the densification of the ECC matrix[1]. Alccofine addition decreases water absorption in concrete compared to the control concrete; the same trend is observed in the composites[2]. Alccofine in concrete plummets the hardened concrete micropores, eventually reducing absorption and increasing compressive strength[4]. Adding fibers along with the coarse aggregate increases the formation of pores, leading to aslightly higher absorption due to accumulation. Still, in the present study, coarse aggregate omitted entirely leads to the shape of a dense matrix that reduces the absorption to an extent[6]. Based on the type of fibres used, the rate of absorption differs. Compared to abaca fibers, PP fibers had less water absorption, whereas, in the present study, PVA shows lower absorption than PP fibers[13]. The effect of fibre and alccofine on absorption following immersion and boiling followed a similar trend, as shown in Table 5. With a higher PVA fiber concentration, the water absorption of ECC mixes after immersion and after immersion and boiling decreases. The water absorption percentage of green concrete decreases due to pore-filling effects and the accelerated hydration of alccofine particles, resulting in a denser and more compact concrete matrix[12].

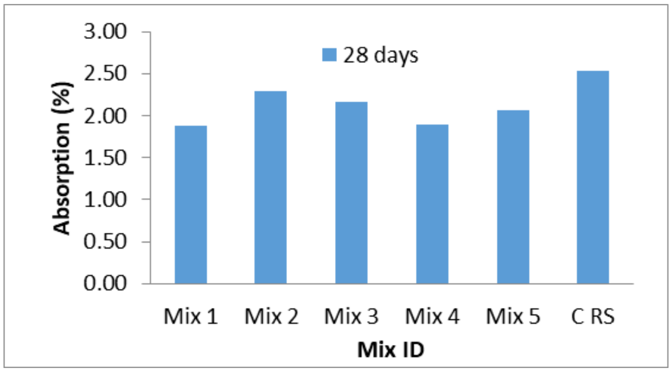

Fig 4. Absorption of ECC mixtures at 28 days

Table 5. Absorption of ECC mixtures (%)

Mix ID	After immersion	After immersion and boiling
Mix 1	1.88	2.02
Mix 2	2.29	2.29
Mix 3	2.16	2.09
Mix 4	1.89	1.96
Mix 5	2.07	2.14
C RS	2.53	2.50

3.2.3 Porosity

The percentage of voids (i.e., porosity) is a good predictor of its durability properties, much as the absorption of cementitious composites. The composite is more resistant to harmful environmental forces with a lower percentage of voids. Lower voids can also improve cementitious composites' compressive and flexural strengths, among other mechanical characteristics. Figure 5 displays the proportion of voids or porosity of each ECC combination assessed in this investigation at 28 days. Figure 5 showed that all ECC mixtures showed more or less the same percentage of voids and lesser than the control mortar.

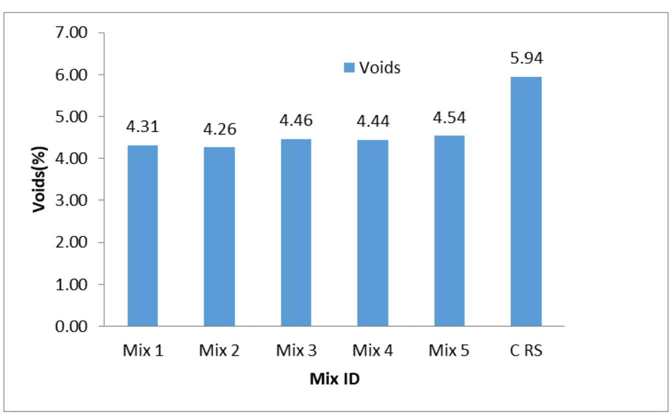

Fig 5. Porosity of ECC mixtures at 28 days

Figures 6 and 7 compare porosity and water absorption and porosity and compressive strength, respectively. According to Figure 6, the porosity and water absorption of the ECC combinations are directly correlated. Because there is no room for moisture to be absorbed, composites with more minor porosity have lower water absorption. As was already noted, the mechanical properties are anticipated to be improved by adding Alccofine and fibers, reducing the ECC mixes' porosity. According to Figure 7, the mixes' compressive strength rises as their porosity falls. All the ECC mixes show similar porosity and compressive strength values, which are superior to the control mortar. The average percentage of voids in all ECC mixes is 4.40%, and the average compressive strength is 73.6 MPa, whereas for the control mortar, the percentage of voids is 5.94%, and the corresponding compressive strength is 54.06 MPa. It shows that fibres effectively changed the tortuosity of the pore system in the ECC mixtures. Glass acts as a filler within the cementitious matrix and reduces the voids, reducing the porosity[(1)]. The addition of Alccofine reduces the porosity in concrete, and the same trend is observed in the composites also[(2,4,6)].

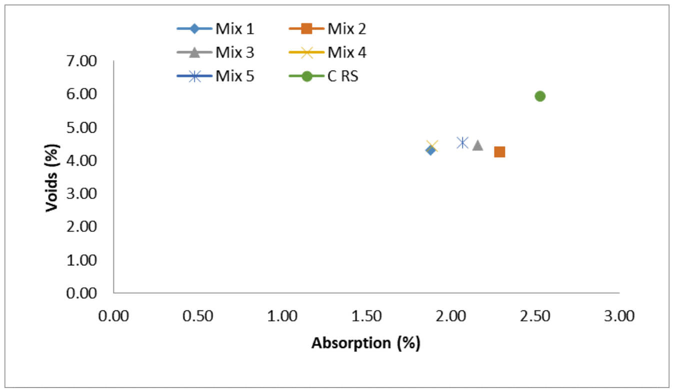

Fig 6. Comparison between porosity and absorption at 28 days

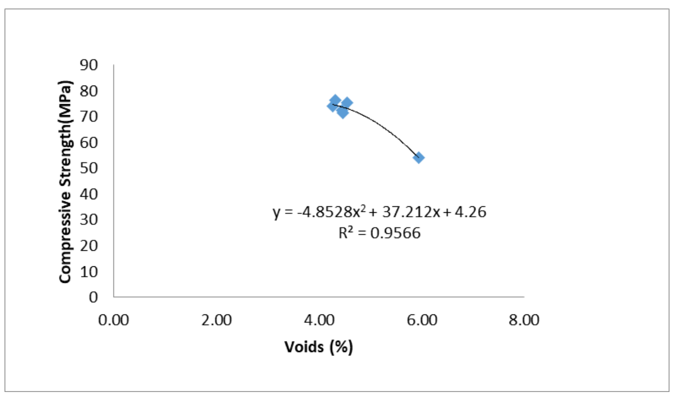

Fig 7. Comparison between porosity and compressive strength at 28 days

3.3 Sorptivity

After the sorptivity test, it was observed that both ECC and HECC showed relatively higher capillary suction in the initial period, which is up to six hours and eventually got reduced when it entered the secondary absorption. At the same time, the control mix shows relatively lesser absorption in the initial absorption period and is more compared to ECC and HECC in the secondary absorption stage. This happens because of the change in the continuous pores in the ECC and HECC. Because of the presence of fibre in a high percentage, both ECC and HECC allow the suction in the initial period. Still, it has eventually reduced when it comes to secondary sorption. This is because fibres obstruct the path randomly, and it changes the tortuosity of the specimen. However, the control mix shows lesser absorption in the initial period, slowly increasing than ECC and HECC in the secondary capillary suction. It happened due to the absence of fibre and alccofine. In contrast, Alccofine plays a significant role in pore refinement, and the fiber become the responsible for the change in the tortuosity of the specimen. Figure 8 shows the sorptivity curves of control and ECC. Figure 9 shows the sorptivity curves of control and HECC. From the graph, it is inferred that initial absorption of all the mixes, including the control mix,offers more or less similar trend, whereas, after 6 hrs, both ECC and HECC showed lesser capillary suction than the control mix. Even though pore refinement occurs because of the Alccofine, the presence of fibres alters the specimens' tortuosity. However, PVA fibre shows higher suction than PP fibres because of their specific gravity. Since PVA is a high-modulus fibre, the given V_f quantity is slightly lesser than polypropylene. The initial and secondary sorptivity of all mixes are tabulated in Table 6. Up to 2% addition of fibres did not affect the sorptivity property of the samples, whereas when it increased to 3%, the sorptivity value in both initial and secondary will increase. The sorptivity test gives essential information about the pore structure of the composites, tortuosity, continuous capillaries and pore sizes[14] . Adding fiber to concrete reduces sorptivity in concrete, and the reduction is up to 25.85% compared tothe control mix[12]. The water absorption and sorptivity rate of ECC show better results when compared to standard concrete[15].

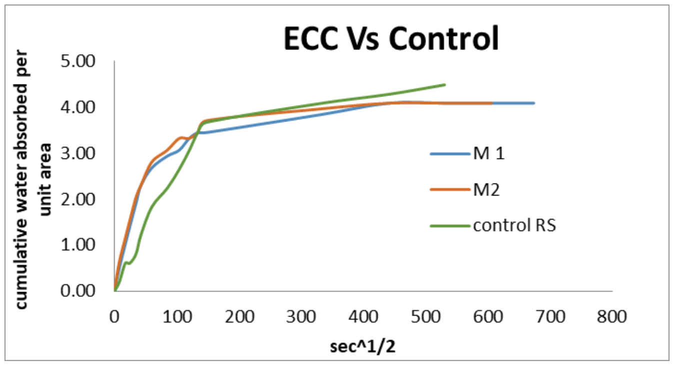

Fig 8. ECC vs Control

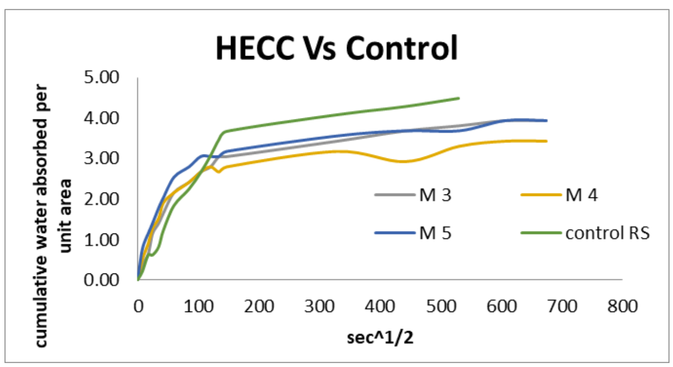

Fig 9. HECC Vs Control

Table 6. Initial and secondary sorptivity of all mixes

Sl No	Mix ID	Avg initial sorptivity in 10^{-3} x mm/sec$^{1/2}$	Avg secondary sorptivity in 10^{-3} x mm/sec$^{1/2}$
1	M_1	20.4	5.15
2	M_2	20.14	5.15
3	M_3	20.80	4.99
4	M_4	21.47	4.35
5	M_5	21.67	4.99
6	Control	24.99	5.93

3.4 Acid Resistance

Figure 10 showed ECC specimens taken out from the acid curing of 28 days, and the graph showed loss of weight and compressive strength in ECC after being immersed in acid. Synthetic fibers resistant to many chemicals but are vulnerable to concentrated sulphuric acids. Sulphuric solid acid can degrade and dissolve PVA and PP fibers, leading to the loss in both weight and compressive strength of the ECC and control mortar. However, ECC showed enhanced resistance to the acid environment compared to the control mortar. The average loss in weight of ECC mixtures is 2.93%, whereas in control mortar, the loss in weight is 3.92%. Similarly, the average loss in compressive strength of ECC mixtures is 14.67%, whereas in control mortar, the loss in compressive strength is 23.30%. Effective resistance against the acid environment in the specimens having PP fibre since it has an excellent binding capacity and is resistant to the tension created by the spalling of ingredients. Hence, the weight and strength loss is minimal compared to the control mix[(6)]. In the acid medium, weight and strength loss occurred in minimal quantity because of the rich fineness of the composite containing Alccofine[(16)].

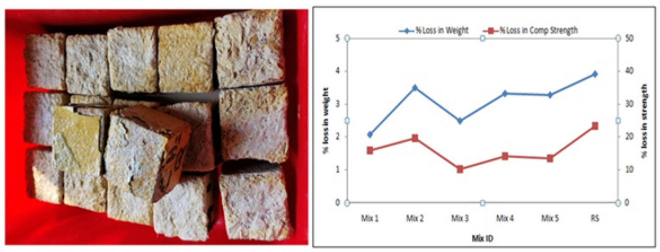

Fig 10. Specimens after immersed in acid solution and Loss in Weight and Compressive Strength After immersed in acid solution

3.5 Alkaline Resistance

Figure 11 showed ECC specimens taken out from the alkaline curing of 28 days and showed loss of weight and compressive strength in ECC after being immersed in alkaline. Mostly, synthetic fibers are resistant to many chemicals and adequately resist sodium hydroxide solution. Both PVA and PP fibre showed effective resistance towards the alkaline medium. ECC showed high resistance to an alkaline environment compared to an acid environment. However, there is a change in weight and loss in compressive strength that occurs in ECC mixtures when it is exposed to more extended curing periods. The average loss in weight of ECC mixtures is 0.55%,whereas in control mortar, the loss in weight is 0.83%. Similarly, the average loss in compressive strength of ECC mixtures is 3.27%, whereas in control mortar,the loss in compressive strength is 8.33%. Because of the densification of the ECC, intrusion of alkaline into the ECC mixtures is limited and leads to a lesser loss in compressive strength.

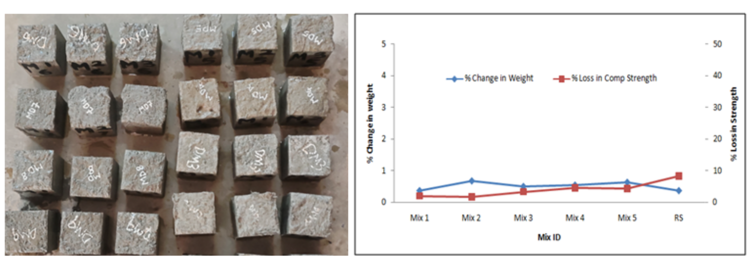

Fig 11. Specimens after immersed in alkaline solution and Loss in Weight and Compressive Strength After immersed in alkaline solution

3.6 Sulphate Resistance

Figure 12 showed ECC specimens taken out from the sulphate curing of 28 days and showed increased weight and compressive strength in ECC after being immersed in alkaline. Mostly, synthetic fibers are resistant to many chemicals and effectively resist sulphate solutions. Both PVA and PP fibers showed effective resistance towards the sulphate medium. In this case, sulphate exposure cause the mortar without Alccofine and fibers to expand due to the formation of expansive compounds, ultimately leading to weight and strength loss. In the ECC mixtures, both PVA and PP fibers resist and help limit the expansion by reinforcing the matrix and minimising the impact of sulphate-induced volume changes. This reduction, in addition, can lead to increased compressive strength. Even when sulfate-rich solutions are present, PVA fibres can strengthen the bonding between the mortar components. A more cohesive structure and, consequently, higher compressive strength can result from improved adhesion. The average increase in weight of ECC mixtures is 0.52%, whereas in control mortar,the loss in weight is 1.51%. Similarly, the average increase in compressive strength of ECC mixtures is 11.2%, whereas in control mortar,the loss in compressive strength is 16.8%. Specimens immersed in sodium sulphate solution decrease their strength and weight. In contrast, in this present study, magnesium sulphate was used and increased its strength and weight because of the pore refinement due to Alccofine and synthetic fibers. Since the microstructure of ECC with Alccofine improved significantly which makes the sulphate ions to enter into the ECC reduces the deterioration and increases its strength as well. These results are for 28 days of immersion. Further investigation is required to see whether the trend is continuous or decreasing when the specimens are immersed for 60 and 90 days[5]. Adding Alccofine makes the composite dense, reducing the amount of sulphate ions that enter the composite. Even though magnesium sulphate solutions are more aggressive on cement paste since there are fewer entry points, they did not damage the composites much. Due to the secondary pozzolanic reaction and densified matrix, both strength and weight are improved significantly.

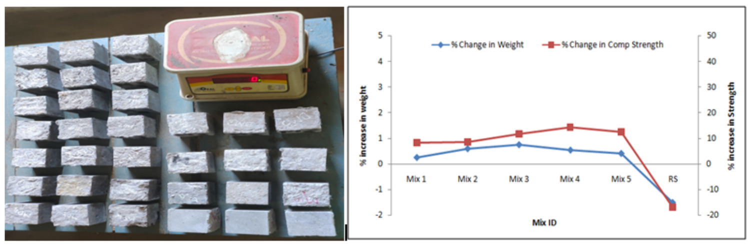

Fig 12. Specimens after immersed in sulphate solution and Loss in Weight and Compressive Strength After immersed in sulphate solution

3.7 Microstructural Properties

One can obtain detailed images of a sample's surface and topography using a SEM. It creates precise images and gathers details about the sample's morphology by scanning a focussed electron beam across the sample's surface and looking for different signals, including secondary electrons, backscattered electrons, and distinguishing X-rays. To ascertain the elemental makeup of a piece, EDS is an analytical method frequently used in conjunction with SEM. When a sample is hit with electrons from the SEM's electron beam, it emits X-rays, which the device detects. These X-rays' energies correspond to particular elements in the sample, making it possible to identify and count the elements present. Figure 13 showed SEM images and EDS of Mixes 1 to 5 and control mortar. All the ECC mixtures formed a dense matrix due to adding Alccofine due to the pore refinement. Based on the EDS results, all ECC mixtures are enriched with silica content, whereas control mortar contains relatively less. After exposure to the different environments, there is not much difference in the composite properties, showing that it has effective resistance towards acid, alkaline and sulphate environments due to its lower absorption properties.

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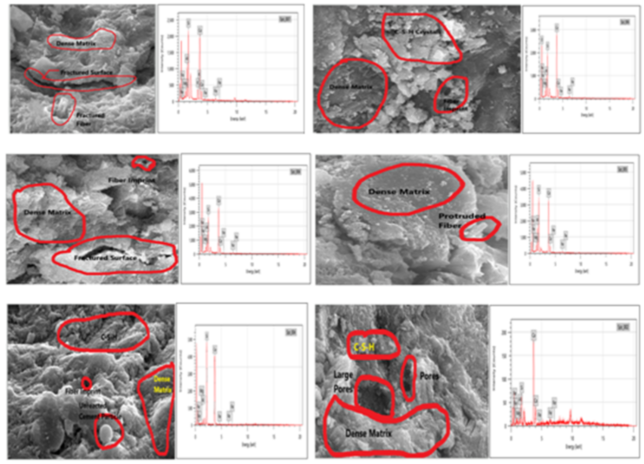

Fig 13. SEM image and EDS of M_1, M_2, M_3, M_4, M_5 and CC

4 Conclusion

The current study described the replacement of fly ash with another industrial byproduct as a mineral admixtures. The addition of alccofine improves the mechanical and durability qualities of composites. However, using alccofine to make ECC and HECC more environmentally friendly and beneficial by reducing cement usage is also the reason for emitting CO_2 into the atmosphere during production. Consequently, the creation of green concrete that reached environmental impact and further strategies to reuse industrial byproducts in construction materials. Based on the experimental works, the following conclusions were made,

1. The water absorption of ECC and HECC specimens showed better results than the control specimen. In contrast, specimens with polypropylene fibres show relatively higher water absorption than those containing polyvinyl alcohol fiber. Since the temperature was not high, boiling the water for 5 hours when the specimens were immersed in it didn't cause any damage to the fibres present inside the models.
2. The water absorption capacity did not vary much after boiling the specimens.The average percentage reduction in water absorption in ECC and HECC is 18.67%, mainly due to pore refinement and changes in the tortuosity in the pores. This significant modification happened due to the addition of Alccofine and fibers. Around 25.89% of pore refinement occurred in ECC and HECC compared to the control mix. The specimen's density increased by about 13.42% compared to the control mortar.
3. Regarding acid resistance, the average loss of weight and compressive strength in ECC is 2.93% and 14.67%, respectively, whilst loss of weight and compressive strength in control mortar is 3.92% and 23.32%,which showed ECC specimens get enhanced to resist acid when incorporating fibre and Alccofine.
4. Regarding alkaline resistance, an average loss of weight and compressive strength in ECC is 0.56% and 3.27%, respectively, whilst loss of weight and compressive strength in control mortar is 0.83% and 8.33%, which showed ECC specimens get enhanced to resist alkaline when incorporating fiber and Alccofine.
5. Regarding sulphate resistance, average gain of weight and compressive strength in ECC is 0.51% and 11.19%, respectively, whilst loss of weight and compressive strength in control mortar is 1.51% and 16.79%, This results are for 28 days immersion. Further investigation required to see whether the trend is continuous or decreasing when the specimens immersed in 60 and 90 days.

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