

Capacity of Self-Sealing Concrete Embedding Crystalline Admixture

Genciana Ndoj, Armona Kastrati, Erisa Elezi, and Klodjan Xhexhi

Abstract — Concrete is one of the most intelligent and widely utilized man-made materials in the construction industry. Despite this, even high-quality concrete is susceptible to porosity, which reduces its serviceability period. Furthermore, there is an increasing need to increase longevity due to environmental exposure such as soil moisture, corrosive outside elements, or structural defects forming in the surface of concrete. The use of crystalline admixtures in concrete is one of the many approaches to reducing these risks. When crystalline admixtures come into contact with water, they form thin crystals that fill pores, capillaries, and micro fractures, as a result making concrete a self-sealing material. When the concrete has dried, the crystalline particles remain dormant until they come into contact with additional water, which causes them to crystallize once more.

This research aims to analyze and compare the material properties between commonly used concrete and concrete where crystalline waterproofing is present. Furthermore, experiments are conducted to evaluate each of the concrete samples: compressive strength, water permeability and flexure strength. As a result, demonstrating benefits or negative aspects in the use of crystalline admixture in the early stages of concrete is important. It is not yet defined, whether this is the future of cutting-edge concrete and the impact that it will have in the Albanian building market.

Keywords — Concrete, compressive strength, crystalline admixtures, waterproof, water permeability.

I. INTRODUCTION

Currently, the most common construction material used world-wide is concrete. This is because of many advantages of concrete, that include its excellent technical properties and market-competitive prices. Admixtures are sometimes added to concrete during the batching process to improve its qualities. They are ingredients other than water, aggregates, hydraulic cement, and fibers that are added to the concrete batch immediately before or during mixing [1]. Capillary crystalline system for over three decades have provided effective waterproofing and protection of concrete structures worldwide. There are many different types of admixtures available today, each of which has its own purpose in the concrete mix. Water infiltration through slabs and beams is a common concern because concrete is not an impervious material. Therefore in several concrete buildings, a type of waterproofing admixture has been implemented in them to reduce these complications [1]. This paper discusses the most

typical issues that arise when concrete constructions come into contact with water and are exposed to various environmental conditions. In addition to, this study covers how to treat and prevent these problems by using a capillary-crystalline waterproofing system to boost concrete durability while also ensuring effective protection of concrete structures. Concrete becomes permanently sealed against the infiltration of water or other liquids from any direction, as well as protected from damage due to harsh climatic conditions, thanks to integral waterproofing. This solution has been particularly developed to work with a wide range of projects and temperatures. During the time of which this component is mixed with concrete, the crystalline elements trigger a chemical reaction that results in the formation of long, narrow crystals to form and fill the capillaries, pores and hairline fractures of the concrete mass. As long as there is moisture in the concrete, crystals will continue to grow. Once the concrete has hardened and dried, the crystalline compounds will remain inactive until water is introduced again (for example through a new crack). This will cause the chemicals to react, resulting in the production of crystals to restrict the flow of water. Reservoirs, sewage, subway and other tube systems, underground vaults, foundations, and swimming pools are all common uses for the material in query. Some famous projects where it has been used include the Statue of Liberty and the Singapore Changi Airport Terminal [1].

II. PROBLEMS RELATED TO CONCRETE WATERPROOFING

Concrete has a relatively good resistance to water and its structural elements have the ability to easily take different shapes and sizes. Concrete and even high-quality concrete is a porous material despite its durability. During the hydration phase, water evaporates, leaving millions of openings and capillaries in the concrete. In the surface transmission areas (existing between the cement hydrated and large aggregate particles) a part of the concrete microstructure that permeates this area, is prone to cracking during the concrete hardening phase, due to shrinkage, temperature rise and the application of external forces. Pores and microfractures increase the overall porosity of the concrete matrix, allowing so air and water to enter the hardened concrete (particularly if they are interlinked throughout concrete) [2]. Water-borne salts and chemicals will cause corrosion of the steel reinforcement and

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other damage to the concrete, further contributing to the deterioration and weakening of concrete strength and directly reducing its longevity. Water (sea water, groundwater, river water, lake water, snow, ice, and steam) is a crucial factor in both the development and destruction of concrete, and it plays a role in practically every type of concrete degradation. Permeability and the presence of water are implicated in the mechanisms of expansion and cracking in Steel reinforcement corrosion, freeze-thaw cycles, alkali-silicon interaction, and chemical activity. The issue of concrete porosity and cracking is becoming more prevalent in structures that are continually subjected to varying loads, pressure redistribution, and seismic tectonic effects. The primary causes of concrete deterioration are discussed in the next section.

III. CORROSION

Steel reinforcement corrosion is one of the most typical causes of concrete issues, particularly in concrete located close or below water. Steel electrochemical reaction that involves the conversion of ferrous metal into rust, which is followed by an increased volume (sometimes depending on the oxidation state, it can go up to 600% of the original steel). [2] This reinforcement expansion leads to expansion and cracking of the concrete accompanied by cracking and eventually a loss complete protective layer of concrete. The end result will be a reduction in the strength of the structure until it is destroyed. Corrosion will occur when two distinct metals (like steel and aluminum) are present in concrete since each metal has a different electrochemical potential that essentially transforms them into a battery. Metal corrosion is less rapid when metals come into contact with an electrolyte. When just one type of steel is present in concrete, then corrosion is caused by the imbalance in the concentration of dissolved ions, of such as alkalis and chlorides. Water entry into the pores and microcracks introduces the ions into the concrete.

Corrosion stages:

- a) Reinforcement embedded in concrete. Chloride and alkaline ions enter through water into cracks and pores meeting the steel reinforcement.
- b) Chlorides reduce the alkalinity of concrete (by lowering the pH level) and destroy the protective layer of the reinforcement. This leads to expansion of the reinforcement, thus cracking it.
- c) The progressivity of corrosion leads to cracks and fissures by increasing the permeability of concrete by reducing its resistance and eventually to the destruction of the structure.
- d) Example of corrosion damage: Hydrated Portland cement includes alkaline components in the pore fluid as well as a sufficient quantity of calcium hydroxide, thus maintaining the alkalinity level over pH12. In an alkaline environment (pH more than 11.5), regular steel and iron produce a thin layer that is compacted and firmly bonded after the layer of iron oxide making the metals more corrosion resistant. However, carbon content or salts in alkalis and especially calcium hydroxide cause the pH of the concrete surrounding the reinforcement to fall under 11.5, disrupting the passivity of the steel and enabling the oxidation reaction

to begin. Even at pH values greater than 11.5, the passive layer is destroyed in the existence of chloride ions. The primary causes of the presence of chlorides in concrete are additional elements such as residual salts in aggregates or seawater.

IV. CARBONATION

Carbonation occurs when carbon dioxide from the air penetrates the concrete and reacts with hydroxides, such as calcium hydroxide to form carbonates.[3] Calcium carbonate is formed in reaction with calcium hydroxide. This reaction reduces the pH in the solution. less than 8.5, where the passive layer of iron oxide in the reinforcing reinforcement will not be stable and will allow corrosion. Carbonatization is highly dependent on the relative humidity of the concrete. The greatest possibility of creating carbonation is when the relative humidity has values between 50% to 75%. For relative humidity below 25% the degree of carbonation is considered negligible. For relative humidity greater than 75%, the pore moisture prevents the passage of CO₂. Corrosion-induced carbonation often occurs in areas of construction facades that are exposed to rainfall., in the shade of sunlight, and having a thin concrete protective layer over the steel reinforcement. Carbonation of concrete also reduces the amount of chloride ions needed to promote corrosion. In new concretes with a pH value of 12 to 13, to start corrosion of steel about (7000-8000) ppm of chloride is needed. If the pH is reduced to a range of 10 to 11, the number of chlorides for corrosion decreases significantly to 100 ppm or below 100 ppm. Like chloride ions, carbonation destroys the passive layer of the reinforcement but does not affect the degree of corrosion.

V. CRACKS

Cracks, in general, enhance the porosity of concrete, allowing water, waterborne salts, and chemicals to enter and hasten the breakdown of the material. Concrete cracks can be caused by a variety of factors.

1) Plastic cracks as a result of shrinking

Plastic cracks form as a result of a fast water loss from the concrete surface before it hardens. It happens when the moisture evaporates faster running water can replace it. Plastic cracks due to shrinkage are typically small and do not extend beyond the slab's edge. Yet, as with any fracture they create the possibility of an entry point for water and chemicals and subsequently initiating the process of degradation.

2) Shrinkage Due to Drying

Like almost every concrete mixture usually has a higher level of water than is required to hydrate the cement, a large portion of this residual water evaporates, creating shrinkage in the concrete. Shrinkage Limits given by the foundation, reinforcement, or any other component of the structure lead the hardened concrete to form elastic cracks. The most prevalent cause of concrete fractures is shrinkage due to drying.

3) Thermal cracks

Thermal cracks occur when there is an excessive temperature difference inside or around the concrete structure. The cold section of the concrete contracts more than the warm part due to the temperature differential. This reduces shrinking and this limitation causes elastic stresses which exceed the elastic resistance of the cast concrete, resulting in the formation of thermal fractures. Thermal fractures can form because of changes in ambient (air) temperature in specific places. High temperatures during the day lead to concrete heating up and swelling. The air temperature decreases dramatically over the night, causing the concrete to shrink. This can result in concrete fractures. These fractures become larger over time as a result of the concrete expanding and shrinking in the presence of temperature changes.

4) D-shaped cracks

D-cracks are a form of damage from the freeze-thaw cycle and are often observed in pavement concretes. Accumulation of water at the concrete base saturates the aggregate. cracks appear and later cracks open the concrete. This process normally begins at the bottom of the slab and works its way up to the surface.

VI. EXPERIMENT

The experiment was conducted on “Eko Geolab & Chimica” sh.p.k. laboratory, located in Tirana, Albania.

A. Main Features of the Admixture

- Waterproofing of concrete structures subjected to positive or negative thrust in the mass.
- Protects concrete and reinforcing rods permanently.
- Permeable to vapor.
- Reduces surface micro-cracks.
- Resists mechanical damage.
- Resists chemicals and freeze / thaw cycles,
- Improves the durability of concrete.
- Seals by waterproofing cracks up to 0.4 mm thick.

B. Technical Features

- Consistency: gray powder
- Bulk density: 1.20 kg / l
- Specific weight of the mixed product: 1.65 kg / l
- Waterproofing of concrete:> 10 atm in negative and positive pressure (100 m of water column)
- Complete hardening: 28 days
- Dosage between 1 and 1.5% of the weight of cement.

C. Assessment of the Depth of Penetration of Pressurized Water into Concrete

The test procedure was carried out on a sample of concrete class C 32/40 in accordance with the requirements of the UNI EN 12390-8 with a pressure of 500 KPa for 72 hours.

The graphic below shows that water penetrates 50 mm into concrete without additives, in a total dimension of 150 mm, which means that it has penetrated almost 33% of the sample. However, in the other sample with the additive it barely reaches 3%. If we would compare them with each-another not considering the sample, it adds up 90% difference. So, 90%

of what would penetrate normal concrete now because of the additive it does not.

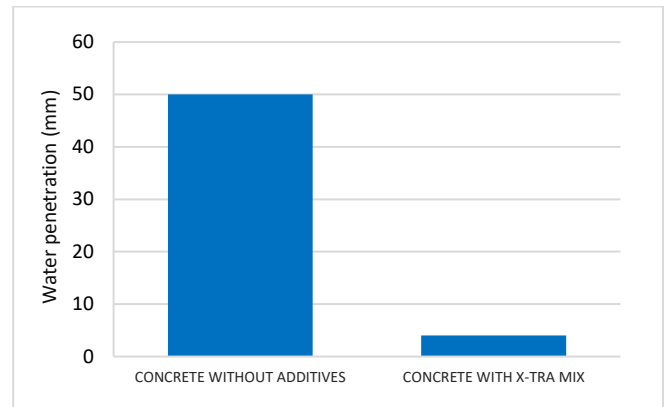


Fig. 1. Penetration of Pressurized water into concrete.

D. Compressive Strength

For the compressive strength test, cubic specimens with dimensions of 150×150×150 mm and aged for 28 days as per UNI EN 12390-3 regulation, were used in the laboratory.

The results on the graphic below refer to tests performed on concrete (class C32/40) of reference (control mixture) and on the effect that the addition of the additive X-tra Mix produces on it (mixture of test) based on the provisions of the UNI EN 934-2 standard. It shows that compressive strength level on the sample without the additive it goes up to 35-37 N/mm², and in the sample with the additive it goes up to 45-47 N/mm². In other terms the additive raised the compressive strength by 22-23%.

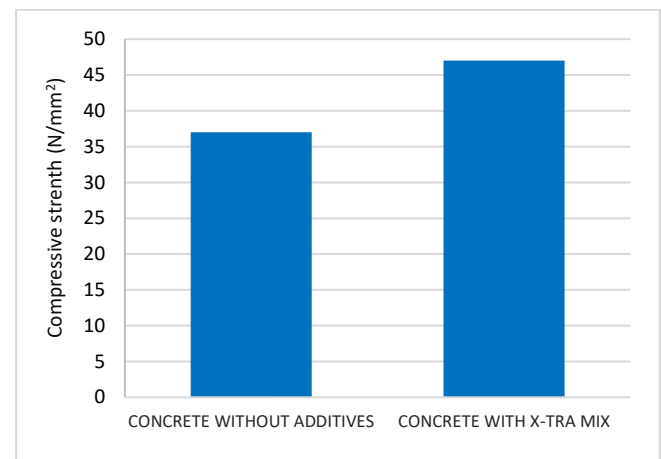


Fig. 2. Compressive Strength.

E. Flexural Strength

The concrete cubic specimens (class C 32/40) were subjected to a bending test by means of a load applied in mid-air and aged for 28 days as required by UNI EN 12390-5.

The results presented below refer to the tests performed on a reference concrete (class C 32/40) (control mixture) and on the effect that produces the addition of the X-tra Mix additive on it (test mix). The sample without the additive reaches up to 4,5-5 N/mm², when the sample with the additive reaches up to 5,8-6 N/mm². Consisting of the additive raising the flexural by 17-25%.

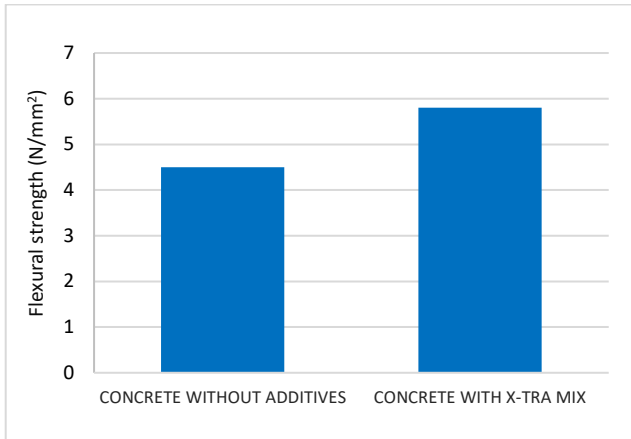


Fig. 3. Flexural Strength.

F. Moisture Levels on Actual Concrete Buildings

The tables below refer to Moisture Levels on buildings built in the same area around 10 years ago. One of the buildings was built without the additive but with Hydromat paint and the other with Admixture. The measurements were taken with a device called Moisture Meter inside the basements on underground level.



Fig. 4. Measure meter on concrete wall with Admixture.



Fig. 5. Measure meter on concrete wall without Admixture.

TABLE I: CONCRETE WITH ADMIXTURE

Distance Measured	1	2	3	4	5
H=0.5 m	10%	11%	11%	9%	13%
H=1 m	7%	9%	11%	10%	10%

TABLE II: CONCRETE WITHOUT ADMIXTURE

Distance Measured	1	2	3	4	5
H=0.5 m	15%	15%	14%	11%	12%
H=1 m	13%	11%	11%	11%	10%

The photos below show the difference between the buildings that the measurements were taken.



Fig. 6. Visible Moisture on concrete wall without Admixture.



Fig. 7. No visible Moisture on concrete wall with Admixture.

VII. CONCLUSION AND RECOMMENDATIONS

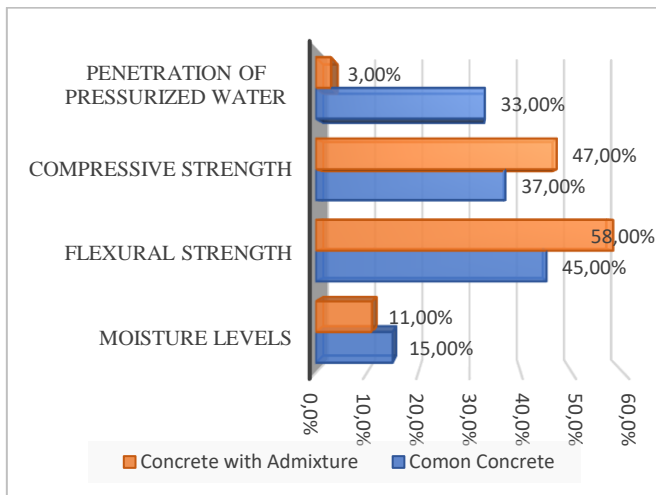


Fig. 8. Conclusion Charter.

The research shows that Admixture:

- 1) Is beneficial in terms of strength gain. Compressive strength goes up by 22-23% and Flexural strength goes up by 17-25%. Higher dosage is even more beneficial; however, the price rate will increase as well.
- 2) The initial and final setting time of the mix will increase which brings an increase of workability. It will be very beneficial when delivering in distant construction sites or if any delays happen.
- 3) Increases compactness factor.
- 4) Significantly decreases permeability by 90%.
- 5) Also, an important factor to be noted is that it does not impact the density.

APPENDIX

A. Alkali-silicon Reaction (ASR)

Alkali-silicon reaction is one of the most common forms of alkali-aggregate reactions (AAR) and can cause serious expansion and cracking in concrete leading to major structural problems sometimes up to its collapse [2]. The alkali-silicon reaction is caused by an action between hydroxide ions in the pores of alkaline cement and reactive forms of silicon in the aggregate (such as opal, quartz crystals). A gel is produced which increases the volume by absorbing water and thus exerts an expanding pressure causing the destruction of concrete. This gel can be created through cracks but also inside the aggregate particles. For the alkali-silicon reaction to occur, it needs a high alkaline content from cement, a reactive aggregate and most importantly water. If there is no water present in the concrete, the alkali-silicon reaction does not occur as the gel requires water. The best way to avoid the alkali-silicon reaction is to use non-reactive aggregates, which is not always possible. In this case it is necessary to be aware of the percentage of Na_2O equivalent in all concrete components [2].

B. Damage due to Freezing-thawing Cycles

Damage caused by freeze-thaw cycles to concrete pavements, retaining walls, bridge floors, and railings is the primary reason for repairs and maintenance in cold areas.

Because water molecules are so small, they may enter even the smallest capillaries and holes in concrete. When water enters the capillary system and freezes, it causes an expansion in volume as well as an expansion and spread in the pores and cavities by applying hydraulic pressure. This pressure will gradually increase the pores and capillaries over multiple cycles. When the water in the pore's melts, it travels further into the concrete, where the process of freezing and melting repeats itself. The majority of the damage produced by these cycles is cracking and breaking of concrete owing to the continued expansion of cement mortar. In the presence of water or road salt for maintenance purposes, the effect of freeze-thaw rises considerably. Because of chlorides and water permeability, cracks in the concrete will ultimately expose the steel reinforcement to corrosion.

Because of its self-healing characteristics, the Admixture will assist prevent the infiltration of water, chemicals, and other corrosive substances via fractures that emerge later in the structure's life.

Corrosion protection of steel reinforcement is achieved by the Admixture filling concrete capillaries, pores, and microcracks with insoluble crystalline forms, preventing water and corrosive chemicals from entering the concrete structure. A test performed in the renowned ENCO laboratory (in Italy 2006) clearly showed a reduction of water permeability in concrete treated with Admixture compared to normal concrete [5].

REFERENCES

- [1] Cadessa AS, Zephir D. Effect of Pentron Admix on the Properties of Concrete. *Ajol.info*, 2014 July 2.
- [2] Diendanxaydung.vn.
- [3] Continuingeducation.bnppmedia.com.
- [4] Sherwin -Williams, available on <https://www.sherwin-williams.com/architects-specifiers-designers/products/resources/SW-ARTICLE-PRO-EFFLORESCENCE>.
- [5] Penetron.com, Products, available on <https://www.penetron.com/products/PENETRON-ADMIX-SB/data-sheet.pdf>.