The International Journal of Engineering and Information Technology

journal homepage:www.ijeit.misuratau.edu.ly

Effect of Organic Corrosion Inhibitor on Mechanical and Transport Properties of concrete

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Abstract—**In this paper, the effect of organic corrosion inhibitors on Mechanical and Transport Properties of concrete was studied. Two types of organic inhibitors, one is added to the concrete mix (sika Ferrogard®-901), and another one applied on the concrete surface (sika Ferrogard®-903. The properties of the fresh concrete (workability and air content) and of the hardened concrete (compressive strength, Porosity, and water absorption) were evaluated. The transport properties (permeability, capillary absorption, and diffusion) were also evaluated. From the results, it was found that the effect of the organic inhibitor (Ferrogard®-901) was clear on the properties of fresh concrete. so that Workability increased with the addition of organic corrosion inhibitors. The effect of (OCI) on the compressive strength at all ages was not significant. The effect of organic inhibitors on the porosity of concrete was also not significant, although the porosity of the samples with Ferrogard®-901 was lower. As for the permeability test, both samples containing (sika Ferrogard®-901) and (sika Ferrogard®-903) outperformed the control sample. In addition to the clear effect of (sika Ferrogard®-901) in reducing the permeability. Both organic inhibitors affected the diffusion and capillary absorption of concrete.**

Index Terms: **Organic Corrosion Inhibitor, Mechanical Properties, Transport properties, Sustainable technology.**

I. INTRODUCTION

Reinforcement corrosion due to chloride attack on structural member increase the cost of construction and later maintenance and eventually the less of the service life of the structure. The technological development of additive material makes it possible to reduce or eliminate the effect of such attacks. The most important materials used to protect from chloride attack are Corrosion Inhibitor Materials (CIM).

Concrete deterioration due to Moisture migration into concrete elements. Mechanisms of water transport through concrete by capillary absorption and permeability. Concrete structures should be designed to resist the impacts of these two common water transportation mechanisms. Controlling the durability requirements of concrete is important to provide the required service life for building exposed to a marine environment. Permeability is the movement of water into concrete under pressure such as dams and submerged bridges. Concrete immersed in water is subjected to pressure, this pressure causes water to enter in concrete through the capillary pores.

The effect of each of the inhibitors mixed into and applied on the surface of the concrete was not definitely determined, especially the difference in chemical composition from one manufacturer to another for the same type of inhibitor. The mechanism of action of the inhibitors is directly related to the transport properties of concrete.

Ammonia is a colorless gas with a distinct characteristic of a pungent smell. A compound of both nitrogen and hydrogen formulate NH3. The chemical structure of Amines consists of a basic nitrogen atom with an unshared electron pair (: N). Amines and Alkanolamines were described as organic basic nitrogen compounds. It consists of salts with organic or inorganic acids to be used as a concrete inhibitor. In the case of the Amine And Alkanolamines synthesis, one or more atom of the hydrogen element is replaced[1]. Mixed inhibitors consist of organic compounds as Amines and Alkenolamines that are adsorbed on the surface of the metal by forming a film and preventing the anodic and cathodic reactions of iron and oxygen. As shown in Figure 1. The mechanism of organic corrosion inhibitors is through adsorption (physisorption and/or chemisorption) on the metal surface[2].

Received 16 Oct , 2021; revised 8 Nov, 2021; accepted 8 Nov, 2021.

Available online 20 Nov, 2021.

Table 1:composition of the same product for different factories Material Safety Data Sheet (MSDS[8].

Country	*Product*	*Method of use*	*Type of ingredient*	*Chemical ingredients disclosed in the MSDS*
Norway	Sika Ferrogard®-901	Mixed into concrete	2-dimethylaminoethanol (DMEA)	5-10
			Organic/inorganic nitrogen compounds	Not given
Canadian			Salt of alkanolamine	15 – 40
Norway	Sika FerroGard® 903	Applied on concrete surface	2-aminoethanol	5 – 10 10 – 30
Canadian			Alkanolamine Ethyl alcohol	1 – 5

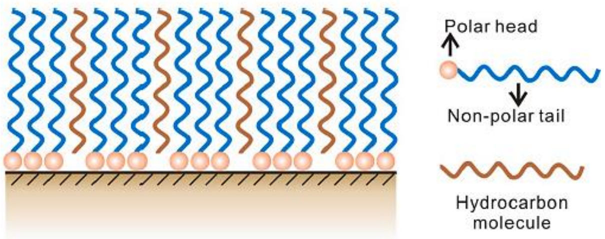

Figure 1:Schematic mechanism of mixed inhibitors[2].

Action mechanism of Organic Corrosion Inhibitor (OCI) depends on its composition (Amine, Carboxylate) and its interaction with the attacking materials and steel reinforcement. The medium through which the inhibitor travels is by diffusion and penetration through micro-cracks in the concrete[1]. An alkaline layer of Ca(OH)2 is formed to protect the reinforcing steel from rust when the concrete is exposed to carbon dioxide and chloride ions. This layer breaks down and the reinforcing steel starts to rust. The life of the concrete is prolonged when corrosion inhibitors are added, where the service life is divided into the initiation and the propagation phase. The action mechanism of inhibitor corrosion is to increased initiation stag, as shown in figure 2.

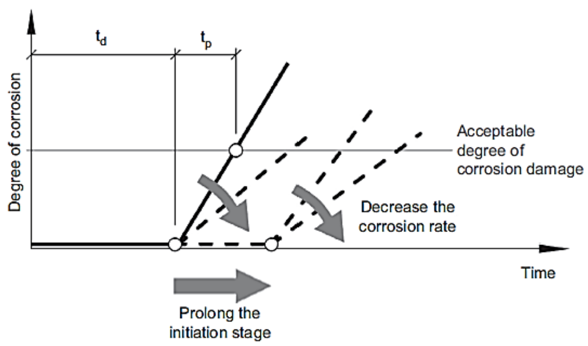

Figure 2: Schematic illustration of service life and the possible effect of corrosion inhibitors[3].

Determining the efficiency of inhibitors type Amines and Alkanolamines (organic basic nitrogen compounds) is difficult. Most commercial Inhibitors are made from a mixture of chemicals whose composition is unknown to the researcher and are not disclosed by the manufacturer. Therefore, commercial inhibitors are called (Amino-Alcohol Based Mixed Corrosion Inhibitor) [4, 5].

Studies have demonstrated the efficacy of Amino Alcohols (AMAs) through the use of Sika Ferrogard®-903 and their interaction with iron. Penetration depends on porosity and moisture and is not affected by water through sprinkling and puddles on the concrete structure[6]. The effectiveness of AMAs was verified in terms of their interaction with rebar and formation of a layer on the iron surface and simulation of concrete conditions was used. The mechanism of action of Sika Ferrogard®-901 is primarily anodic protection and it must be added in the appropriate amount so that corrosion acceleration does not occur[7]. The effectiveness of the inhibitors was verified during and after exposure, and the study proved that the efficacy of the inhibitors is good after exposure to the chloride environment. This enable the use Migrating Corrosion Inhibitors (MCIs) for the purpose of treating concrete exposed to the harsh marine environment[8]. The components are rarely identified from the factory, Material Safety Data Sheet (MSDS), but some of them were examined under the safety and security requirements of some countries, where the great difference in the composition of the same product for different factories [9], as shown in table 1.

There are five common types of primarily Organic Alcohol Amines, including Diethylenetriamine (C4H13N3), Aminoethylethanolamine (C4H12N2O) Triethanolamine (C6H15NO3), Triisopropanolamine (C9H21NO3) and, Polyvinyl Ammonium phosphate (C9H21NO3) (C2H4NO3). Several studies indicate that compressive strength is affected by the increase in the Inhibitor content according to the type of Inhibitor. compressive strength decreases with increasing the content of Diethylenetriamine (C4H13N3)[10].

Many studies proved that add Amines and Alkanolamines to a concrete mixture has no effect on air content and density was detected using DMEA inhibitors [11]. Many research found that Compressive strength reductions of about 12% and 14% at 14 and 28 days respectively compared to reference concrete by use AMAs inhibitor (W/C = 0.45, C = 350 kg/m3) [12]. Two studies that use organic corrosion inhibitors found that the compressive strength at the ages of 28 and 365 days was 13% lower and 15% higher than compared to reference concrete[12, 13]. Sika Ferrogard®-901 was added in amounts of 0.1, 0.2, and 0.3% the weight of cement in the concrete mix, and the w/c ratio of 0.52. The results were Slight increase in compressive and Splitting tensile strength when the percentage of Sika Ferrogard®-901 corrosion inhibitor increased[14]. The addition of Sika Ferrogard®-901 to concrete at a percentage of 5% of the weight of cement affects the properties of concrete, the compressive strength decreased by 10% compared with the reference sample[15]. Amino-Alcohol Base Mixed Corrosion Inhibitor experienced a decrease in the diffusion coefficient of approximately 30% in chloride migration testing in compared to the reference sample. also, the capillary absorption was decreased by 56% [16].

There is an insufficiency understanding of the effect of organic corrosion inhibitors on the mechanical and transport properties of concrete. In addition, each company has a chemical composition that may differ from others that manufacture the same type of inhibitor. Therefore, in this study, both sika Ferrogard®-901 and sika Ferrogard®-903 available in the local market were used.

The effect of sika Ferrogard®-901 on concrete characteristics is proportional to the percentage added to the mix. Adding sika Ferrogard®-901 with a percentage up to 0.3 by weight of cement improves the characteristics of concrete, but adding it with a percentage of 0.5 decreases compressive strength. The percentage of 0.35 by weight of cement advised by the manufacturer was used in this study, in order to determine the effect of inhibitors available on the local market on both mechanical and transport properties of concrete.

Sika Ferrogard®-903 has been used based on manufacturer recommendations. Several studies have shown that application of sika Ferrogard®-903 may act as a corrosion accelerator if it was less than the required quantity.

Contrary to what many studies have revealed, the majority of manufacturers of organic corrosion inhibitors on the market say that their products have no effect on the characteristics of concrete. This paper investigates the effect of both organic corrosion inhibitors (OCI) on the following properties of concrete.

Mechanical Properties of concrete.

Organic Corrosion Inhibitors (OCI) used on concrete by two methods, in addition to the mixture or applied to the surface, during a curing period of 90 days. The compressive strength, porosity and, absorption of concrete was tested at ages 3-7-28-90. The effect of Ferrogard®-901 on the fresh concrete tested by the slump, and air content.

Ions and Liquid Transport Mechanisms in Concrete.

Transfer of liquids and ions through concrete is important to know the concrete durability. Previous studies confirmed that the organic corrosion inhibitors Ferrogard®-901 do not interact with cement and remain inside the pores. As for the other type Ferrogard®-903, it moves inside the concrete through the capillary absorption property, then it moves through the concrete by diffusion and remains inside the pores. A study of the capillary absorption, diffusion and, permeability property of each of the sika Ferrogard®-901 and, sika Ferrogard®-903.

II. EXPERIMENTAL INVESTIGATION.

A. *Materials.*

The real challenge at this stage is to match the materials with the standard. River sand and aggregate to quarries that conform to standards are not available therefore certain measures were taken such as washing both local sand and coarse aggregate. The materials used in this study were Sika Ferrogard®-901, Sika Ferrogard®-903, Ordinary Portland Cement (OPC).

Coarse aggregate conforming to American standers ASTM C33 was used. The sizes of coarse aggregates were 12.5 mm maximum. Local sand analysis according to ASTM C33. with a specific gravity of 2.56. The sands were oven-dried at 100°C and cooled for at least 24 hours before use. Sand contains chloride in addition to its granular irregularity, so it was important to take samples from different places and to adopt the one that conforms to standards.

Corrosion Inhibiting Concrete Admixture (FerroGard®-901)

It is a liquid concrete admixture based on Sika ferrogard® technology for use in reinforced concrete and mortars. It acts as an inhibitor to protect steel reinforcement from corrosion. Designed for reinforced concrete especially the building exposed to chloride environment. it provides protection against corrosion caused by chloride. It is often used in structures that have a long service life such as concrete roads, bridges, tunnels and, retaining walls. Mechanism of Sika® FerroGard®-901 is anodic and cathodic reactions to reduce electrochemical corrosion process. The product forms a film on the steel surface which delays the damage of corrosion and also reduces the degree of corrosion. Sika® FerroGard®-901 was mixed with water. The quantity of Sika® FerroGard®-901 in the mix design was taken into consideration when determined the quantity of water for a specific W/C ratio.

Table 2 show the chemical composition of Sika® FerroGard®-901 according to the manufactory description[17].

Table 2: chemical composition of Sika® FerroGard®-901[17].

Chemical name	***Concentration (% w/w)***
2-dimethylaminoethanol	%10
2,2'-(methylimino)diethanol	%10

Corrosion Inhibiting Concrete Applied on surface (Sika® FerroGard®-903).

Sika® FerroGard®-903 is a surface coating that works by impregnating through hard concrete. It is designed to cross by first penetrating the surface and then diffusion through concrete in the form of vapor or liquid to steel reinforcement bars embedded in the concrete. Sika® FerroGard®-903 forms a protective film on the steel surface which delays the corrosion process caused by the presence of chlorides as well as the carbonation of concrete. Sika® FerroGard®-903 consists of a mix of amino alcohols and organic and inorganic inhibitors that protect both the anodic and cathodic parts of the corrosion cell. It increases the service life of buildings by delaying the onset of corrosion and reduces the overall corrosion activity. Sika® FerroGard®-903 protects steel reinforcement by forming a protective layer on the surface of steel reinforced. Table 3 showed chemical composition of Sika® FerroGard®-903 according to the manufactory description[17].

Table 3:Chemical composition of Sika® FerroGard®-903[17].

Chemical name	***Concentration (% w/w)***
2-aminoethanol	20 %
Tributyl phosphate	1 %

B. Mix Proportions of Concrete.

The mix proportions of concrete are summarized in Table 4. The amount of Ordinary Portland Cement type I (OPC) of 360 kg/m3 was used in all mixes. All concrete mixtures had a water-to-cement ratio of 0.6 and an estimated slump of fresh concrete between 150 and 200 mm. Control specimen (C) with no admixture or surface coating. Ferrogard®-901 specimen (OA) and Ferrogard®-903 specimen (OS) were used as corrosion inhibitors. Ferrogard®-901 was added to the concrete at a ratio of 12.5 kg / m3. Ferrogard®-903 was used as an application on the surface at a rate of 0.4 kg / m^2.

Table 4: The mix proportions of concretes.

MIX ID	PER WEIGHT CEMENT %				Slump cm
	Cement	*Aggregate*	*Sand*	*water*	
C	360	989	679.3	216	15
OA	360	971	667.4	216	23.5
OS	360	989	679.3	216	15.2

C. Method.

Organic Corrosion Inhibitor (OCI) one added to concrete and another one applied to the surface to reduce the chloride effect. The use of organic inhibitors (Amine) is environmentally friendly and non-toxic. The percentage recommended by the manufacturer was used. To know its effect on the mixture, the durability of the concrete and, corrosion resistance.

Compressive Strength of Concrete.

The specimens casted according to the standard ASTM C31/C31M. Form and Standard Practice for Making and Curing Concrete samples in the laboratory according to ASTM C192/C192M. The compression process is applied in accordance with the American stander ASTM C30. The compressive machine was used to test the compressive strength. Concrete cubes (100*100*100) mm were used to obtain the compressive strength. The moulds were filled with freshly mixed concrete in three layers of approximately equal volume. Each layer was tamped 25 times. The mixes were then covered with a non-absorptive, non-reactive sheet of tough, durable impervious plastic for 24 + 8 hours. Concrete specimens C, OA, OS were cured in water until the date of testing to determine the compressive strength at 3, 7, 28, and 90 days. The average of three concrete samples was taken as the compressive strength of concrete at each age. The OS specimen was coated with Sika Ferrogard®-903 material several times and left one hour before painting the second coat. Then it was left for one day to dry before being exposed to water.

Porosity.

Porosity was determined by the Vacuum Saturation method, the porosity of hardened concrete. The cement used is Ordinary Portland Cement (OPC) ASTM C150. Mix proportions of concretes are summarized in Table 2. The raw materials were mixed with tap water and compacted into moulds (50mm×50mm×200mm) and placed in a curing tank, until the ages of 7 days,14 days,28 days and, 90days. The samples are first oven-dried at 60℃ for 4 days and then be weighted. The air was withdrawn from the dry samples by placing the dry samples in a vacuum machine for 1 hour. Then the samples were soaked in the water while continuing to withdraw air from the samples for two hours. The ratio of weight difference before and after soaking in water divided by the concrete volume is considered as porosity. The Vacuum Saturation technology method was used based on the recommendations of many studies [18].

water permeability pentration tests.

The permeability of concrete was determined by the water permeability test for each type of concrete. Water permeability was determined by the water penetration from the bottom surface of the cube, and these tests were performed on three samples for each type of concrete. A water penetration depth test was performed according to BS EN 12390-8, where the sample was not pre-saturated. During testing, the water pressure of 500 ± 50 KPa was applied to the bottom face of each cubic. concrete cubes specimens of (150*150*150) mm were cast and were allowed to set for 24 Hrs. Concrete specimen C, OA, OS were cured in water until the date of testing to determine the permeability at 28 days. Water pressure was applied to the sample for 72 ± 2 Hrs. Samples were removed from the apparatus and, then each sample was split into two halves to measure the depth of water penetration. The result of water penetration depth was taken as the maximum depth of water penetration for the three cubic samples poured from the same batch of concrete and tested at the same time. all specimens are unsaturated (partially saturated concrete) the water is penetrated externally. The OS concrete specimen was coated with Ferrogard®-903 material several times and left an hour before painting the other coat. then it was left for a day before being to water.

Capillary absorption test

OA, C, and OS specimens were tested for penetration rate by Capillary absorption of 3.5 % NaCl. This Test conforms with BS EN 13057:28. In the capillary absorption test, the uncoated surface of the concrete cylinder specimen was put in contact with a liquid inhibitor (sika Ferrogard®-903) in a plastic container. For the purpose of comparison, tests were performed also with a 3.5 % NaCl solution. Concrete specimens were immersed at a depth of 5 mm. specimens were dried at 50

C^0 up to stationary weight (change less than 1%). After drying, capillary absorption tests started: inhibitor and 3.5 % NaCl absorption were monitored by weight measurements performed every 5 min for the first 2 h, then hourly for 8 h, and then daily for 4 days.

Diffusion tests.

The apparent Chloride Diffusion Coefficient was determined to conform to ASTM C1556. OA, C, and OS specimen were tested to a penetration rate by Diffusion of 5 % NaCl. Concrete samples are Cylindrical with a diameter of 100 mm and a height of 50 mm were used, and the samples were processed in a curing tank. Concrete samples were immersed in distilled water for 3 days to saturate the pores. The samples wereleft in the air to dry for 24 hours. The side and bottom surfaces of the samples were coated with waterproof. The samples were placed in special containers with a concentration of sodium chloride 5 % for 4 months. The chloride ion concentration in the concrete depth was determined as showed in Table 5. specimens were tested to a penetration rate by Diffusion of 5 % NaCl.

Table 5: Recommended depth (mm) for powder grinding.

Depth (mm)	*Sample weight (g)*
1	3
1-3,3-6	3
6-10	3
10-15	3
15-20	3
20-25	3
25-30	3

III. RESULTS

A. Compressive Strength

The compressive strength at ages of 3,7,28 and 90 days for all specimens is shown in Figure 3. The effect of Ferrogard®-901 in specimen OA shows that the full strength of concrete reacted at 7days. The corrosion inhibitor applied to the surface Ferrogard®-903 OS did not significantly change the strength of concrete at 3, 7 and, 28 days. At the age of 90 days, the compressive strength of the C specimen did not change. The compressive strength of the OA specimen increased by 2.3 MPa higher than that at age 28 days' strength. OS specimen increased by 2.9 MPa higher than that at age 28 days' strength. From Figure 4, it was noticed that the C specimen had full strength at 28 days. The OA specimen stabilized its strength from 7 to 28 days and increased strength at the age of 90 days. The OS specimen did not change from the strength of the C specimen at the age of 3, 7 and, 28 days, while its strength increased at the age of 90 days.

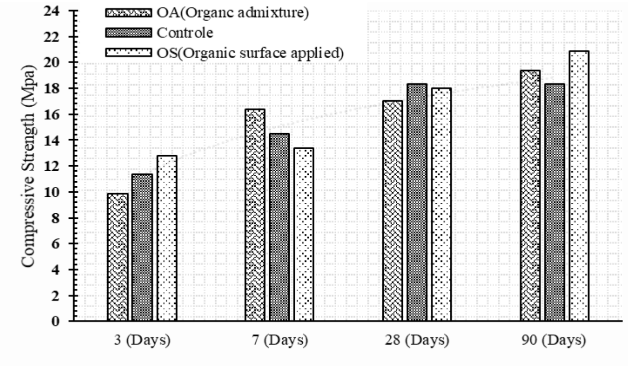

Figure 3:compressive strength at age of 3,7, 28 and 90 days.

B. Porosity.

Figure 4 shown the porosity percent for every age of 3,7,28 and 90 days. The effect of Ferrogard®-901 on the OA sample showed that the porosity of the concrete stabilized in 14 and 28 days. However, the porosity of the OA sample significantly decreased at 90 days. This could be explained by the presence of Ferrogard®-901 inside the pores which reduced the percentage of air in the OA sample voids.

At the age of 7 days, the porosity ratio of the OS sample was greater than that of C sample. Also that, Ferrogard®-903 OS surface-applied corrosion inhibitor did not significantly change the porosity of concrete at 14 and, 28 days compared to C sample. However, the porosity of the OS sample decreased about 1.3% less than that at the age of 28 days. While OS sample is 1% decreased than that at the 28-day lifespan. While at 90 days The porosity percent was the closest to C sample at the same age.

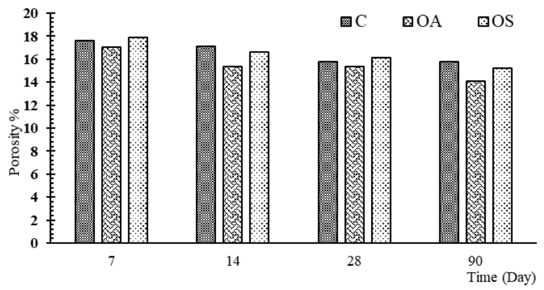

Figure 4:the porosity of hardened concrete by vacuum water absorption.

The result of the water absorption test was shown in Figure 5. At ages 7 and 14 days, the results showed that the OA samples had a decrease in the water absorption rate, the OA water absorption rate was equal to 10.6, while it was 11 and 11.2 for the reference and OS samples, respectively. For both 14 and 28 days of age, the absorbance of the OA and OS samples was lower than the control sample C. However, at the age that of 90 days, the OS samples were less absorbent than the OA and C samples. Organic corrosion inhibitors generally reduce the absorbent property of concrete, which may be due to the saturation of concrete with Ferrogard®-901 and Ferrogard®-903, which reduces its water absorption.

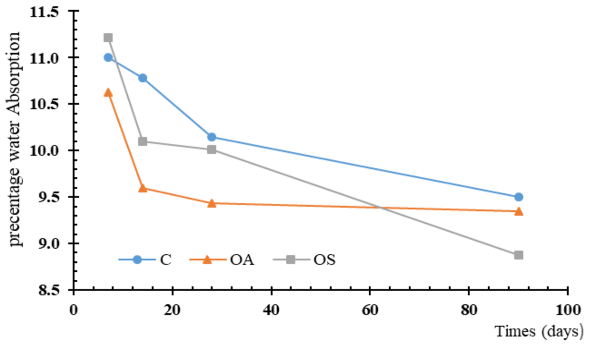

Figure 5: water absorption of hardened concrete.

C. water permeability pentration tests.

This test determines the amount of water entering the sample under a pressure of 5 bar for three days. as shown in figure 6. The control specimen C gave a value of 4.8 cm. However, the OA specimen gave a value of 4.1cm, it resisted water ingress better than control specimen C. Ferrogard®-901 inside the pores gave hydraulic resistance to water ingress. For OS concrete the penetration resistance of water by Ferrogard®-903 that exists into pores is not sufficient to resist the ingress of water.

The permeability coefficient values of the studied concrete increased with the addition of Ferrogard®-901 in the concrete mix or application of Ferrogard®-903 on the concrete surface. As shown in figure 7. This can be explained by that the liquid of Ferrogard®-901 and Ferrogard®-903 ware remained in the pores and caused the clogging of the capillary pores.

In general, the effect of organic corrosion inhibitors on the permeability coefficient of concrete is not great, but it contributes to increasing the resistance to water or liquids passing through it.

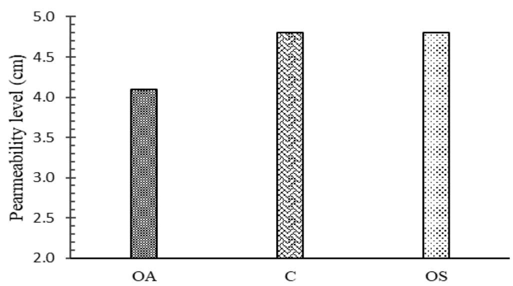

Figure 6: permeability coefficient at 28 days.

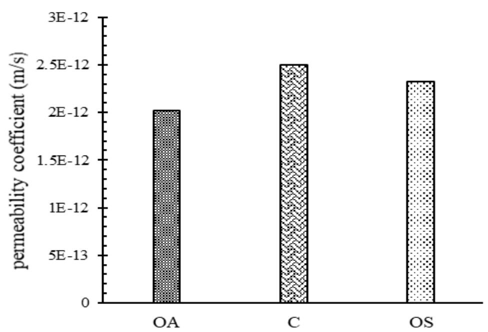

Figure 7: permeability coefficient under pressure at 28 days.

D. Capillary absorption.

After drying, concrete samples were exposed to 3.5 NaCl of solution and organic inhibitor penetration by capillary absorption. Weight variation for a unit of concrete surface exposed to the solution is reported in Figure 8 and Figure 9. Generally, the Capillary absorption of chloride solution is higher than absorption of migrating inhibitor sika Ferrogard®-903. The Saturation conditions are achieved after two days of exposure. The capillary absorption ratio of (OS) and (OA) samples give lower values compared with reference concrete (C). The effect of the organic inhibitors applied to the surface was higher than the inhibitor added to the mix. It may be due to the saturation of the surface with Ferrogard®-903, however, the capillary absorption of (OA) sample is more difficult than the reference concrete. the concrete capillary absorption of the chloride solution (3.5% of NaCl) is higher than the Ferrogard®-903 solution (OIC).

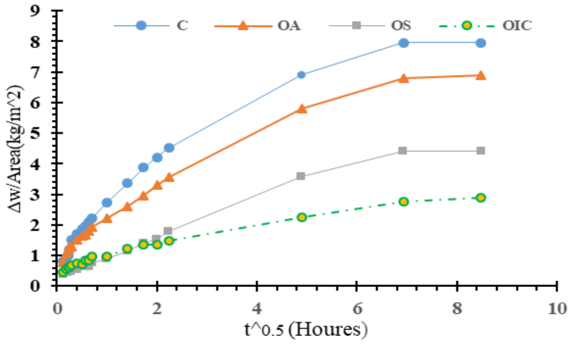

Figure 8: Capillary absorption by area surface every root of Hours.

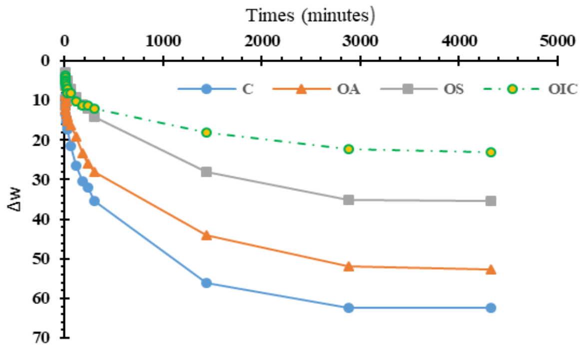

Figure 9: Weight variation during capillary absorption.

E. Diffusion.

The concrete specimens containing cement according to ASTM C150, W/C=0.60 are submerged in a tank containing 5% of chloride solution. The chloride content value in depths was calculated as shown in Table 5. From figure10, it was noticed that the addition of inhibitors to concrete or applied on the surface that affects differently the diffusion of chloride ions into concrete. So that the concrete containing Sika Ferrogard®-901(OA) had a greater prevalence of chloride than that containing Sika Ferrogard®-903 (OS) and of the control samples. However, the spread of chloride in the concrete of Sika Ferrogard®-903(OS) was higher than in the reference concrete. The effect of Sika Ferrogard®-903 was significant on the first 15 mm of the sample, then the diffusion rate of chloride became close to the reference sample. Previous studies have shown that the inhibitors applied on the surface reduce the value of chloride coefficient exposed to the chloride environment[19]. As for Sika Ferrogard®-901, previous studies showed that Sika Ferrogard®-901 reduces the diffusion coefficient of chloride ions inside the concrete. Also, the effect of Sika Ferrogard®-901 on the diffusion of chloride ion varies according to the water-cement ratio. The diffusion coefficient is lower than the reference sample in concrete with a water-cement ratio of 0.4 and it is higher than the reference sample in concrete with a water-cement ratio of 0.6[20].

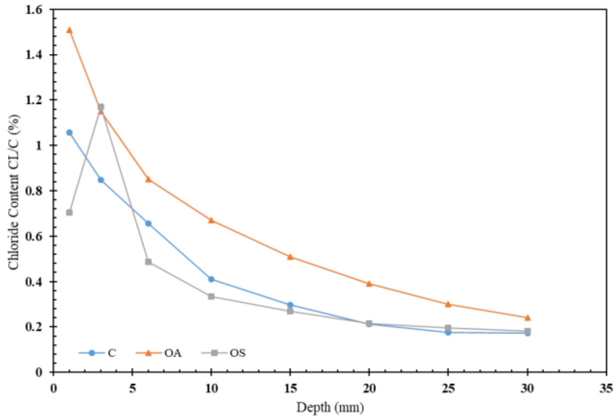

Figure 10: Chloride penetration profiles after one and four months.

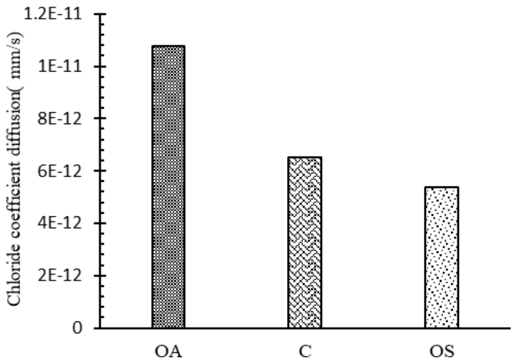

Figure 11: Apparent diffusion coefficient of chloride in concrete

IV. CONCLUSION

Based on results on concrete the following conclusions were obtained:

1. The workability of the concrete mix increases with the addition of organic corrosion inhibitors Ferrrogard®-901.
2. The compressive strength of the OA sample with Ferrrogard®-901 is higher than that of OS samples with Ferrrogard®-903.
3. The effect of organic inhibitors on the porosity of concrete was not evident.
4. The permeability test, indicate the use of (sika Ferrogard®-901) and (sika Ferrogard®-903) reduce the permeability.
5. The use of (sika Ferrogard®-903) contributes to the reduction of both OCI have an effect on capillary absorption, and, diffusion properties. however, the effect of sika Ferrogard®-901 is more significant.

RECOMMENDATION.

Based on this research result on the following recommendations were obtained:

1. Investigate the effect of temperatures on the efficacy inhibitors.
2. Study the impact of a wet-dry cycle on the inhibitors' efficiency.
3. Study of the efficacy of the inhibitor in corrosion resistance.
4. Studying the effect of organic inhibitors on concrete properties with smaller w/c ratios.

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