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Effect of Crystalline Admixture on the Mechanical and Durability Properties of M40 Grade of Concrete

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ABSTRACT

Crystalline admixtures (CA), also known as permeability reducer admixtures, are used in binder-based materials to improve concrete durability by reducing water permeability depth, increasing compressive strength, and stimulating crack healing. The purpose of this study is to evaluate the potential of crystalline admixtures to enhance the self-healing characteristics and durability attributes of concrete and to contribute to the understanding of their role in the design of long-term efficiency and sustainability. The 28 days specimens of M40 grade concrete were prepared by adding CA and cast as 150 mm cubes, 25 × 25 × 285 mm prisms and disks with a diameter of 100 mm and height of 50 mm. All samples were then tested for compressive strength, water permeability, dry shrinkage, sodium sulfate attack test, Rapid Chloride Migration Test (RCMT), and rapid chloride penetration test (RCPT) to study the behavior of incorporating crystalline admixtures in concrete. The conclusion drawn from this study was that the addition of a crystalline admixture of 0.8% resulted in an increase in the compressive strength by 7.98% and a decrease in water penetration depth through the cube by 71.5%, while the dry shrinkage of the specimen incorporated with the crystalline admixture was 65.21% less than that of the specimen without the crystalline admixture. These results substantiate the beneficial role of CA in increasing

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the durability of concrete through increased strength, lower permeability, and better dimensional stability, thus making crystalline admixtures beneficial for incorporation into high-performance concrete applications.

Keywords: Crystalline Admixture; Self-Healing; Permeability; RCPT; Construction Chemicals

1. Introduction

Protecting buildings from subsurface moisture and water is a critical aspect of the building design. Crystalline admixture (CA) materials are often used to prevent the corrosion and deterioration of infrastructure foundations. The crystals fill the capillary pores and microcracks in the concrete and permanently seal it against water and waterborne contaminants. If new cracks develop, the presence of water causes the growth of additional crystals that seal the cracks, thereby providing a self-healing mechanism. These admixtures are VOC-free and environmentally friendly, offering long-term cost savings by reducing the need for repairs and replacements [1–5]. These materials can be applied through several methods, such as coating the surface, spraying, repairing, and casting with cementitious or waterproofing admixtures alone [4–7]. Building on these traditional waterproofing methods, the innovation of self-healing concrete is an excellent idea. This involves further modification of the concrete mix via the addition of specific compounds [8–11]. The chemicals are released to develop crystalline substances that seal the cracks and fill the voids, thereby repairing the integrity of the structure. Recently constructed buildings with waterproof concrete foundations require the use of a specialized waterproof admixture to ensure maximum protection against water damage [12–15]. These crystalline matrices used to protect buildings from subsurface moisture typically consist of cement blended with specially treated quartz sand and active chemical compounds [16,17]. Through the use of chemical admixtures, concrete improves in strength, durability, and impermeability when it is in its fresh state or when it is already hardened [18]. The effectiveness of the self-healing properties of early age concrete engineered using a crystalline admixture (4% by weight of cement) was investigated by measuring the permeability of cracked specimens and their crack widths. The strength is a measure of the ability of concrete to absorb compressive forces and other stresses. Durability, on the other hand, is related to concrete permeability. Treatment can reduce the penetration of chloride into concrete structures, slowing the process of water diffusion and capillary absorption [19,20].

According to a recent study by Naidenov [21], analysis to detect needle-shaped crystals developed in CA-treated concrete specimens. However, these crystals remained absent in the reference concrete samples. The RCPT tests confirmed these findings when they recorded lower electrical charge passage in CA-treated materials than in standard concrete. The measurements showed that the concrete treated with CA experienced better self-healing performance because the cracked specimens of the treated concrete allowed for decreased fluid passage. This research demonstrates how CA treatment enhances both the lifetime expectancy of concrete and its self-repair capabilities [21]. Some studies have also reported the influence of chemical admixtures on concrete shrinkage and cracking behavior. Studies have shown that free and restrained shrinkage increases with the addition of chemical admixtures (CA). Xypex, a CA with a mineral composition similar to that of cement, promotes early age cement hydration through accelerated hydration, which in turn leads to increased moisture loss and a significant increase in shrinkage. In addition, the study found that the age at which cracking occurs increases with higher amounts of CA added to the concrete mix. According to a previous study, progressive strength gains were obtained using CA dosage of 0%(X00), 0.5%(X05), 1.0%(X10), and1.5%(X15). The most pronounced effect on the earliest cracking age was observed for Mixture X15, which showed 79.14% earlier than that of Mixture X00. More precisely, the respective enhancements in the compressive strength values were 3.16%, 9.30%, and 13.29% for 0.5%, 1%, and 1.5% CA dosages, respectively at 28 days of curing compared to the control mixtures [22]. Further Sisomphon et al. [23] examined the self-healing capability of cement-based mortars that included calcium sulfoaluminate (CSA)-based expansive and crystalline additives (CA). Mortars with CSA/CA additives demonstrated a rapid decrease in water passing rates within the first five days of exposure. After 56 days, the specimens with additives achieved zero permeability under a 100 mm water head. Even under high pressure (2000 mm water head), mortars with additives exhibited significantly lower permeability than the control [23]. Similarly, in another study, the compressive strength of CA specimens was approximately 4.3% lower than that of the reference specimen after standard curing for one day. However, the compressive strength of the CA specimens was approximately 4.0% higher than that of the reference specimen after standard curing for 28 days, and the CA content of the cementitious materials was 1.2% [24]. The study of the new shrinkage-reducing agent N-SRA was tested against the conventional shrinkage-reducing agent C-SRA. The experimental data showed that N-SRA and C-SRA reduced the concrete shrinkage by 50% compared with the control mix. Compared with C-SRA, the new shrinkage-reducing agent N-SRA required only one-percent cement by weight while achieving equivalent results. According to the author, concrete mixtures with N-SRA showed better 28 days compressive strength than both C-SRA-incorporated mixtures and the reference concrete, while maintaining higher surface tension [25]. Further investigation is required on the utilization of crystalline admixtures within conventional concrete to boost durability by minimizing porosity and sealing cracks. The authors measured that the total pore area decreased from 6.461 m^2/g to 5.083 m^2/g during the one-month water immersion period. The admixture added to the concrete resulted in better self-healing abilities because it accelerated and optimized the process of crack repair [26].

Dao et al. [27] showed that permeability-reducing admixtures benefited chloride penetration resistance in concrete samples placed under conditions representing coastal regions. The measurement results indicated that the concrete mixture diffusion coefficients experienced a significant reduction during the test period. The measurement of diffusion coefficients at 365 days showed reductions ranging from 65-85% against the 28 days values, and 730 days values showed 3-40% more reductions than those at 365 days. The formation of hydration products led to reduced pore size structure in the concrete. A hydrophobic substance combined with pore-blocking properties yielded notably lower diffusion coefficients relative to both the control mixture and crystallization-based admixture [27]. An investigation of the dynamic characteristics of LC^3 composites showed improved self-healing responses during contact with seawater. Brucite and aragonite formation inside the cracks ensured that the durability improved, while aggressive chloride penetration was restricted. Research findings had demonstrated that crystalline admixtures create substantial improvements in the self-healing properties when added to OPC and LC^3 composites. The denser microstructure from the additional hydration processes stems from crystalline admixtures that encourage supplementary hydration actions and provide better chloride prevention. The results demonstrated that these admixtures created especially strong healing products under chloride-rich conditions. The test results revealed that lower chloride penetration levels existed within the LC^3 composites relative to regular OPC concrete materials, producing better chloride resistance [28]. Further investigation of the effect of CA and sustainable waste wood biochar (WWB) on the self-healing of cement pastes exposed to seawater (SWWD) and a 5% sodium sulfate solution (SWD). The results showed that after 28 days of wet/dry cycles using the SWWD solution, specimens containing 1 wt% CA (CCA group) healed up to 86.36% of the cracking surface area, whereas the CWB group referred to specimens containing 1 wt% CA and 5 wt% WWB, healed 82.01%. At 42 days, all samples containing CA (with or without WWB) healed completely, whereas only approximately 40% healing was observed in specimens without CA. The results showed that complete crack healing occurred in CA-based samples exposed to wet/dry cycles in both seawater and sulfate solutions [29]. According to Krelani et al. [30], the durability of concrete in severe environments, particularly in seismic areas, showed that concrete treated with crystalline admixtures exhibited remarkable self-healing properties. The authors assessed two concrete mix designs, CMD-01 (mass concrete) and CMD-02 (underwater concrete). Both the mixes achieved or exceeded the required strength. In addition, permeability tests demonstrated improved water penetration depth resistance, with results exceeding the standards defined by EN 12390-8 and EN 206, according to EC2 specifications [30]. In another study, the authors examined two types of ultra-high-performance fibre-reinforced cementitious composites (UHPFRCCs) together with the potential advantages of crystalline admixtures that activate autogenous healing functions. The high quantity of anhydrous particles and narrow multiple cracks in UHPFRCCs increase the effectiveness of autogenous healing [31]. Further, concrete impermeability can be improved using (CA) and waste glass powder (WGP). The individual effects of these materials are also investigated. The results showed that the WGP decreased concrete permeability. A high rate of substitution can significantly reduce the compressive strength. The compressive strength and permeability tests on WGP- and CA-modified recycled aggregate concrete (WRC) at a high rate of substitution showed that the WRC strength was reduced by approximately 23%, while increasing (CA) content from 0% to 2% yielded only 5% weakening. The permeability coefficient (K) of the WGP was substantially reduced to 5×10^{-13} and 1.5×10^{-13} ms^{-1}; however, the CA effect in long-term water absorption was not observed [32]. Similarly in another study, the addition of a crystalline admixture (CA) created more robust self-healing in mortar structures. A specific design approach allowed researchers to identify the optimal CA configurations in which triethanolamine (TEA) and glycine performed better than sodium citrate as a complexing substance. The optimal ratio for the mixture consisted of 1.0% Na_2SiO_3, 1.0% Na_2CO_3, 0.04% TEA, 1.0% glycine, 0.5% $Ca(COOH)_2$, and 1.0% nano-SiO_2. The coupling of TEA with glycine promoted rapid aluminate-phase hydration, which expanded the total hydration levels within the cement-based pastes. The modified paste containing CA exhibited higher levels of $CaCO_3$ along with C-S-H and ettringite but less $Ca(OH)_2$ when measured at 28 days. The presence of $Ca(OH)_2$ decreased the amount but produced larger crystals that effectively occupied the pore spaces. The mortar treated with CA demonstrated increased compressive strength and improved self-healing, together with better water imperviousness [33].

In this study, the effect of using a waterproofing crystalline admixture was evaluated to prevent concrete from being permeable and resistant to water penetration depth, chemical attack, and the negative effect of reinforcement corrosion. To carry out the investigation, different properties, such as compressive strength (at 7 and 28 days), water permeability, drying shrinkage, RCPT, sodium sulfate attack, and RCMT, were conducted after 28 days. This study investigated the impact of crystalline admixtures on the morphology and performance of healing products in concrete. The use of these admixtures results in dense rough scab formation, which produces better durability than without crystalline admixture-incorporated concrete. Chloride penetration levels have been measured in research in which crystalline admixtures create a stable chloride distribution near the surface to minimize destructive particles that harm concrete structures. The research demonstrates that concrete components with pre-applied admixtures show better recovery of compressive strength than intact specimens after damage occurs, which implies that the healing process strengthens concrete structures. The inclusion of crystalline admixtures in construction offers various benefits, based on this study. This study investigated how crystalline admixtures enable concrete to heal. Crystalline admixtures boost compressive strength while reducing dry shrinkage, while self-healing abilities become stronger because of their ability to minimize water penetration depth and help in cracked areas repair. The development of this technology is important for preserving concrete structures throughout their lifespan.

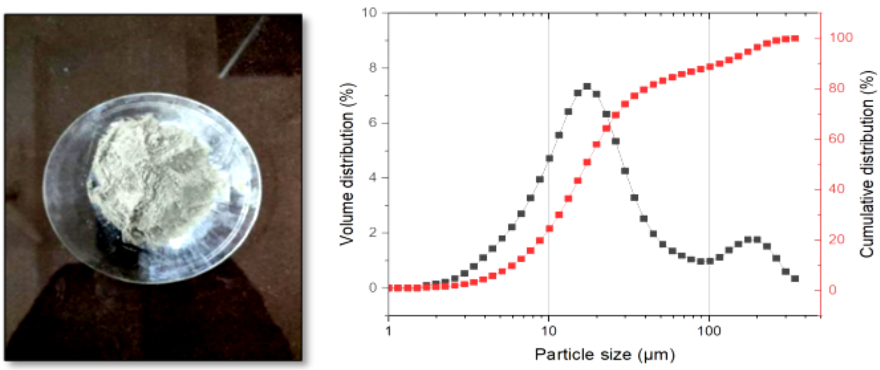
2. Materials and Methods

2.1. Materials

Controlled mix samples CC1, CC2, and CC3, which were prepared without using a crystalline admixture, were used as references. Samples CA1, CA2, and CA3 were prepared by adding 0.8% grey crystalline admixture powder (**Figure 1a**) to the control mix samples. Particle size analysis of CA shown in **Figure 1b**. After analyzing **Figure 1b**, the value of D10, D50, and D90 was 5.92 µm, 17.10 and 117.15 µm, respectively was observed. The most effective range for CA dosage is 0.6-1.0% of cement weight [34]. The water-to-cement ratio was 0.36. Superplasticizers enhance the workability characteristics of concrete, whereas crystal-based admixtures are known to enhance the self-healing capabilities and permeability of the resulting concrete mixture. UltraTech grade 43 Ordinary Portland Cement (OPC) (446.5 kg/m^3) was used for casting. The sand used in this study was Zone 2, collected from a local river. 640.8 kg/m^3 sand was used. The proportions of 10 mm and 20 mm coarse aggregates used were 4:6. A 0.8% superplasticizer was added to all the samples. As for the accumulated aggregates, the coarse aggregates provided 10 mm and 20 mm fractions, the weight of which was up to 1219 kg/m^3.

2.2. Methods

In this study, cubes, prisms, and discs of M40 grade concrete were cast under two different conditions: one without a crystalline admixture (control sample) and another with a crystalline admixture as shown in **Figure 2**. The study used a standard 28 days curing period that matches the concrete testing standards specified in IS 516 [35]. This period functions as the reference point for investigating the performance along with the early strength development of concrete to determine the initial phenomena. This study provides crucial information about the effect of a crystalline admixture (CA) on shrinkage behaviour, together with strength measurements during the construction period. Subsequently, the samples were compared based on the different studies performed. Six 150 mm cubes were cast to evaluate the compressive strength, as per IS:516. Another six cubes with a size of 150 mm were cast to evaluate the water permeability depth as per DIN 1048 (Part V) [18]. Six mortar prisms with dimensions of 25 mm × 25 mm × 285 mm were cast for the dry shrinkage test and Sulfate attack test as per IS 4031(Part10) [36] and ASTM C1012 [37] respectively, and six disks with a diameter of 100 mm and height of 50 mm were cast for the RCPT and RCMT, as per ASTM C 1202 [38] and NT Build 492 [39] respectively.



(a) **(b)**

Figure 1. (**a**) Crystalline admixture powder, and (**b**) particle size analysis of the CA.

Additionally, a computer vision-based method can be investigated to automatically measure cementitious sorptivity, which would make sorptivity testing more efficient. This technological advancement enables measurement of concrete absorption to generate information about durability and performance quality [40,41].

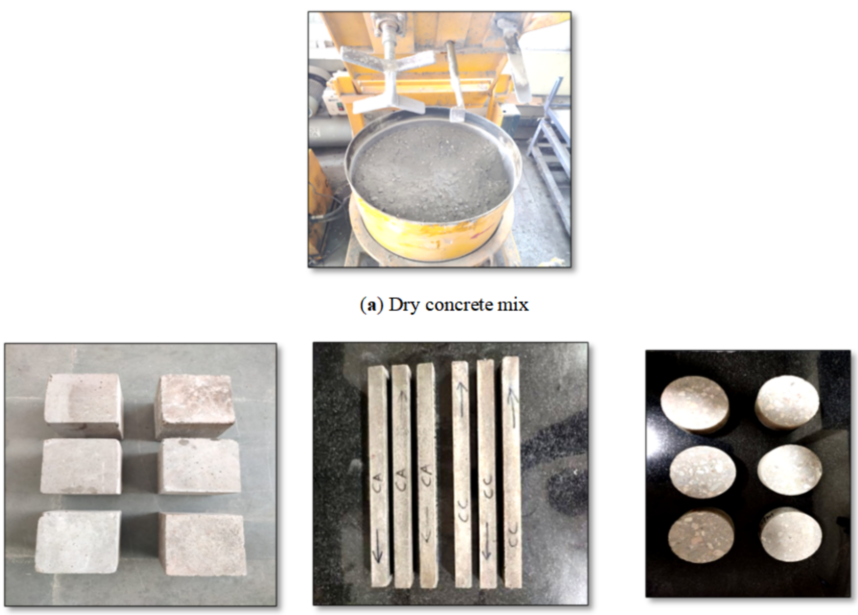


Figure 2. Pictorial presentation of the (**a**) M40 drying mix, and (**b-d**) casted samples: cubes, prisms and discs.

3. Results and discussion

3.1. Compressive strength

Six cubes with a size of 150 mm (CC1, CC2, CC3, CA1, CA2, and CA3) were cast, and the compressive strength of these cubes was calculated after curing for 7 and 28 days using universal testing machine (UTM, 100 T), as shown in **Figure 3**. The compressive strength values for the control samples CC1, CC2, and CC3 (without admixture) were found to be in the range of 46.5 MPa to 47.8 MPa and had an average of 47.3 MPa. The range of compressive strength values of samples (CA1, CA2, and CA3) with crystalline additive was 50.5 MPa to 51.9 MPa while the mean value was 51.11 MPa. The compressive strength data are shown in **Figure 4**.

Figure 3. Universal Testing Machine (UTM-100T, SHIMADZU).

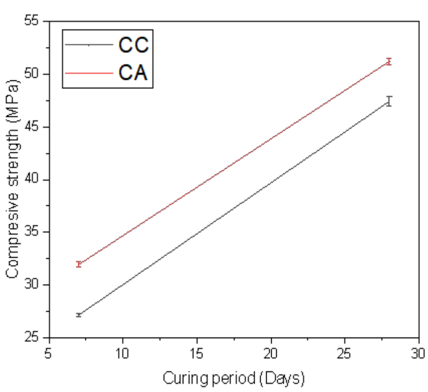


Figure 4. The result of compressive strength of the 150 mm cube specimens was tested after 7 and 28 days of water curing.

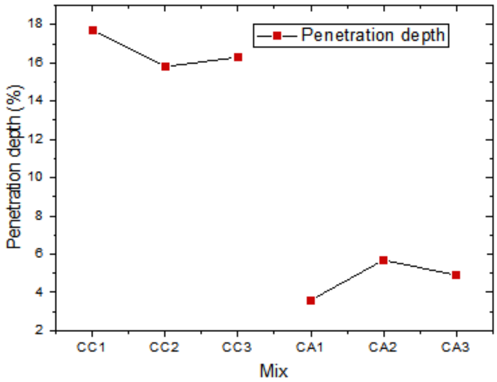
According to the concrete compressive strength data, the concrete with a crystalline admixture had an average compressive strength that was 7.98% higher than that of concrete without a crystalline admixture. This implies that the addition of a crystalline admixture to the batch increases its compressive strength. It was due to the fact that the hydrated crystals of crystalline waterproofing admixtures filled the pores of the concrete and thus, densified the microstructure of the hardened concrete by reducing the porosity.

3.2. Water permeability

Six cubes with a size of 150 mm (CC1, CC2, CC3, CA1, CA2, and CA3) were cast, and the water penetration depth was evaluated using a water permeability test apparatus as per DIN:1048 (Part V), as shown in **Figure 5(a–b)**. For the control samples CC1, CC2, and CC3 (with no admixture), the initial weight readings varied between 8.020 kg and 8.310 kg, whereas the final readings ranged from 8.030 kg to 8.317 kg. The water penetration depth varied between 15.8 to 17.7 mm. The overall average depth value was found to be 16.6 mm. The admixed samples, CA1, CA2, and CA3, showed initial readings ranging from 8.250 kg to 8.490 kg, whereas the final weight ranged from 8.253 kg to 8.492 kg. The water penetration depths varied from 3.6 mm to 5.7 mm and the overall average depth was found to be 4.73 mm.

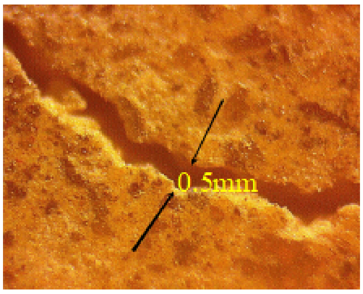
The water permeability study showed that specimens with a crystalline admixture had an average permeability depth of 4.73 mm, but specimens without a crystalline admixture had an average permeability depth of 16.6 mm, which shows that in the concrete mix with a crystalline admixture, the permeability was reduced by approximately 71.5%. The reduction in water penetration depth in crystalline admixture-added samples as compared to control samples is due to active chemical compounds present in crystalline admixtures, such as sodium silicate and calcium oxide, combining with cement paste water and calcium ions to produce dense calcium silicate hydrate crystals. The self-healing process of concrete specimens starts when admixtures cause crystals to precipitate inside the cracks, thus closing the gaps and restoring the structural integrity. The addition of CA resulted in improved crack closure, enhanced impermeability, and recovery of mechanical properties such as strength and durability after 90 days (**Figure 6(a–b)**).

(a)

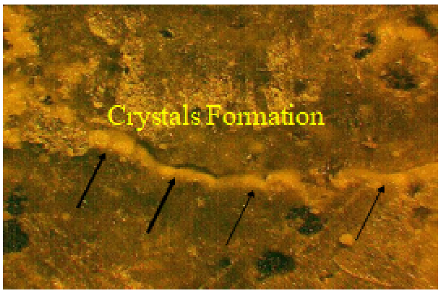


(b)

Figure 5. (**a**) Water penetration testing was performed using a water permeability test apparatus, and (**b**) Penetration depth values were calculated for the samples using a water permeability test apparatus after 28 days of curing.



(a)



(b)

Figure 6. (**a**–**b**) Before and after the self-healing process of concrete specimens filling the crack after 90 days.

3.3. RCPT

Six disks with diameters of 100 mm and heights of 50 mm (CC1, CC2, CC3, CA1, CA2, and CA3) were cast, and the total coulombs were calculated to evaluate chloride ion penetration using the apparatus shown in **Figure 7**. The mean of total coulombs moved in the control samples was 483.81 coulombs, which was higher than the mean for the crystalline admixture incorporated samples (301.02 coulombs). It was inferred that the samples with crystalline admixtures had higher resistance to chloride ion penetration. Using the ASTM C1202 classification chart, both series of samples were grouped under the "Very Low" category, ranging between (1000-100). This category applies to reinforced concrete structures in chloride environments (e.g., fluid saltwater and seawater). **Figure 8** shows the total number of coulombs that passed through all samples.

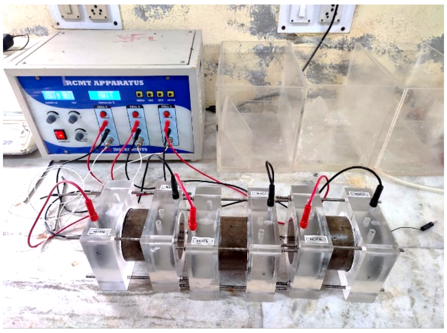


Figure 7. RCPT setup.

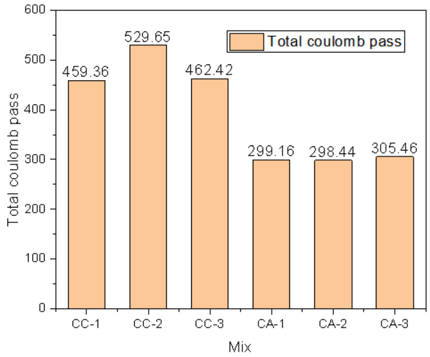


Figure 8. The total coulombs were measured to evaluate chloride ion penetration using the RCPT apparatus.

3.4. Drying Shrinkage

The drying shrinkage test is a method for ascertaining the volume of concrete, mortar, or other cementitious materials, which decreases when these materials lose moisture over time. It is intended to provide information on the potential cracking behavior of materials because of the restraint of material shrinkage during drying. Excessive drying shrinkage may cause problems such as cracking or weakening the durability of concrete structures. Six mortar prisms of size 25 mm × 25 mm × 285 mm were cast, and the dry shrinkage was measured using the apparatus shown in **Figure 9**. **Table 1** shows the dry shrinkage (%) of specimen with CA and without CA (Control specimen).

Table 1. Dry shrinkage % data.

Dry shrinkage (%)- Control specimen (CC)	Dry shrinkage (%)- Specimen with crystalline admixture (CA)
0.0092	0.0020
0.0100	0.0024
0.0084	0.0052
Std dev.-0.0008	**Std dev.**-0.001744
Average –0.0092	**Average – 0.0032**

Figure 9. Drying shrinkage test apparatus.

The data show that the drying shrinkage of samples without a crystalline admixture (CC1, CC2, and CC3) was 65.21% higher than that of specimens with a crystalline admixture (CA1, CA2, and CA3). This implies that the drying shrinkage was reduced when a crystalline admixture was added to the concrete mix with a 0.8% cement weight. The most effective range for CA dosage is 0.6-1.0% of the cement weight to minimize shrinkage. However, dosages above this value may generate adverse effects such as expansion. The addition of CA to cement hydration promotes the development of ettringite products that enhance concrete microstructure and inter-particle bonding. The addition of Crystalline admixtures (CA) to concrete triggers the formation of crystalline structures that fill voids and capillaries and decreases concrete porosity to minimize drying shrinkage [34]. A single specimen exhibited substantial data variations owing to the varying environmental and curing conditions observed in the experiment. Drying shrinkage rates increased with increasing temperature and decreasing moisture content in the environment. Variations in the curing process during the initial stage resulted in hydration variations. The analysis demonstrates how external conditions affect the test specimen results [42].

3.5. Sodium sulphate attack test

Six prisms of size 25 mm × 25 mm × 285 mm (CC1, CC2, CC3, CA1, CA2, and CA3) were cast, and the average length of these prisms was calculated after curing for (1,2,3,4,8,13,15) week as per ASTM C1012, as shown in **Figure 10**. The length change (%) values for the control samples CC1, CC2, and CC3 (without admixture), and the length change (%) values of the samples (CA1, CA2, and CA3) with crystalline additives are shown in **Table 2**.

Table 2. Results of sodium sulfate attack of the prepared mortar samples.

	Control Sample(CC)		Crystalline Admixed Sample(CA)	
Age (week)	**Avg. Length change (mm)**	**Length change (%)**	**Avg. Length change (mm)**	**Length change (%)**
1	2.676667	0.0028	3.044667	0.0016
2	2.678333	0.00347	3.049667	0.0036
3	2.683667	0.0056	3.053667	0.0052
4	2.691	0.00853	3.064	0.00933
8	2.754667	0.034	3.113667	0.0292
13	2.779333	0.04387	3.123	0.03293
15	2.788333	0.04747	3.137	0.03853

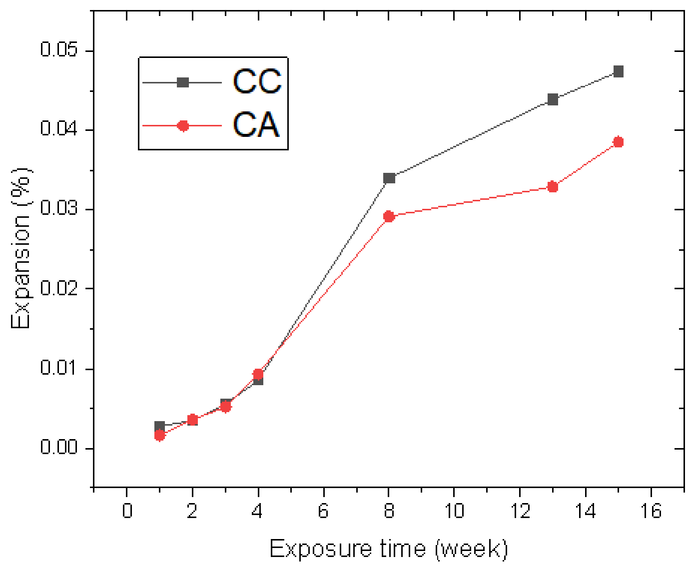


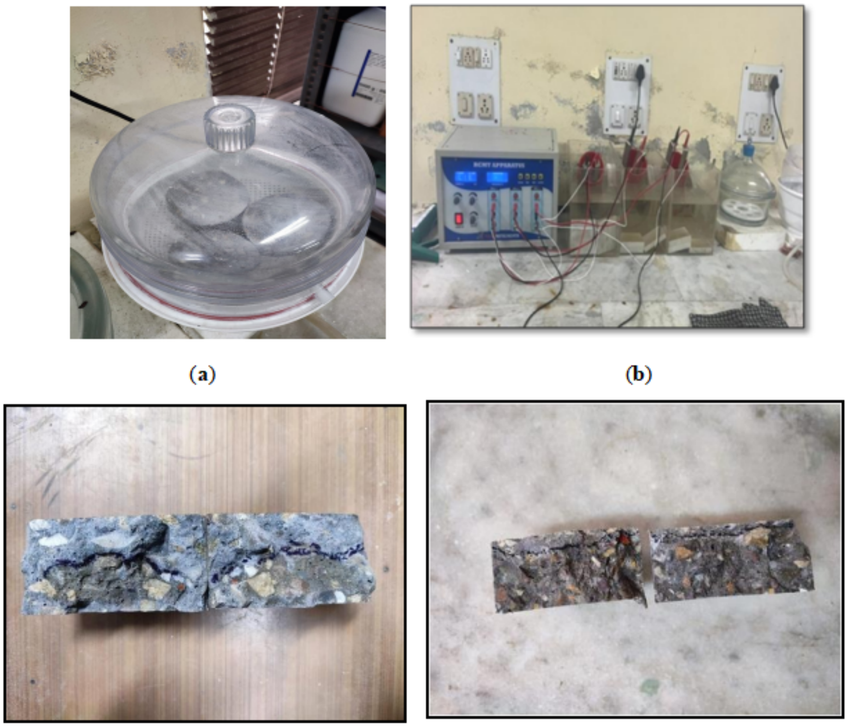
Figure 10. Expansion change (%) of CC and CA specimens during different exposure times in sulfate attack test.

Concrete with and without CA showed low expansion until 4-8 weeks thus indicating their resistance period. A significant improvement in sulfate resistance appeared at 13 weeks in the comparison between the control and CA groups, which showed an approximately 0.01% difference.

Hardened concrete without CA can cause Delayed Ettringite Formation (DEF) when ettringite produced during hydration decomposes before eventually reforming inside concrete products. Internal concrete damage occurs when this reformation process destroys the structure of concrete by forming cracks surrounding non-expanded aggregates, where ettringite redevelops. The observed difference demonstrates an important inability to minimize Delayed Ettringite Formation because this process continually reduces concrete integrity. However, concrete containing CA appeared to undergo modifications from crystalline admixtures, which suggests interference with ettringite formation, thereby lowering the expansion rate. Restricting ettringite crystal expansion through this process is an effective method to prevent destructive internal sulfate attacks that cause concrete deterioration. The CA mixture expansion curve displays decreased expansion owing to the improved pore structure, which enhances the formation of dense uniform crystalline structures throughout the concrete components.

3.6. Rapid Chloride Migration Test (RCMT)

In this method, the initial voltage was set to 60 V. The equipment demonstrated in this investigation is presented in **Figure 11** (a) and (b); the test lasted 18+ h. Subsequently, two halves of the specimen were split. Next, the chloride penetration front was observed by spraying the fracture surface with 0.1 normal silver nitrate solution. The chloride migration coefficient was reproduced by ensuring distinct colour contrasts, as shown in **Figure 11** (c) and (d). The mean penetration depth was largely dependent on the type of concrete; thus, the rate of chloride penetration was estimated using NT Build 492, as shown in **Table 3**.



(a) (b) (c) (d)

Figure 11. Sample preparation after 28 days of curing for RCMT Test (**a**) vacuum pump chamber. (**b**) RCMT Test setup. (**c**) shows the penetration of chloride ions in Control specimen (CC). (**d**) shows the penetration of chloride ions in Crystalline mixed concrete specimen (CA).

Table 3. Results of Rapid Chloride Migration Test (RCMT).

S.N.	CC		CA	
	Specimens	**Chloride Migration Coefficient (m^2/sec)**	**Specimens**	**Chloride Migration Coefficient (m^2/sec)**
1.	CC-1	3.78×10^{-12}	CA-1	1.03×10^{-12}
2.	CC-2	3.64×10^{-12}	CA-2	1.6×10^{-12}
3.	CC-3	4.78×10^{-12}	CA-3	1.4×10^{-12}
	Standard deviation (SD)	**0.621**		**0.289**
	Avg. of 3 specimens	**4.066×10^{-12}**	**Avg. of 3 specimens**	**1.34×10^{-12}**

4. Conclusions

Various Mechanical and Durability properties were studied for the concrete specimens with crystalline admixture and without crystalline admixture. On the basis of the above test results, the following conclusion can be drawn

1. The compressive strength of the concrete specimens using a 0.8% crystalline admixture was 7.98% higher than that of the control specimens.
2. The water permeability depth of the crystalline admixed concrete was reduced by approximately 71.5% compared to that of the control samples.
3. The drying shrinkage of the samples without a crystalline admixture (control sample) was 65.21% higher than that

of the samples with a crystalline admixture.

4. In the sodium sulfate attack mortar specimens of each admix concrete specimen, the length change was reduced over the entire testing period compared with the untreated specimens, which continued to expand until the end of the testing period. The admix-treated specimens were moderately resistant to sulfate attacks.
5. Chloride ion penetration can be reduced by incorporating CA into concrete.

Based on the test results, concrete with CA can be expressed as a reduction in harmful ion penetration. This can be inferred from the very high percentage (71.5%) decline in the water permeability depth of the crystal admixed concrete. It should be noted that lower water permeability depth mechanisms prevent chloride ions from entering the concrete matrix. Studies have shown that crystalline additives deliver substantial improvements in concrete structure durability, particularly when high water and chemical resistance are needed.

Laboratory examination of compressive strength and shrinkage effects uses both the 150 mm cube test and prism test as essential procedures. The cube test involves casting 150 mm concrete cubes that undergo proper curing before strength evaluations with compression testing. This study predicts the concrete load-bearing behavior that will occur in future construction applications. Testing cubes deliver critical information that engineers use to confirm that concrete structures and elements exceed the minimum strength thresholds. During the prism test, researchers evaluate concrete or mortar shrinkage effects using conditions that approximate real-world construction environments. Application design decisions that focus on safety and construction performance depend on the direct information from these studies.

The applications of these admixtures are prominent in tunnel systems with underground installations and moisture-retaining structures of dams and reservoirs. Marine locations benefit strongly from crystalline admixtures that protect structures, such as piers, jetties, and seawalls, and bridge foundations receive additional protection because they encounter both water and de-icing salts. Solutions that incorporate crystalline admixtures protect both basement walls and slabs from water intrusion and harmful ions when situated beneath the groundwater level, and industrial structures from chemical harm.

Research should concentrate on determining how crystalline admixtures affect concrete durability through extended testing under real-world environmental conditions. Comprehensive research must assess the performance of these admixtures throughout periods of extreme temperature changes combined with moisture exposure, solar radiation, and continuous chemical attacks. Studies must extend to investigate how structural performance due to seismic activity or large flexure affects treated concrete. Furthermore, there are synergies between crystalline admixtures and advanced materials, such as fiber-reinforced polymers (FRP) or nanomaterials.

Author Contribution

Conceptualization, Methodology, Writing–Original Draft, Editing, Validation: A.Y.; Conceptualization, Methodology, Writing- original draft, Writing – review & editing, Funding acquisition, Project administration, Supervision: R.K.; Methodology, Writing- original draft, Editing: A.Y.; Writing- original draft, Writing – review & editing, Validation, Methodology: N.S.N. Writing – review and editing, validation: A.P.

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Data Availability Statement

Data will be made available by the authors upon request.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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