Original Research Paper

Effects of Different Environments on Reinforcement Concrete Corrosion

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Abstract: This research focuses on various forms of steel bar corrosion located in different environments and the factors affecting the corrosion process, both the external (surrounding environment around concrete elements) and the internal environment (concrete itself), as well as on the investigations and tests for this type of damage, in order to develop measurements and recommendations that will reduce harmful investment as much as possible, by increasing the durability and resistance to aggressive environments throughout their life span. The results showed that the concentration (100%-75%) of sulfuric acid decreases more in steel bars diameter than in the second week, but the difference is negligible, and there is no change in the color of precipitation. Concentration (50%-25%) of sulfuric acid also showed decreases in bars diameter than in the second week, but the difference could be omitted, except for the concentration (50%) of sulfuric acid white layer appearance on the steel. In the fourth week, in NAOH, there has been no obvious change in the diameter of steel and an increase was noticed in the deposits substance as well as the appearance of external rust of Steel. HNO_3 with a 25% concentration continued a dramatic corrosion of steel and a large decrease in the diameter of steel was observed, which led to a change in the color of the liquid to brown, due to the fragmentation of steel, and the corrosion of the non-soaked steel. When exposing the reinforcing bars for acid and base at different concentrations to investigate the ultimate tensile stress, a high decrease in the tensile strength of the steel bar was found, due to the concentration of nitric acid (25-50%) compared to the other acids and base, and this decrease is caused by a high degree of corrosion.

Keywords: Environment, Factors, Damage, Acids, Steel Bars, Concentration, Tensile, Strength

Introduction

Corrosion can be defined as the destruction or deterioration of materials due to its reaction with the environment. Reinforced concrete is a versatile, economical and successful construction material (Diamond, 2007). It can be molded into a variety of shapes and finishes. Usually, it is durable and strong, performing maximally all through its service life which typically exceeds 50 years. Sometimes, it does not perform efficiently as a result of poor design, poor construction, inadequate materials selection, a more severe environment than anticipated or a combination of these factors (John, 1997). Reinforced concrete superstructures along the coast can corrode, due to marine atmospheric exposure, if not properly designed. Marine atmosphere can be defined as the atmosphere within 300m (1000 ft) of ocean or tidal water. Tidal water is anybody of surface water having a chloride content of 500ppm or greater (Corrosion Guidelines, 2003, Nilsson, 2009). Reinforcing steel embedded in concrete shows a high amount of resistance to corrosion because the cement paste when in good quality concrete provides an alkaline environment with pH (12.5-13.5)

that protects the steel from corrosion, by passivating or a protective ferric oxide film that forms on the surface steel bar when it is embedded in concrete (de Viedma *et al.*, 2006). This passive film is only a few nanometers thick and is stable in the highly alkaline concrete (pH approx. 11-13.5) (John, 1997). The protective action of the passive film is immune to mechanical damage of the steel surface, but it can, however, be destroyed by the carbonation of concrete or by the presence of chloride ions. The reinforcing steel is depassivated when the pH falls below 10 for any reason, then, the corrosion may occur (Paul, 2000). Thereafter, carbonation or chloride ions can penetrate through the concrete pores to the oxide layer on the rebar, breaking down the passive layer and leaving the steel bar vulnerable against aggressive agents (Page, 2009); corrosion occurs in the presence of moisture and oxygen (Corrosion Guidelines, 2003). Most problems associated with the corrosion of steel in concrete are not due to the loss of steel, but are as a result of the growth of the oxide, that has a volume of about twice to six times that of the steel it replaces, when fully dense (Bertolini *et al.*, 2004; Bertolini and Polder, 1997). When it becomes hydrated, it swells even more and becomes porous. This means that the volume increases at the steel/concrete interface ranging from two to several times (Strehblow, 2002). This leads to the cracking and spalling of the concrete cover which we observe as the usual consequence of the corrosion of steel in concrete and the red/brown brittle, flaky rust on the bar, as well as the rust stains seen at cracks in the concrete (John, 1997).

Material and Methods

The objective of this experiment is to determine the rate change in diameters of reinforcement steel, due to the effect of different chemicals during specific time interval and how they react with these materials. The material include, steel reinforcing long bars (10-15cm) with a diameter of (12mm), Digital measuring device of varying diameters (caliber), Chemical materials: Sulfuric acid, Nitric acid, Chlorine and Sodium hydroxide. We have developed different concentrations of each chemical as follows: 100%, 75%, 50% and 25% by putting it in 400 ml of each material in the template and we put four bars of steel and leave it and observe the change in the diameters every week, using digital measuring device diameters (caliber). Objective of the protection methods of concrete due to the influence of chemical reactions in this experiment are as follow: (1) to protect the concretefrom the harsh environment and conditions surrounding it, by providing it with an insulating material, which protects the concrete from harmful chemicals (acids or basic) (Garca *et al.*, 2010) (2) to prevent the penetration of these materials in the concrete, (3) to ensure the longest permanence of

concrete and (4) to prevent these harmful substances from reaching the reinforcing steel. The materials used for protection are Epoxy and Asphalt. We have prepared eight samples of concrete, we then covered 3 samples with epoxy and covered the other three samples with asphalt, in order to provide protection and isolation using epoxy and asphalt, and two samples were left without protection, thereafter, these protected and unprotected samples were soaked in the chemicals under unfavorable conditions and these chemical compounds are: concentration (100%) of CLNAO; Concentration (25%) of HNO_3; Concentration (25%) of H_2SO_4.

Results and Discussion

In the first week, the corrosion rate was very small and the change in diameter also was small with a the concentration (100%) of sulfuric acid and the white color concentration (75%) of sulfuric acid have Light Pink color precipitate and the change in diameter also was small. Concentration (50%) of sulfuric acid has white precipitate and the change in diameter also, is small. The concentration (25%) of sulfuric acid precipitates green color as well as the bacteria formation in the dry part of the steel, as shown in Table 1.

In the first week, no obvious change was noticed for Steel when we put in the sodium hydroxide. The corrosion rate of steel and the loss in diameter was not obvious in the concentration (100%-75%) of the nitric acid and the nitric precipitate (yellow– orange) color, but the concentration (50%-25%) of the nitric acid precipitate (dark brown- black) color and the loss of diameter, was very large at this tow percentages. At 50% and 25% in the first week, the speed of corrosion of the steel was noted and there was a crusting of the steel surface and a small change in the diameter of the steel. Also, at 75% and 100% in the first week, the same effect was observed but there were stronger corrosion than the chlorine (50%-25%). In the second week, the rate of corrosion and decrease in diameter was low in the concentration (100%) of sulfuric acid and has a white color precipitate.

Table 1. Variations in steel bar diameters corresponding concentrations of different asides in first week

H_2SO_4	D1(mm)	D2(mm)	D3(mm)	D_{Avg}(mm)
25%	10.85	11.15	11.12	11.0
50%	11.33	11.63	11.74	11.6
75%	11.71	11.75	11.46	11.6
100%	11.79	11.77	11.80	11.8
HNO_3				
25%	10.64	11.43	10.70	10.9
50%	10.20	9.82	9.98	10.0
75%	44.54	11.61	11.85	11.6
100%	12.04	11.87	11.97	11.9

Concentration (75%) of sulfuric acid has a liquid light pink color. Concentration (50%) of sulfuric acid has white precipitate. Concentration (25%) of sulfuric acid precipitate has a green color, as well as the bacteria formation in the dry part of the steel and the loss in diameter was very large, as shown in Table 2.

In NAOH, there was no obvious change in the diameter of steel and the presence of few deposits of the substance was noticed, but without any effect on the Steel. The corrosion rate of steel and the loss in diameter was more this week than in the first week, but the difference is not too large for all concentrations of the nitric acid. CLNAO at 25% and 50%, the corrosion continued, but there was a slight change in the diameter of iron and the presence of rust-colored sediment in small amounts. At 75% and 100%, the corrosion continued, but there was a slight change in the diameter of steel and an increase in the amount and presence of rust-colored sediment.

In the third week, considering NAOH and H_2SO_4, there has been no obvious change in the diameter of steel and the increase in the deposits of the substance was noted, but without any effect on the Steel. HNO_3 Concentration (100%-75%) showed no significant corrosion of steel, but showed a slight change in the diameter of steel, At a concentration of (50%-25%), there is an increase in corrosion and a dark brown precipitation, due to of the steel. CLNAO at 25% and 50% concentration, the corrosion continued and the rough surface of the Steel began to emerge and there was a slight change in the steel diameter as well as no noticeable increase in the sediment. At a Concentration of 75 and 100%, corrosion continues as well as the emergence of non-smooth surface of the Steel and little change in the diameter of steel and an increase in the sediment was noticed and the color of steel began changing to black and thereafter, it began to disintegrate, as mentioned in Table 3.

Concentration (100%-75%) of sulfuric acid showed decreases in diameter this week than in the second week, but the difference is negligible and there is no change in the color of precipitation. Concentration (50%-25%) of sulfuric acid also showed decreases in diameter than in the second week, but the difference is not too large, the concentration (50%) of sulfuric acid results in the appearance of the white layer on the steel. During the fourth week, in NAOH, there has been no obvious change in the diameter of steel and an increase in the deposits substance was noticed, as well as the appearance of external rust of Steel. HNO3 at 25%, the corrosion of steel continued dramatically and a large decrease in the diameter of steel was observed, which led to a change in the color of the liquid to brown, because of the fragmentation of steel and the corrosion of the non-soaked steel. At 50%, the corrosion of steel increased from the previous weeks and a significant decrease in the diameter of steel was observed than in any other concentrations of nitric acid,

which led to the color change, to a dark brown liquid because of the fragmentation of steel and the erosion of the non-soaked steel. At 75%, there was no significant corrosion of steel, as well as no change in the diameter of steel and there was the appearance of yellow liquid because of the slight corrosion of steel. CLNAO at 25% and 50% showed a non-smooth surface of the steel, small change in steel diameter and there was no noticeable increase in the sediment and changes in the steel diameter. At 75% and 100% non-smooth surfaces of the steel, there is an emergence of rust in non-soaked Steel by the escalation of vapor and change in steel diameter and there was no noticeable increase in the sediment, also, there is a total change in the color of the soaked steel to black, as listed in Table 4.

Table 2. Variations in steel bar diameters corresponding concentrations of different asides in second week

NAOH	D1(mm)	D2(mm)	D3(mm)	D_{Avg}(mm)
25%	11.78	11.73	11.82	11.80
50%	11.88	11.96	11.94	11.90
75%	12.00	11.87	11.97	11.90
100%	12.01	12.04	11.98	12.01
H_2SO_4				
25%	9.70	9.89	10.13	9.9
50%	11.54	11.53	11.44	11.5
75%	11.59	11.53	11.57	11.6
100%	11.74	11.69	11.76	11.7
HNO_3				
25%	9.72	9.33	9.26	9.4
50%	7.90	7.73	7.35	7.7
75%	11.73	11.62	11.55	11.6
100%	11.74	11.82	11.97	11.8
CLNAO				
25%	11.32	11.29	11.34	11.3
50%	11.72	11.68	11.70	11.7
75%	11.48	11.55	11.62	11.5
100%	11.55	11.45	11.53	11.5

Table 3. Variations in steel bar diameters corresponding concentrations of different asides in third week

H_2SO_4	D1(mm)	D2(mm)	D3(mm)	D_{Avg}(mm)
25%	9.40	93.00	9.70	9.5
50%	11.52	11.47	11.23	11.4
75%	11.26	11.34	11.39	11.3
100%	11.71	11.67	11.64	11.7
HNO_3				
25%	9.48	9.45	9.32	9.4
50%	7.88	7.53	7.38	7.6
75%	11.40	11.65	11.7	11.6
100%	11.86	11.88	11.39	11.7
NAOH				
25%	11.69	11.75	11.72	11.7
50%	11.89	11.87	11.94	11.9
75%	11.93	11.86	11.98	11.9
100%	12.02	12.01	11.96	12.0
CLNAO				
25%	11.17	11.22	11.22	11.2
50%	11.52	11.45	11.48	11.5
75%	11.39	11.40	11.45	11.4
100%	11.40	11.45	11.27	11.4

Table 4. Variations in steel bar diameters corresponding concentrations of different asides in fourth week

H_2SO_4	D1(mm)	D2(mm)	D3(mm)	D_{Avg}(mm)
25%	9.73	9.4	9.11	9.40
50%	11.26	11.36	11.47	11.40
75%	11.27	11.26	11.19	11.20
100%	11.49	11.53	11.58	11.50
HNO_3				
25%	8.25	10.02	9.71	9.30
50%	7.48	7.27	7.61	7.45
75%	11.52	11.56	11.62	11.56
100%	11.66	11.68	11.72	11.68
NAOH				
25%	12.60	11.98	11.05	11.70
50%	12.10	11.96	11.68	11.90
75%	11.88	11.93	11.92	11.91
100%	11.92	11.95	12.02	11.97
CLNAO				
25%	11.16	11.25	11.15	11.20
50%	11.52	11.47	11.18	11.40
75%	11.43	11.39	11.36	11.39
100%	44.28	11.19	11.34	11.27

Table 5. Ultimate tensile stress for two weeks

Material	F(KN)
Stander	80.0
CLNaO 50%	78.6
CLNaO 75%	76.3
CLNaO 100%	86.6
Na(OH) 100%	80.0
H_2SO_4 25%	78.2
HNO_3 25%	69.6
HNO_3 50%	66.7

Table 6. Ultimate tensile stress for Four weeks

Material	F(KN)
Stander	80.0
CLNaO 50%	74.9
CLNaO 75%	71.8
CLNaO 100%	62.4
Na(OH) 100%	80.0
H_2SO_4 25%	73.6
HNO_3 25%	62.4
HNO_3 50%	58.9

Tensile Test

The objective of this experiment is to investigate the behavior of steel under a tensile test, which is affected by the chemical compounds (sulfuric acid, nitric, sodium hydroxide, chlorine). The following tools were used in this experiment: Steel bars having a length of 30 cm and a diameter of 12 mm, Chemical additives (nitric acid, sulfuric acid, chlorine and sodium hydroxide), Templates and Tension Device. The difference in chemical concentrations of the most influential to the steel bar taken are: (HNO_3 50%_HNO_3 25%_ H_2SO_4 25%_CLNaO 100%_ CLNaO 75%_ CLNaO 50%_Na (OH) 100%), and there are two steel bars soaked in each concentration, finally, the ultimate tensile stress by the tension device was measured every two weeks, the results are listed in Tables 5 and 6.

When exposing the reinforcing bars for acid and base in different concentrations in order to investigate the ultimate tensile stress, a height decrease in the tensile strength of steel bar was observed, due to the concentration of nitric acid (25-50%) compared with the other acids and base, and this decrease is caused by a high degree of corrosion. Also, it observed a decrease in the tensile strength of the steel bars exposed to chlorine, where the concentration was 100% of the chlorine, but the decrease in the tensile strength is not more than that of nitric acid. Decrease in the tensile strength of steel bar exposed to sulfuric acid, where the concentration was 25% and close to it, the decrease of steel bar exposed to chlorine with a concentration of 50% indicates that sulfuric acid and chlorine have the same effect.

Finally, the rate of decrease in the tensile strength of steel bar exposed to the basic (sodium hydroxide) concentration of 100%, was low, and there was no difference compared to the tensile strength of the stander bar. Gulikers (2005) found a linear relationship between concrete resistivity and corrosion rate of steel reinforcement. The concrete (protected and non-protected) was immersed in the chemical compounds for four continuous weeks and the effect of these compounds on the concrete was studied and it has been found that some of the samples become fragmented. Thereafter, we compared the amount of damage caused and the changes that occur between the protected and the non-protected concrete caused by compounds and the Fig.1-8 shows the variation on corrosion respect to time.

There was an appearance of (smooth, soft) layer on the surface of the unprotected concrete; this indicates that chlorine was able to penetrate through the spaces of non-isolated concrete.

It was clearly shown that the use of epoxy cover had protected the concrete from fragmentation, which might cause possible damage.The effect of chlorine on the layer of asphalt can be clearly seen, which is an indicator of the penetration of chlorine into the concrete and this will affect the reinforcing steel in the future (Morris et al, 2004).

Notes the fragment of the insulating layer of asphalt and concrete sample, this method of protection from sulfuric acid failed.

A High fragmentation of the insulation layer and the concrete sample, as well as the appearance of rust is shown to reach the H_2SO_4 acid, to the steel, leading to damage in the future. Fragmentation of concrete sample occurs due to the presence of nitric acid and it forms voids, paving the way for nitric acid to penetrate and gain access to the reinforcing steel, thereby, causing corrosion.
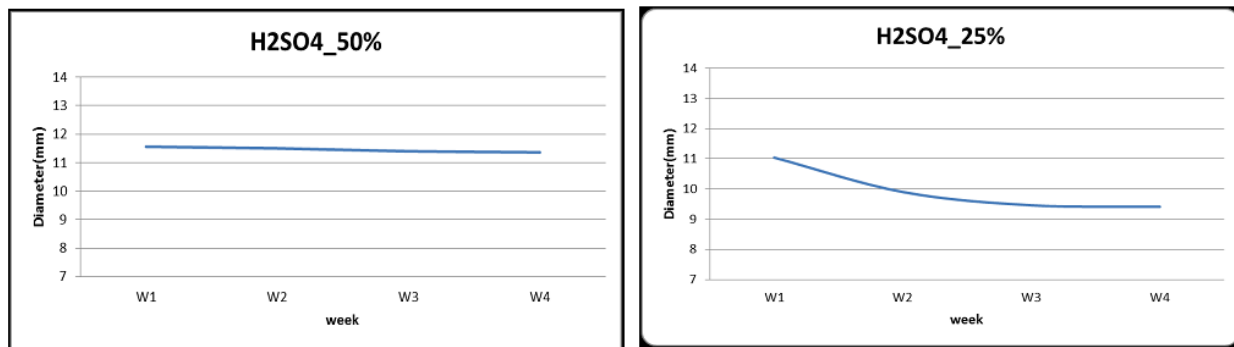
Fig. 1. Variations of corrosion levels corresponding to different H_2SO_4 additives
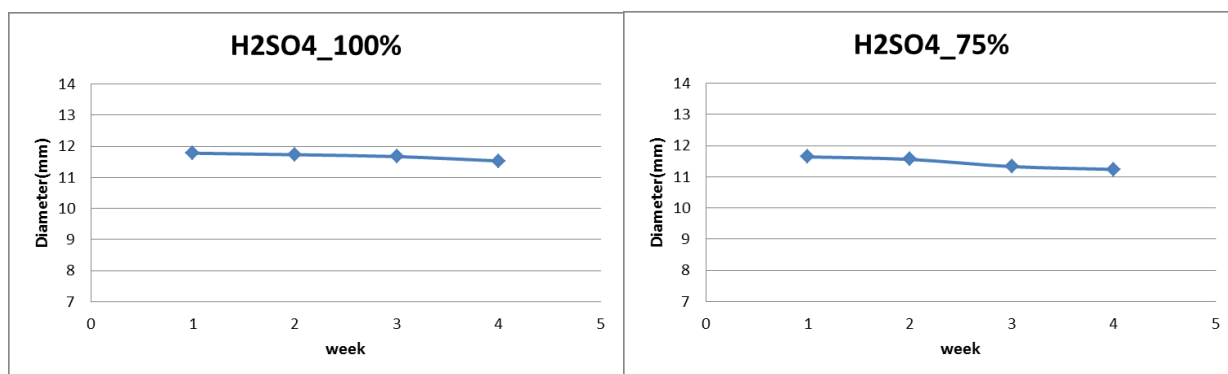

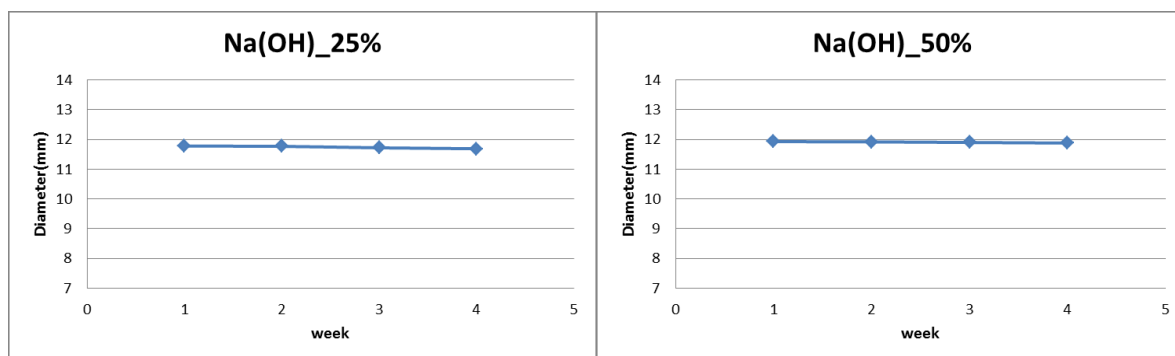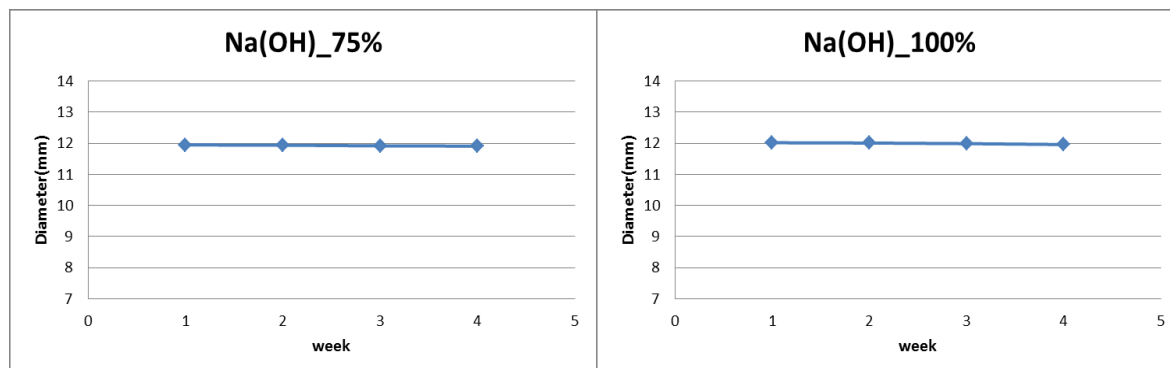Fig. 2. Variations of corrosion corresponding to different H_2SO_4 additives

Fig. 3. Variations of corrosion corresponding to different NaOH additives

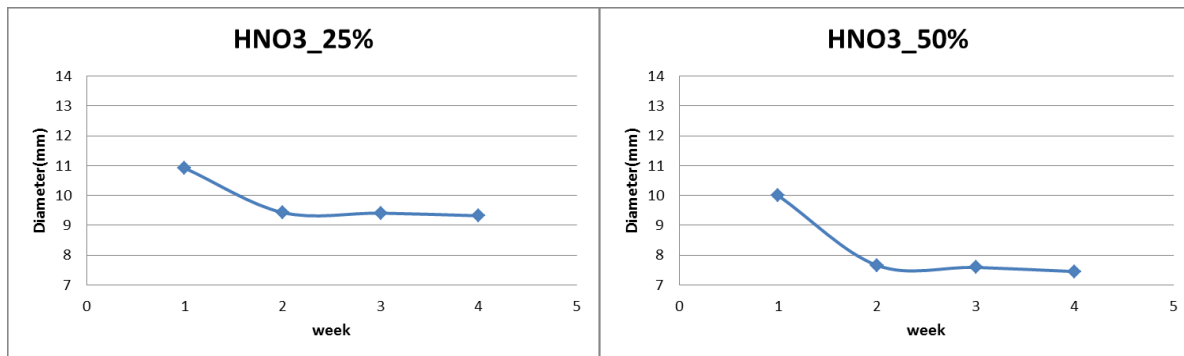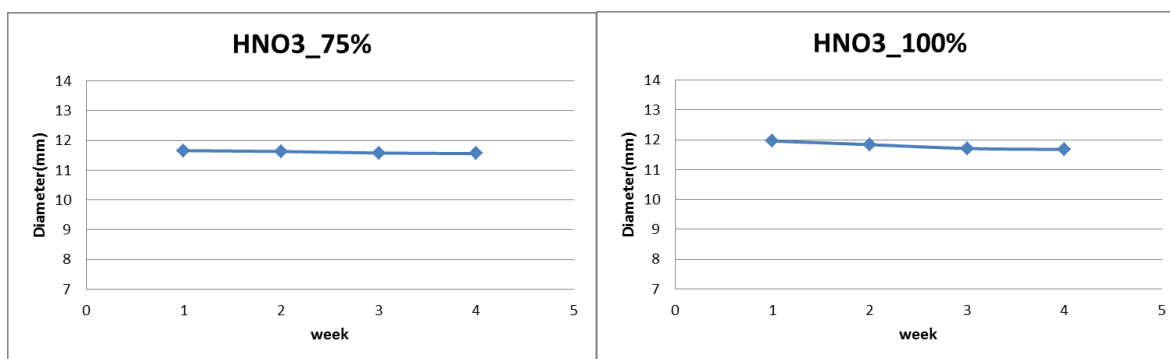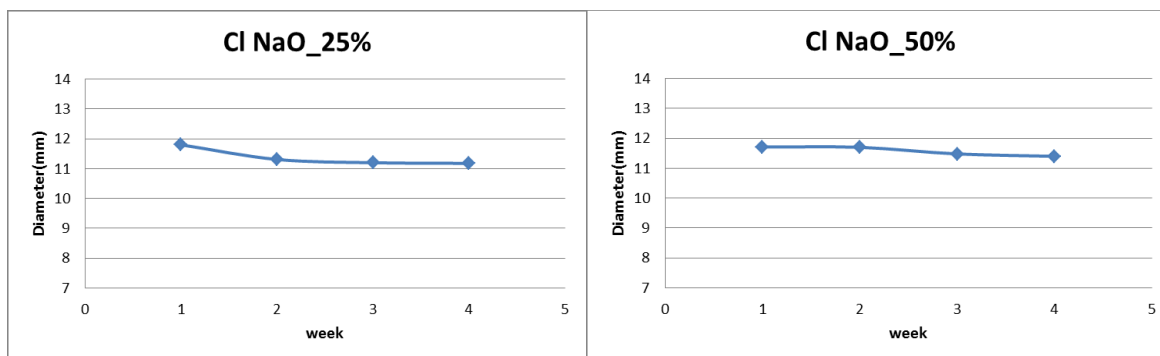Fig. 4. Variations of corrosion corresponding to different NaOH additives

Fig. 5. Variations of corrosion corresponding to different HNO$_3$ additives

Fig. 6. Variations of corrosion corresponding to different HNO$_3$ additives

Fig. 7. Variations of corrosion corresponding to different ClNaO additives
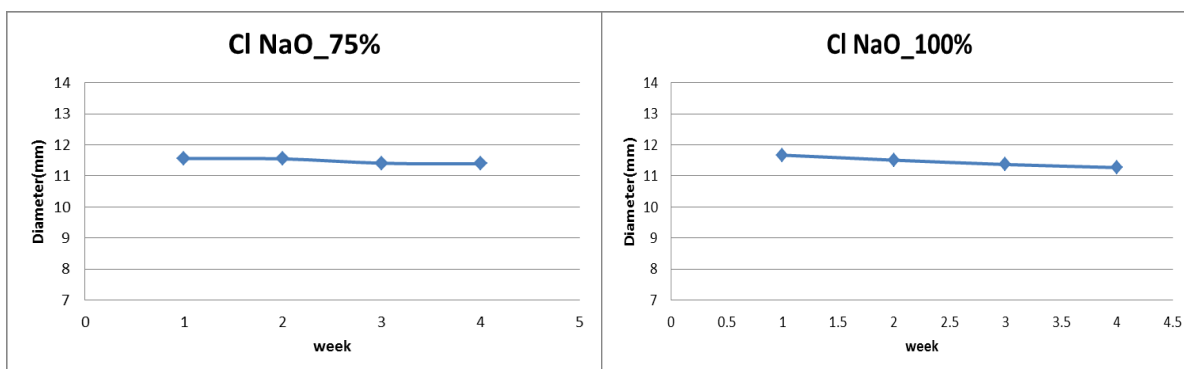

Fig. 8. Variations of corrosion corresponding to different ClNaO additives

It clearly shows the fragment of asphalt and concrete, but the effect was small compared to the concrete sample that was exposed to the sulfuric acid. (Nygaard, 2008) absorved the same results. There was no fragment of concrete and epoxy was used as the layer of protection.

Using the asphalt protection for concrete samples and the fragment of the concrete (due to nitric acid, sulfuric acid, chlorine), it can be concluded that, we cannot use the asphalt as a protection. When using an epoxy as an insulator for concrete, we found some protective agents (nitric acid and the chlorine). When using an epoxy as insulator for concrete, we found that the epoxy does not protect the concrete from the sulfuric acid.

Conclusion

Based on achieving results, a good compaction of concrete is clearly seen, and when given enough coverage, it will protect the reinforcing bars from corrosion, the ions of chlorides in concrete was high, but if the compaction of concrete was bad, it will not protect the reinforcing bars from the effects of the marine environment or the effects of the harmful industrial environment, and may speed the corrosion rate of the soaked reinforcing steel bars, because it has become a suitable environment for corrosion. The unavailability of a suitable drainage system for rainwater from rooftops, leads to the leakage of water and access to steel reinforcement, creating conditions for the corrosion of steel, and contributes to the concentration of chloride ions in the lower level of the roof. The phenomenon of a decrease in concrete alkaline in facilities, under the harmful effects of the industrial environment, is a common phenomenon due to the presence of vapors, harmful chemical substances, and combustion products. The effect of the marine environment in concrete damage is much less than the industrial environments. The concentration of the gases that result from the combustion of fuel in the Air, can lead to the emergence of acidic rainwater, which lead to increase in the rates of corrosion reinforcing steel and then, damage the concrete.

The corrosion of steel reinforcement may lead to the deterioration of the building and shorten its lifespan and the investment in the shortest period of time may not exceed 15 years or less, as well as it could involve a lot of money and generate a feeling of fear and insecurity for users of this building. The unprotected concrete surface of facilities directly exposed to spray from seawater, led to the penetration of chloride ions from the spray into the concrete and resulting in corrosion in the steel reinforcement.

Engineers must take account of these general recommendations in order to reduce the corrosion of reinforcement: Perform a chemical analysis of components and additions to the water used in reinforced concrete, not only in marine area, but also in other areas, to ensure that the chlorides and sulphates ions do not exceed the acceptable limits. The necessary tests to determine the level of groundwater at the construction site should be performed, also, a chemical analysis of the water and soil should be conducted to ensure that the salts do not exceed the acceptable limits. A drainage system must be put in place, to drain rainwater from the upper surfaces of the buildings, and to prevent the stagnant pools. Water systems and heating systems must be visibly performed. Perform concrete with low (W / C) and good aggregate gradation. An isolated system must be provided to protect the buildings near the seashore or the affected building from sea spray. Perform maintenance to dispose the harmful industrial product. Control the curing of concrete mix in hot weather to prevent the cracks. Must develop pre-stressed structure by Standard specifications. Reinforcement steel should not be left exposed, it must be covered with suitable isolation materials.

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Author's Contributions

Mohammed Thalji Awwad: Participated in all experiments coordinated the data-analysis.

Omar Asad Ahmad: Contributed to the writing of the manuscript. Revision and final approval.

Ethics

This article contains unpublished and original work of the authors. All authors are in one consent as regards to the manuscript and have read and approved the manuscript and no ethical issues involved.

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