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Durability Evaluation of Cactus-infused M25 Grade Concrete as a Bio-admixture

M. Velumani[1*], R. Mohanraj[2*], R. Krishnasamy[3], K. Yuvaraj[1]

[1] Department of Civil Engineering, K. S. Rangasamy College of Technology, Tiruchengode, Namakkal, Tamilnadu 637215, India
[2] Department of Civil Engineering, SRM University, Delhi-NCR, Sonipat, Haryana 131028, India
[3] Department of Civil Engineering, Erode Sengunthar Engineering College, Perundurai, Erode, Tamilnadu 638057, India
[*] Corresponding author, e-mail: velumani@ksrct.ac.in; rsrirammohan@srmuniversity.ac.in

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Abstract

The durability of concrete incorporating cactus extract as a bio-admixture is the focus of this study, which is the first of its kind in the literature. Cactus-infused concrete is a novel type of concrete with exceptional fluidity, strength, and durability. In this project, cactus was employed as an addition to M_{25}(3626 psi) concrete, which was designed to Indian standards. Cactus extract (1% to 9% of the total weight) was used to replace the water in the mix. In order to look into the durability properties of cactus concrete, durability experiments such as drying shrinkage test, water absorption, porosity, sorptivity, accelerated carbonation, acid, and alkalinity tests were carried out on the material. ETC concrete enhances the fluidity of the mixture, making it more workable. To determine the particle distribution in concrete, scanning electron microscopy (SEM) was used to investigate the material. According to experimental research, polysaccharides and fats in concrete have increased their durability properties by 30% when used at their optimal level. However, a high level of durability is attained, which encourages concrete voids to be effectively filled.

Keywords

concrete, Euphorbia tortilis cactus, durability, bio-additive, green material

1 Introduction

Cement composite is the most often used construction material. A potential issue with concrete is its strength and durability, which are regulated by numerous criteria such as lower compressive strength values, a high likelihood of clogging, and reduced resistance to corrosion in harsh conditions. To obtain good outcomes, concrete is altered in a variety of ways, including modifying mix proportions, changing composition, replacing it with alternative waste products, and adding admixtures (high strength, workability, high performance, and viscosity of concrete). The current improvement in concrete construction technology shows the possibility of increasing concrete quality by modifying its fiber content. Cement is the primary binding agent in concrete. More carbon dioxide is emitted during the making of cement in industry, which is harmful to the environment. In ancient times, lime was employed as a binding substance instead of cement, however, it is not long-lasting. Chemical additives are used in concrete to modify its qualities. The usage of synthetic polymer additives will release more harmful species into the environment. Furthermore, the use of chemical admixtures is costly. According to current research, the use of low-cost natural additions (*Euphorbia tortilis* cactus) can help to reduce these drawbacks in concrete.

Adewuyi and Umoh [1] prepared the laterite soil brick with bamboo leaf blended cement. Compressive strength, water absorption, and abrasive resistance were increased from 2.39% to 3.95%. Akindahunsi and Uzoegbo [2] studied starch admixtures (Maize and Cassava) with cement to evaluate sorptivity, oxygen permeability, and strength of concrete. They discovered an improvement in sorptivity and strength (1.5 to 3.8%) and less oxygen permeability. According to Bezerra [3] bio-superplasticizers had a minor impact on porosity in concrete. Bouakba et al. [4] used cactus fiber as bio-polyester in the concrete and they investigated the flexural behavior of concrete under cyclic loading. Bouakba et al. [4] observed high flexural strength the conventional concrete. According to Chandra et al. [5] research, cactus extract enhances plasticity and water-retaining capacity. Also, cactus minerals act as air

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entertaining agents and retarders. To change the characteristics of concrete, Cárdenas et al. [6] substituted nanoparticles with cement, but the results eventually deteriorated. Cárdenas et al. [7] reported that the early strength of concrete achieved when cement reacts with nano-SiO_2 minimizes CO_2 emissions. Another natural additive, black gram, increased the water-holding capacity of cement mortar but slowed the hydration process. Cardenas modified the characteristics of lime mortar with *Ficus-indica* mucilage; an increase in strength was noticed in these admixtures. Dwivedi et al. [8] reduced the heat of hydration in Portland cement by using black gram and superplasticizer with the calorimetric method. At the end of the investigations, nano size hydration productions were produced. The heat of hydration was observed to be lowered at a high level. Hazarika et al. [9] and Hanehara and Yamada [10] demonstrated that low-cost bio admixtures prevented concrete degradation. The compatibility of concrete was also disturbed by the addition of alkaline sulfate.

The durability and mechanical performance of concrete with water/cement ratios of 0.30 and 0.60 that contain solutions containing cactus mucin and brown marine seaweed extract (at 0.5° Brix concentrations) were experimented by Hernández et al. [11]. The results showed that the durability of concretes including organic additives was improved in comparison to the control in terms of carbonation, chloride diffusion, and fast chloride permeability. According to Izaguirre et al. [12], mechanical and durability qualities were attained by using biodegradable natural polymers. Jensen and Hansen [13] carried out experiments with a water-entrained solution to determine the theoretical background. Jonker employed super adsorbent polymer as water-entrained cement paste which fills the voids in the concrete. Less density and capillary action were observed. Jonkers et al. [14] employed starch by biotech methods to improve the durability of concrete. The test results show that the porosity value and capillarity of concrete were less, and the mechanical strength and durability of concrete increased by 15% while adding an optimum dosage of 0.5%. Jumadurdiyev et al. [15] conducted the bleeding test with three phases of molasses and reported on the water retention capacity reached by utilizing beet molasses in concrete. The weight of the concrete was reduced considerably while using cactus in concrete reported by Kammoun and Trabelsi [16]. Karandikar et al. [17] reviewed that bio-admixtures and bio-additives are modifying the properties of concrete at a considerable level. In an experiment, natural polymers were used by Kizilkanat [18] to alter the mechanical characteristics of cement composite. There was an improvement in the outcome. According to Kyomugasho et al. [19], natural biopolymers (broccoli) increased compressive strength by up to 10%. The broccoli contains a high amount of pectin and protein. Concrete strength was raised by 10% by using vegetable-based biopolymers [20]. The heat of hydration was significantly reduced, and the workability of the concrete was improved when chitosan ethers were added to fresh concrete [21–23]. 84 numbers of mortar cubes were cast with nopal (*Opuntia ficus indica*) and tested after 900 days of curing period. The test results of wet electrical resistivity, ultrasound wave propagation, and compressive strength shows a marginal increment. Dehydrated nopal additives did improve the mortar's physical performance over time proved by Martínez-Barrera et al. [24], Murthi and Sivakumar [25], Murugappan and Muthadhi [26] and Otoko and Ephraim [27]. Cactus was used as a natural additive in M_{20} concrete by Pattusamy et al. [28]. According to their report the strength of the concrete enhanced by polysaccharides and fats helps to improve durability properties. Peschard et al. [29, 30] used chromatography and conductivity measurements to assess the hydration of cement. According to the test results, retardation rises with polysacradice value. Poinot et al. [31] asserts that there doesn't seem to be much of an effect on cement hydration kinetics from cellulose ether breakdown. Also, the early strength of the concrete was improved by polysaccharides [32, 33]. When cactus mucilage was used as a biopolymer in concrete, the rate of carbonization accelerated and served as an advantageous catalyst [34–36]. Sathya et al. [37] noted that this admixture was a retardant due to the lignocellulose in cactus, unsaturated fatty acids, and saturated fatty acids [38], which finally increased its strength. Super absorbent polymers [39] and plant extracts [40] were used to cure concrete internally, and improvements in concrete shrinkage were made [41]. In a study by Vaidevi et al. [42], the internal shrinkage and mechanical strength of M_{30} concrete were improved marginally by the addition of cactus extract by the weight of water. Only tests carried out 14, and 28 days after the cylinders where cast were included in the results; tests after longer curing durations were not conducted. When Woldemariam et al. [43] employed the extract to lessen the concrete's tendency to shrink, improvements in cracking and youthful shrinkage were seen. According to Wu et al. [44] and Wei et al. [45], graphene oxide is responsible for improving the physical characteristics of cement composite and decreasing cracks. The use of natural bio-admixtures to improve the qualities of lime mortar and brickwork was examined by Shanmugavel et al. [46]. The polysaccharide-rich extract Bilwa Extract (BEX), which was previously utilized in ancient mortars, was added to the lime mortar. The mechanical strength of modified mortars was examined, and masonry qualities such as shear of masonry wallets, bond, and compression were also investigated. The microstructure of the masonry mortar was revealed by using mineralogical investigation techniques such as bedding mortar morphology, TG-DSC, and XRD. The additive has improved the mechanical characteristics of masonry and demonstrated improved bond strength.

According to the literature, concrete quality was raised using a variety of polymer-based techniques. Success is contingent on the material's accessibility, simplicity of preparation, cost-effectiveness, and peak performance [47]. Natural additives are intriguing and difficult to use when trying to increase the mechanical and corrosion resistance of concrete specimens, as has been discussed previously. In the current study, cactus extract (*Euphorbia tortilis*) is employed as a natural addition in cement composite to improve durability qualities. As a result, there is no literature based on *Euphorbia tortilis* cactus concrete of M_{25} grade. Through a variety of intriguing experimental activities, such as rapid chloride penetration test, saturated water absorption test, sorptivity, porosity tests, drying shrinkage, accelerated carbon test, acid, and alkalinity test, the impact of *Euphorbia tortilis* extract on hardened cement concrete was investigated.

2 Materials and sample preparation

2.1 Cement

In this study, OPC 53 in compliance with IS: 4031-1988 (Reaffirmed 2011) [48] and IS: 12269-2013 [49] was used. According to the codal procedures, which are given in Table 1, the cement is tested.

2.2 Aggregates

This study used natural river sand from the nearby Cavery River as a fine aggregate, with a percentage passing through 4.75 mm and retained on a 600 mm sieve. Prior to testing, the sand is cleaned and screened locally in accordance with the procedure defined in IS: 2386-1963 to remove any potentially dangerous materials (Reaffirmed 2011) [50]. The selected mechanical characteristics are displayed in Table 1. The test results demonstrated that Zone III applies to the sand. While making ETC Concrete, coarse aggregate

Table 1 Physical properties of materials

Physical property	Cement	FA	CA	Cactus extract
Specific Gravity	3.15	2.67	2.75	-
Fineness (m^2/kg)	327	-	-	-
Fineness modulus (%)	2.31	3.72	7.41	-
Le-Chatelier expansion (mm)	3.5	-	-	-
Water absorption (%)	-	0.6	0.5	-
7- and 21-days compressive strength (MPa)	38.91 and 54.66	-	-	-
Consistency (%)	30.5	-	-	-
Setting time: initial and final (minutes)	34 & 600	-	-	-
Bulk density (kg/m^3)	-	1770	-	-
Fats (%)	-	-	-	0.10
Protein (%)	-	-	-	1.9
Polysaccharides (%)	-	-	-	5.2
Water (%)	-	-	-	92.85

(CA) that complies with IS: 383-1970 [51] specifications can be used (Reaffirmed 2002). Taking into account all of the aforementioned considerations, angular CA with a maximum size of 20 mm was selected for this study. Table 1 displays the outcomes of tests conducted on coarse aggregates using the methods outlined in IS 383-1970 (Reaffirmed 2011) and IS 2386-1963 (Reaffirmed 2011).

2.3 Euphorbia tortilis cactus (ETC)

Synthetic additions like setting retarders and plasticizers have become normal practice in mortar formulations in recent years, despite their possible negative environmental impacts. According to Ventolà et al. [53], organic additives have been used in lime-based mortars and concrete from the beginning of time to increase their working characteristics and durability. These methods are slowly being reintroduced and carefully explored in order to promote the usage of environmentally friendly products. Cactus extract from the *Euphorbia tortilis* is one of the many different plant-derived extracts used as cement composite additives that are well-liked in western Tamilnadu. The plant is easily collected and processed to make the organic addition and is widely distributed in warm climates, making it a perfect organic additive. From Pallakapalayam and the surrounding Komarapalayam area in the Namakkal district of Tamil Nadu (Fig. 1), a natural organic additive made from the ETC was extracted. The ET (*Euphorbia tortilis*) gel was taken from out of the cactus leaves [57]. 2.5 kg of plant stems were cut into small pieces, added

Fig. 1 Cactus in the western part of Tamilnadu

2 liters of distilled water, and boiled for 20 minutes until the color changed to green light and soft tissue. The pieces were separated from the extract by using a sieve with large pores, and then a ratio of 1:1 of cool ethanol 96% was added to the extract to precipitate mucilage, and the mucilage was separated by 1.16 mm sieve. (Sieve No:16).

Table 1 analyses and lists the extract's qualities. Polysaccharides behave as retardants, whilst proteins act as air-entraining agents [5]. At weight-based concentrations of 1%, 3%, 5%, 7%, and 9%, the water was replaced by cactus extract. A crude fat test was carried out on a dried gel in accordance with IS:7874-1975 (Reaffirmed 2014) [58] to determine the amount of fats, polysaccharides, and proteins, present in the ETC. Table 2 displays the results of calculating the number of polysaccharides using the protein and fat percentages. *Euphorbia tortilis* contains 1.9% proteins and 5.2% polysaccharides.

3 Experimental study

3.1 RCPT test

An FHWA research program is where the RCPT was developed. The aim of the program was to create methods for durability testing the concrete's in-place permeability to chloride. Even in cement composite with a high water/cement ratio, chloride migration through the concrete is a relatively sluggish process. Therefore, scientists chose a test strategy that would hasten this movement. When an electrical current was supplied to a concrete specimen, it was discovered that the rate at which the chlorides migrated into concrete increased and accelerated. Additionally, the researchers discovered that there was a strong association between the numbers obtained from a ponding test and the coulombs (the integral of current vs. time plot) that were measured and traveled through the sample. The test protocols that are currently codified in ASTM C1202 [59] and AASHTO T277 [60] were developed by researchers. These discoveries were the basis for these protocols.

Table 2 Mix design for ETC concrete

Grade	Mix ID	Water in kg/m^3	Cement in kg/m^3	F.A. in kg/m^3	C.A. in kg/m^3	ETC in kg/m^3	W/C ratio
M_{25}	Ref. conc.	197.16	442.9	572.88	971.43	-	0.45
	ETC1	195.26	442.9	572.88	971.43	1.9	0.45
	ETC2	191.46	442.9	572.88	971.43	5.7	0.45
	ETC3	187.36	442.9	572.88	971.43	9.8	0.45
	ETC4	183.46	442.9	572.88	971.43	13.7	0.45
	ETC5	179.46	442.9	572.88	971.43	17.7	0.45

A core or cylinder sample of the cement composites being examined with a diameter of 100 mm (4 inches) is taken as part of the test procedure. The sample is sliced into a 50 mm (2 inches) specimen. Epoxy is applied to one side of the cylindrical specimen, which is then placed in a vacuum chamber for three hours to dry. After being vacuum saturated for an hour, the specimen is left to soak for 18 hours. The acrylic cell test apparatus is then used to house it. A 3 percent NaCl solution is present in the test cell's left side (–ve). A 0.3N NaOH solution is placed on the test cell's right side (+ve). After connecting the system, 60V potential is applied for 6 hours. There are readings every 30 minutes. The sample is taken out of the cell after six hours, and the number of coulombs that traveled through the sample is computed. The ions moving through the concrete specimen's pores, particularly chloride ions, determine how much current is passing; this, in turn, determines how permeable the concrete is. Chloride ion permeation is measured by using Eq. (1). The following calculation is used to determine the total charge Q passed in six hours:

$$Q = 900x\left(I_0 + 2I_{30} + 2I_{60} + \ldots + I_{360}\right). \quad (1)$$

After the concrete has had time to cure, tests on durability are conducted (like 28 days and more). According to their protocols, the hardened concrete specimens are prepared in the necessary sizes for various durability tests.

3.2 Saturated water absorption and porosity test

A 150 mm cube specimen was subjected to an ASTM C642 saturated water absorption test after 28 days and 90 days of cure [61]. The amount of water that is absorbed by the pore volume or porosity of hardened concrete when it is saturated is referred to as saturated water absorption. The amount of water that can be extracted from a saturated specimen after drying is what is meant by this phrase. The porosity obtained from absorption testing is known as effective porosity.

3.3 Sorptivity test

According to ASTM C642 [61], a sorptivity test was conducted. The rate at which water percolates into the pores of cement composites under capillary pressure is measured as sorptivity. The crushed pieces of the tested samples were re-broken into small pieces and ground using a ball mill and a hammer. Following grinding, the powders underwent an ASTM C1202 [59] alkalinity test to determine their composition.

3.4 Drying shrinkage test

Prismatic specimens with dimensions of 285 mm × 25 mm × 25 mm are used to measure drying shrinkage. The ASTM C596-09e1 [62] code of practice is followed when conducting the test. After one day, the demolded shrinkage specimens are transferred to the environmental chamber (40 percent relative humidity), where the beginning lengths of the specimens are measured using a digital comparator with an accuracy of 0.001 mm. After a month, the specimen is taken out of the autoclave apparatus, and any length loss is measured and reported. In accordance with ASTM C1012 [63] , tests for acidity and alkalinity were also performed on the specimen.

3.5 Alkalinity and acid test

Liquids with a pH of less than 6.5 can damage concrete, however, the attack becomes serious only at a pH of 5.5. The attack will be quite serious if the pH falls below 4.5. All of the cement compounds finally break down during the attack and are leached away along with any carbonate aggregate. After being attacked by sulfuric acid, calcium sulphate can continue to react with calcium aluminate in cement to create calcium sulphoaluminate, which, upon crystallization, can cause concrete to expand and crack. Concrete will crack if acids are able to enter the concrete's pores or fissures and reach the reinforcing steel. Concrete cubes and cylinders are to be submerged in the following solutions: 5 percent HCl and 5 percent H_2SO_4 are combined and diluted in 1 liter of water. In order to maintain consistency, the pH of the solutions is frequently checked and modified. Based on the evaluation, the effectiveness of concrete is visual inspection, mass loss, and strength deterioration factor.

3.5.1 Visual observation

There are no set standards for measuring concrete's resistance to chemical acid. Table 3 displays the scale that was recommended for visual observation by Murthi and Sivakumar [25].

3.5.2 Mass loss

The specimens' initial weights are recorded. After 90 days in the acid, the specimens are removed, dried for one day, and their final weights are recorded. It is calculated how much mass changes.

3.5.3 Strength deterioration factor

A strength deterioration factor is calculated as the difference between the initial and changed compressive strength. The strength deterioration factor, which is derived using the equation and given as a percentage, is used to measure the deterioration of concrete cube specimens.

$$SDF(\%) = \frac{f_i - f_0}{f_i} \times 100 \quad (2)$$

f_i – Initial compressive strength
f_0 – Final compressive strength

4 Results and discussion

4.1 Scanning Electron Microscope (SEM) analysis

This examination provides a visual representation of the pore structure of concrete as well as the cohesion and adhesion between the particles. SEM pictures are used to capture information regarding particle sizes and mixture ratios. The strength of concrete will be increased by the stronger interfacial transition zone between the aggregate and hydrated cement paste. The internal structure or surface morphology of concrete is studied by using a SEM and displayed in the comparative microstructure photographs that are shown below from reference concrete (RC). The microstructure view of reference concrete particle distribution and sizes at a magnification of 10 µm is shown in Fig. 2(a).

Table 3 Deterioration level by Murthi and Sivakumar [25]

Deterioration level	Scale
No attack	0
Very slight attack	1
Slight attack	2
Moderate attack	3
Severe attack	4
Very severe attack	5
Partial disintegration	6

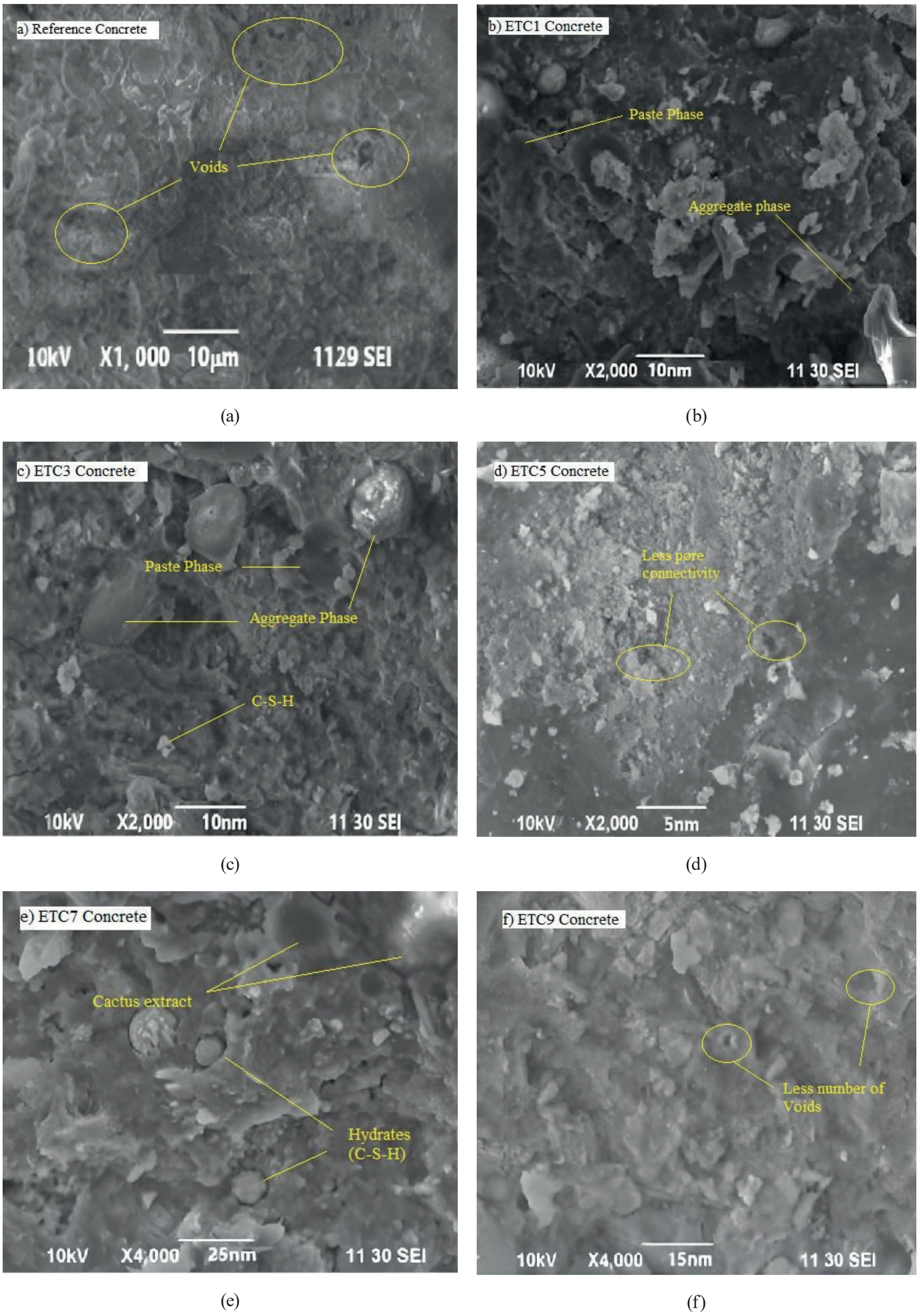


Fig. 2 SEM images (a) Reference concrete at 10 μm range, (b) ETC1 at 10 nm range, (c) ETC3 at 10 nm range, (d) ETC5 at 5 nm range, (e) ETC7 at 25 nm range, (f) ETC9 at 15 nm range

From Fig. 2(a), it is observed that the gap between paste phases and aggregate phases is more in conventional concrete. Because of CaO in the cement dissolved and $Ca(OH)_2$ leaching. Concrete subject chemical reaction and physical adhesion. Fig. 2(b) depicts the microstructure view of the ETC1 cement composite sizes and particle distribution at a magnification of 10 nm. From the figure, it is observed that the gap between paste phases and aggregate phases is less when compared to reference concrete. The pore connectivity system shows larger which does not resist the leaching of $Ca(OH)_2$. The pore structure in the concrete provides access for some ions like CO_2 and Cl- diffuse in the concrete mixture which changes the microstructural behavior of concrete. Fig. 2(c) depicts the 3% *Euphorbia tortilis* cactus moderated cement composite sizes and particle distribution in the range of 10 nm. In ETC3, the gap between the phases is a little less when compared to ETC1 and conventional concrete. The ingress chloride can produce solid phases at a larger size which precipitated in the pores. The variations between ETC1 and ETC3 are marginal. The microstructure view of 5% ETC cement composite sizes and particle distribution at a magnification of 5 nm is shown in Fig. 2(d). From Fig. 2(d), it is observed that the pore connectivity is slightly reduced in ETC5 concrete than in ETC3. The concrete lost some of its porosity and permeability.

The 7% ETC moderated cement composite sizes and particle distribution are represented in Fig. 2(e) at a scale of 25 nm. The denser microstructural view can see in Fig. 2(e) as compared to other concrete because ETC acts as better leaching resistance. The product is more fully hydrated. The microstructural view of 9% ETC concrete is shown in Fig. 2(f) in the range of 15 nm. These images depict the pore size has reduced significantly. ETC fills the area encircled by cement hydrates (C-S-H), which clog concrete pores and enhance concrete density. Permeability as well as the porosity of the concrete reduced and very tight to water movement. As a result of all the microstructural images, it is evident that ETC concrete has little voids and permeability when compared to conventional concrete, also it has a dense microstructure, because of amorphous and crystal elements in ETC such as high surface area, hematite, and magnetite, mullite, quartz, and low LOI. According to the SEM investigation, ETC is a pozzolanic substance that strengthens ITZ (Interfacial Transition Zone).

4.2 Mechanical strength of concrete

4.2.1 Compressive strength

The strength of the concrete is assessed using its compressive strength. With the use of a Universal Testing Machine, the test was carried out at curing periods of 7, 28, 56 and 90 days. In Fig. 3 and Table 4, the compressive strengths of RC and altered cement composite (1% to 9%) are displayed. According to the results, increasing the ETC dosage led to a drop in strength throughout the course of the 7-day cure period. With ETC dosage, modified concrete's strength is rising after 28, 56, and 90 days of curing. The most significant effect on the characteristics of cement composite is the addition of ETC. 90% of the ETC additive demonstrates the desired strength. ETC concrete's early strength reduction may be brought on by its low reactivity and sluggish pozzolanic reaction. The "pozzolanic effect," which claims that unfixed Polysaccharides in ETC can be activated by CaOH, a result of cement hydration, and produced more hydrated gel, is the main benefit of ETC.

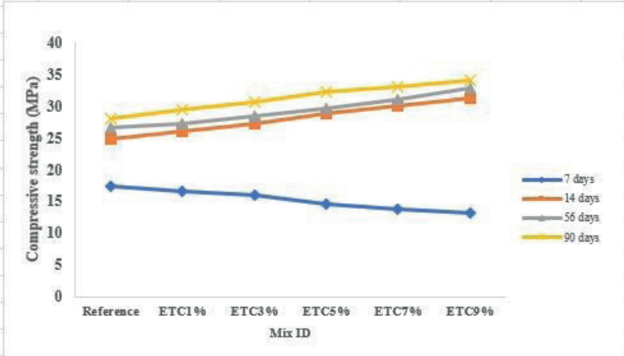


Fig. 3 Compressive strength of concrete with and without ETC

Concrete strength is substantially increased by the gel produced by pozzolanic activity since it can fill up the capillaries in the substance. In comparison to reference concrete, the strength of the concrete increased by 5.24%, 9.68%, 16.13%, 20.97%, and 25.8% after 28 days of curing by adding 1%, 3%, 5%, 7%, and 9% ETC. At 56 days, the strength rose by 2.45%, 6.38%, 10.86%, 16.4%, and 22.8% compared to the reference concrete. 4.6%, 9.25%, 14.95%, 17.8%, and 21.3% after 90 days of curing. With ETC dosage, modified concrete's strength is rising after 28, 56, and 90 days of curing. The most significant effect on the characteristics of concrete is the addition of ETC.

Table 4 Average compressive strength of Euphorbia tortilis cactus cement composites with standard deviation

Mix Index	Compressive Strength (N/mm^2)				Increase percentage of Compressive strength at 28 days	Crushing value at 28 days in N/mm^2 (X)	Average Strength (Y)	Deviation (X-Y)	Standard deviation $\mu = \frac{\sqrt{(\Sigma X - Y)2}}{\sqrt{N-1}}$
	7 days	28 days	56 days	90 days					
Reference	17.3	24.8	26.7	28.1	-	24.8	28.02	-3.22	0.0089
ETC1%	16.5	26.0	27.3	29.4	5.24	26.1	28.02	-1.92	
ETC3%	15.9	27.2	28.4	30.7	9.77	27.2	28.02	-0.82	
ETC5%	14.6	28.8	29.6	32.3	16.13	28.8	28.02	0.78	
ETC7%	13.7	30.0	31.1	33.1	20.97	30.0	28.02	1.98	
ETC9%	13.1	31.2	32.8	34.1	25.81	31.2	28.02	3.18	

90% of the ETC additive demonstrates the desired strength. ETC concrete's early strength reduction may be brought on by its low reactivity and sluggish pozzolanic reaction. Concrete strength is substantially increased by the gel produced by pozzolanic activity since it can fill up the capillaries in the substance. ETC combination of 9% extract has given higher compressive strength when compared with the reference mix, and also the strength has been gradually increased due to later age strength Shanmugavel et al. [54] and Chandra et al. [5].

Pattusamy et al. [28] said that the replacement of water with *Euphorbia tortilis* of 9% gives better compressive strength when compared with other mixers and control mixers of concrete. However, the increase in ETC replacement levels slows down the pozzolanic reaction and slightly reduces the compressive strength.

4.3 Durability on hardened M_{25} concrete

4.3.1 Saturated water absorption test

Saturated water absorption tests are performed on cube specimens measuring 150 mm × 150 mm × 150 mm at 28 day sand 90 days of curing time in accordance with ASTM C642 [61]. Prior to drying, the specimens' initial weight was recorded. The sample was dried by maintaining it in a hot air oven at 105°C. The drying process was continued until the mass alteration between 2 consecutive values recorded at 24-hour durations was almost similar. After being chilled to room temperature, dried specimens were submerged in water. The samples were taken out at set intervals. Before being weighed in a machine, the cement composite specimen's surface was dried using a clean towel.

The fraction of measured water-saturated mass divided by the oven-dried mass yields the water-saturated absorption value.

The weight difference was used to calculate the saturated water absorption values, and the results are shown in Fig. 4 and Table 5. A dosage of ETC percentage was found to improve water absorption. Fig. 4 shows that, when compared to reference concrete, the water absorption for the ETC9% mix has the lowest percentage at 73.1% and 76.8% at the end of 28 days and 90 days, respectively. It demonstrates that the depth of water penetration decreases as more ETC are added to the concrete. In comparison to the standard mix of ETC (1%, 3%, 5%, 7%), 9% ETC provides less depth of water absorption because they are meant to be able to fill in the gaps in the samples. When compared to control concrete, ETC concrete's water absorption was reduced because of its thick microstructure.

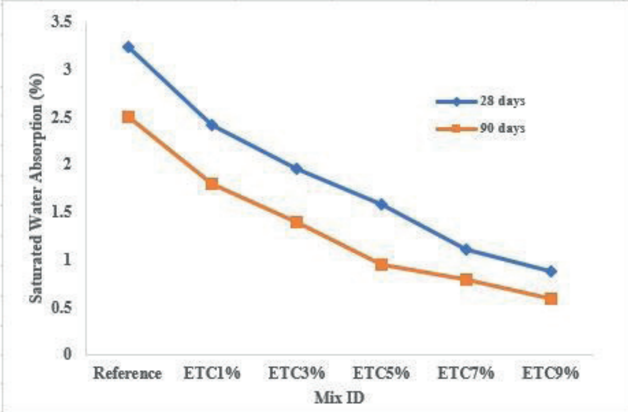


Fig. 4 Water absorption percentage of concrete

4.3.2 RCPT

Table 5 presents the outcomes of the RCPT tests for control and ETC concrete. The result shows that the minimum value observed at ETC9%. The amount of charges calculated for the ETC concrete 1%, 3%, 5%, 7%, and 9% was 1424, 1406, 1325, 1363, 1197, and 1050 for M_{25} grade. As per ASTM C1202 [59], the condition falls between 1,000 and 2,000, therefore it is apparent that the values under RCPT under normal curing, are subject to "Low" permeability conditions. Despite additions, the hardened specimen retains more moisture due to the presence of very minute holes in a negligibly low percentage of low heat of evolution. Another factor was the additional CSH gel in concrete, which made it dense and compact and

Table 5 Results of the durability test of hardened concrete

Mix index	Saturated water absorption (in %)		% of Porosity		pH	RCPT	Drying shrinkage
	28 days	90 days	28 days	90 days			
Reference	3.23	2.50	11.06	10.84	8.45	1424	2.5
ETC1%	2.41	1.80	10.11	9.67	9.0	4106	2.0
ETC3%	1.96	1.39	9.51	9.23	9.1	1325	1.0
ETC5%	1.58	0.95	8.16	8.01	10.4	1363	0.9
ETC7%	1.10	0.78	7.45	7.23	12.3	1197	0.9
ETC9%	0.87	0.58	7.01	6.89	13.1	1050	0.9

limited the amount of charge that could pass through it. Both Harbec et al. [55] and Liu et al. [56] highlighted the same reasons for the lowering of charge and the causes of low permeability. The ETC 9% mix contains 31.7% less porosity than the reference concrete mix.

4.3.3 Sorptivity test

By use of capillary action, the water passes through the concrete's crevices. Additionally, water absorption has an impact on the quality of concrete since, according to Hall's theory, water entering through pores could compromise the durability of concrete. Sorptivity analysis can be used to determine the rate of water penetration. According to ASTM C 1585-2013 [64], this test was conducted using various ETC concrete ratios ranging from 1% to 9%. Concrete cubes of 150 mm × 150 mm × 150 mm were exposed to ambient temperature after a 28-day cure process. The test specimens for the various cactus ratios (1%, 3%, 5%, 7%, and 9%) are constructed with lengths of 150 mm and diameters of 10 cm (4 inches). The sliced specimen is further rounded for an additional 1 cm on each side. The specimen is then divided into 4 further sections, each with a thickness of 3 cm. Furthermore, both sides of these little examples have been polished. The specimen's original weight was recorded. The average weight of the samples was recorded at 30, 60, 120, 180, 240, and 300 minutes after they were submerged in water. Fig. 5 and Fig. 6 illustrates the making process and the results that were attained. Fig. 7(a) provided an explanation of the reference concrete's absorption slope and square root time. It should be noted that the association between the square root of time and absorption was adequate. The outcome makes it clear that water absorption was significant in the steeper curve at the early stage.

The water absorption was significantly less over time in a gentle curve. When compared to the beginning stage, the weight was 4.96%, 4.2%, 4.4%, 1.64 %, 2.9%, and 3.1% higher for the reference mix, ETC 1, ETC 3, ETC 5, ETC 7, and ETC 9 mix, respectively. Because of this, it is clear that *Euphorbia tortilis* cactus cement composites have far less water absorption than traditional concrete, as well as a less porous, uniform, and dense microstructure.

4.3.4 Porosity test

After the water-saturated absorption test, the concrete specimen's porosity was immediately evaluated. This phrase describes the volume of water that can be extracted from a saturated specimen once it has dried. The porosity obtained from absorption testing is known as effective porosity.

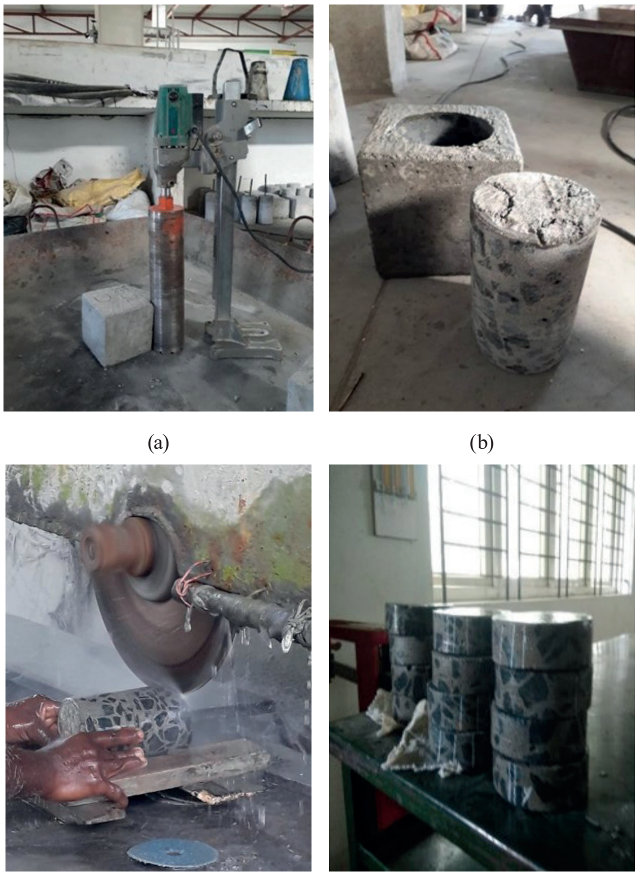
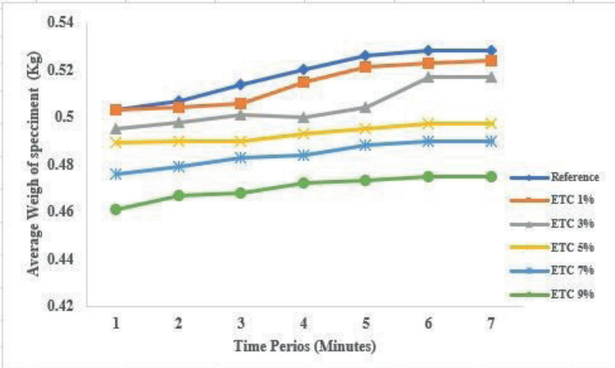


Fig. 5 Making of sample for sorptivity test (a) Drilling of concrete cubes, (b) Drilled concrete cubes, (c) Cutting of concrete cylinder, (d) Sample for sorptivity test

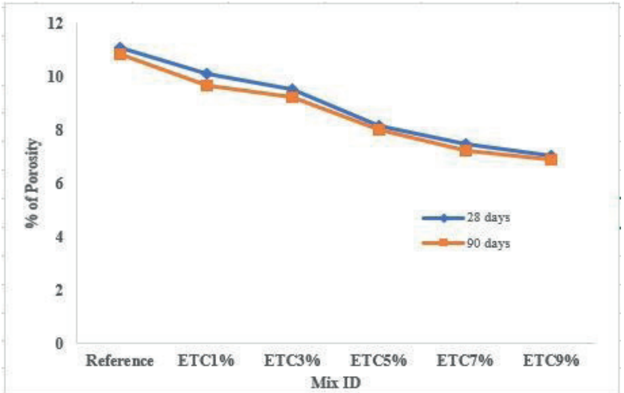
(a) (b)

Fig. 6 Test set-up for half-cell potential (a) Test setup, (b) Probability of corrosion measurement

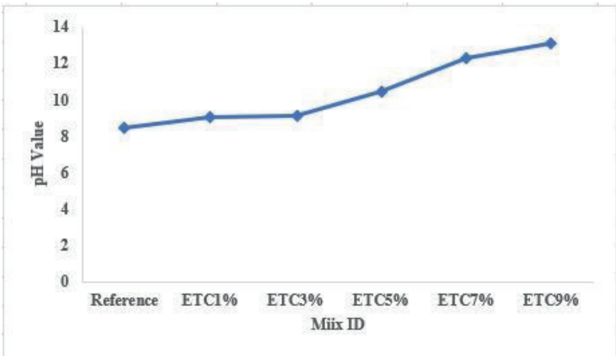
A calculation of the concrete's effective porosity is presented in Table 5 and Fig. 7(b). The obtained results demonstrate that as the ETC dose was increased, the concrete's porosity was reduced. Porosity and water absorption are directly proportional to one another. At the age of 28 days



(a)



(b)



(c)

(d)

Fig. 7 Various Durability Test results (a) Results of sorptivity test, (b) Porosity of concrete, (c) Alkalinity of concrete, (d) Acid test samples

after curing, the percentage of porosity was 10.11, 9.51, 8.16, 7.45, and 7.01 less than reference concrete even after adding ETC1%, ETC3%, ETC5%, ETC7%, and ETC9%. ETC concrete has a thick microstructure and reduced porosity than control concrete because of the impact of fats, and polysaccharides. In comparison to ordinary concrete, 9% ETC concrete had the lowest values at 28 and 90 days, respectively, of 5.9% and 4.72%.

4.3.5 Drying shrinkages

Table 5 shows that the specimens subjected to normal water curing exhibit very small differential shrinkage as compared to conventional concrete. It was found that 1 mm drying shrinkage at the optimum mix for M_{25} grade. In the end, drying shrinkage strain is shown to have a very small impact since it has no impact on the properties of concrete. The excellent internal bonding of the elements inside the mix, which inhibits the elongation of the element with regard to age, is the cause of the reduction in the overall effect of shrinkage.

4.3.6 Alkalinity measurements

The test samples from the CTM (Compressive Testing Machine) that broke into smaller pieces were collected, divided, and again ground in a ball mill. The powdered materials were diluted in a beaker with 100 ml of distilled water. The alkalinity level in an aqueous solution was tested with the use of a pH meter. Table 5 and Fig. 7(c) display various ETC mixed concrete's alkalinity values. ETC9% includes significantly more alkaline than regular concrete. According to Chandra et al. [5] proteins and lipids are constructed and organized by amino acids into a long chain and connected by peptide bonds (=$CONH_2$=). Shanmugavel et al. [46] state that polysaccharides (IR Spectra 1000 cm^{-1}) work highly in an alkaline environment. As er Pattusamy et al. [28] investigated fats and polysaccharides help to improve alkalinity in concrete. The high impact of the polysaccharides and fats present in the ETC may be the cause of the elevated alkalinity in the ETC concrete (M_{25}).

4.3.7 Acid attack

The average visual assessment of exposed M_{25} grade concrete to H_2SO_4 assault was 2, which indicates only slight damage. Similar to this, Table 6 finds that the average visual scale factor for M_{25} concrete treated with HCl is 1. Fig. 7(d) depicts the various samples of ETC concrete cubes after an acid attack. At 90 days old, M_{25} concrete significantly decreased weight compared to reference concrete

Table 6 Acid Test results

Mix index	Visual scale value		Weight loss (%)		Initial compressive strength at 90 days (N/mm^2)	Strength of concrete after the acid attack (N/mm^2)		Strength deterioration factor (in %)	
	H_2SO_4	HCl	H_2SO_4	HCl		H_2SO_4	HCl	H_2SO_4	HCl
Reference	3	3	5.765	5.711	28.1	25.1	24.9	10.68	11.39
ETC1%	2	2	4.102	4.010	29.4	26.2	26.1	10.88	11.22
ETC3%	2	2	3.866	3.512	30.7	27.4	27.3	10.75	11.07
ETC5%	1	1	3.215	3.105	32.3	28.9	28.8	10.53	10.83
ETC7%	1	1	2.709	2.852	33.1	30.3	29.7	8.46	10.27
ETC9%	1	1	2.114	2.464	34.1	31.1	30.7	8.80	9.97

at 10.88%, 10.75%, 10.53%, 8.46%, and 8.8% with H_2SO_4 solution and 11.22%, 11.07, 10.83%, 10.27%, and 9.97% with HCl solution. Additionally, concrete's strength is significantly decreased as a result of the acid reaction. For ETC concrete, the strength deterioration values (1% to 9%) fell between the ranges of 3 and 5%. Despite RC losing 6.11% and 6.60% of its weight in the same solution, H_2SO_4 and HCl assaults changed the weight by 2.438% and 2.895%, respectively. The observation demonstrates that the ordinary curing type of cement composites has surprisingly little harm.

4.3.8 Accelerated carbon test (ACT)

From Fig. 8, it is observed that the specimens under any type of curing possess a negligible carbonation value. The significance of the test is to evaluate the obtained value with the cover thickness of the concrete specimen (normally 25 mm) as per IS 456:2000 [65] code of practice. It is found that the carbonation value for all the specimens was 5% or less average for ETC9. Fig. 8 clearly shows the uncarbonated surface from the change of grey color to pink and slight carbonated surfaces are observed for the conventional concrete involving ETC than reference concrete. So, it proves that cactus-inferred concrete has less carbon content.

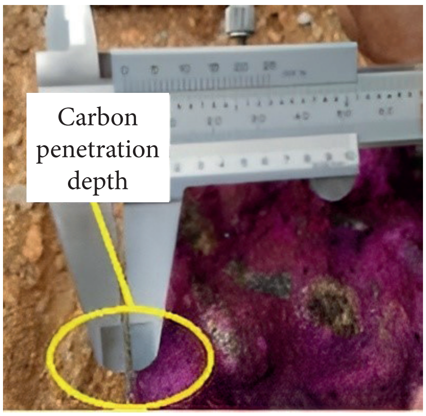


Fig. 8 Measurement of ACT Value for ETC9

5 Conclusions

In this investigation, tests were carried out to evaluate the effectiveness of a cement composite using a natural addition, namely *Euphorbia tortilis* (ETC), which was derived from a cactus. The following point summarizes the most significant findings of this research:

1. The ETC reduces the fluidity of the concrete because it contains polysaccharides that function as an additive to adjust viscosity. Additionally, increased uniformity Additionally, it changes the setting time of concrete and lowers the water demand for concrete.
2. As a result of all the microstructural images, it is evident that ETC concrete has little voids and permeability when compared to conventional concrete, also it has a dense microstructure, because of amorphous and crystal elements in ETC such as high surface area, hematite, and magnetite, mullite, quartz, and low LOI. According to the SEM investigation, ETC is a pozzolanic substance that strengthens ITZ (Interfacial Transition Zone). Also, the Perfect nature of the core matrix is well observed for ETC9 and the weaker part of the conventional concrete is shown in SEM images.
3. Alkalinity, Acid, RCPT, porosity, sorptivity, and saturated water absorption tests were used to assess the effects of durability on the behavior of modified cement composite with natural additives. Large-scale results in durability were seen in these analyses. Due to the presence of protein and lipids in ETC, the concrete has a lower sorptivity value, less volume of porosity, a lower percentage of water absorption, and is more alkaline than reference concrete.
4. Increasing the ETC percentage has an overall positive influence on the strength and durability of concrete. Specifically, pectin and polysaccharides increase mechanical strength whereas proteins and fats enhance durability properties. According to the test results, all the properties of the concrete are directly correlated to the ETC content.

5. Construction companies seeking alternatives to water curing and bonding by cement. Academic institutions, adopt the investigated results for their research and development. Government firms are those seeking to minimize and protection of water to meet demand in the future. Environmental organizations for the understanding of the interaction behavior of admixtures with the atmosphere. Natural additions are more affordable, user-friendly, and environmentally friendly than chemical additives. The use of natural additives would be the superior option for sustainability because modern society depends on eco-friendly systems.

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Declaration of interest

The authors have no conflicts of interest to declare.

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