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Electrochemical Evaluation of Reinforcement Concrete Exposed to Soil Type SP Contaminated with Sulphates

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The present research evaluates the electrochemical behaviour of concrete exposed to SP soil type, sand from marine environment and contaminated with 1, 2 and 3 % de $MgSO_4$, this experimental setup simulates what happens on the foundations of civil infrastructure as bridges, docks, highways, etc., when they are built on contaminated soils with this aggressive agent due to discharges of wastewater, marine waters or areas polluted by agrochemicals. The concrete used in making specimens of study was designed according to the ACI method 211.1, it was considered to design the concrete mixture a ratio w/c=0.65 (f´c=250 kg/cm^2), two types of cement, ordinary portland cement (CPC 30R) and sulphate-resisting cement (CPC 30R RS), in the specimens were embedded as reinforcement bars of steel AISI 1018 and Galvanized steel. E_{corr} was evaluated according to the standard ASTM C-876-09 and the corrosion kinetics I_{corr} it was monitored by the technique of Linear Polarization Resistance (LPR), according to standard ASTM G-59-97(2009). The results of E_{corr} and I_{corr} correspond to 266 days of exposition in specimens to SP soil type contaminated with $MgSO_4$ indicating with increasing concentration of aggressive agent to 3% it is considerably decreased the corrosion resistance of the concrete specimens produced with sulphate resisting cement and reinforced with galvanized steel.

Keywords: Soil, Concrete, Corrosion Potential, Electrochemical, Sulphates

1. INTRODUCTION

The deterioration of civil infrastructure constructed of reinforced concrete, that has long time it has been the most widely used building material in the world, corrosion of reinforcing steel is for many researchers, it is the principal cause which gives rise to premature maintenance of structures such as bridges, docks, floors, buildings, plants of wastewater treatment, etc., maintenance that are around thousands of millions dollars quantified only in industrialized countries [1-6].

While it was thought that the concrete by their physical and mechanics characteristics inherent internal structure, considered durable material without maintenance, demonstrate has been for several decades with various research on the phenomenon of corrosion in reinforced concrete structures and especially to the development of electrochemical techniques, that idea of reinforced concrete as an almost eternal material and without maintenance problems has been changed [7-9].

The process of corrosion of reinforcing steel embedded in concrete is electrochemical nature, where it has in the same steel the presence of anode where oxidation occurs and a cathode where reduction occurs [10-12], where concrete functions as the electrolyte, having that same steel bar as the electric wires closing the circuit of the electrochemical cell that is necessary for this phenomenon.

Corrosion of reinforcing steel in concrete structures can be caused by various factors, among the most important is the entry of aggressive ions depassivating, as chlorides that are present in marine environments and are more aggressive development of corrosion [13-17] and sulphates, which can be found in the inorganic salts which are usually present in soils, for wastewater discharge, contact with marine water, groundwater and surface water, or in areas where agricultural chemicals have been used [18-21], however the degree of concentration of these salts can vary greatly. When sulphates are presents in water contacting with a hardened cement paste, this can significantly increase the solubility of the components of the paste, and cause, on one side degradation development concrete leaching and following exposure of steel to be unprotected, which it gives rise to corrosion process [22,23], there have been studies where it has been shown that the galvanized steel reinforced concrete have a better performance against corrosion, when exposed to aggressive environments laboratory simulated, contamination with prior concrete mix, limited resistance to corrosion to the level of concentration of the aggressive agent present in the media exposure studied or incorporated into the concrete mix [24-27].

Also in recent decades there has been an increase in research and studies on corrosion resistance of reinforced concrete with the use of alternative materials to the Portland Cement, partially replacing Portland Cement by materials with pozzolanic characteristics as they are silica fume, fly ash and in the last 20 years by ash from sugarcane bagasse, ash from rice husk etc., the above with the goal to decrease the corrosion problem and contribute to developing sustainable concrete they are friendly to our environment and contribute to sustainable development of our societies [28-34].

It has, according to the preceding paragraphs, magnitude an idea of the importance of the problem and corrosion in concrete structures, both economic, social and environmental, although abundant research work on this problem, with many variables studied in a lot of research around the world, It can be mentioned, that information corresponding to corrosion in reinforced concrete due to sulphates present in soils, it is minimal with respect to the abundant literature on the corrosion reinforced concrete present in marine or industrial environments, from there the importance of studying this mechanism and at the same time use galvanized steel and cement resistant to sulphates, to develop reinforced concrete that can withstand or mitigate the damage that can be caused in concrete elements what supporting structures (foundations) and they are in contact with the soil, considering that its importance is more 95% of civil infrastructure have structural foundation elements such as footings, foundation slabs, retaining walls, etc., and who will be throughout their lifetime in service in contact with soil and of course with this aggressive agents depassivating it may contain.

2. EXPERIMENTAL

The parameters to be considered in this work are a mix of concrete with a a ratio water/cement = 0.65 (f´c=250 kg/cm^2), two types of cement CPC 30 R and CPO 30R RS, carbon steel AISI 1018 and corrugated galvanized steel with diameter of 3/8 ", four environments of exposure or contact (sand contaminated with: 0, 1, 2 and 3% of magnesium sulphate), monitoring potential and interpretation according to standard test method ASMT C876-09 [35]; and the monitoring of the corrosion kinetics through the technique of linear polarization resistance (LPR) according to standard test method ASMT G59-97 [36].

2.1 Design and proportioning of concrete mixture

The formulation of concrete mixtures was carried out according to the method ACI 211.1 [37]; in which the characterization of the physical properties of aggregates should be used, based on the ONNCCE regulations. This method allows us to determine the proportioning of the mixture, i.e. it indicates the amount of material needed to produce a meter cubic concrete for ratio water/cement = 0.65 (f´c=250 kg/cm^2) established; table 1 shows the amounts used for this research.

Table 1. Dosage of the concrete mixture.

Content (Kg/m3)		**Ratio w/c = 0.65**
Cement		316
Water		205
Aggregate	Coarse	912.12
	Fine	911.88

2.2 Features and specifications of study specimens

As previously mentioned two types of reinforcing 3/8¨ steel, AISI 1018 carbon steel and galvanized steel were used as working electrode (WE) and in the centre of each specimen was placed a stainless steel bar which serves as auxiliary electrode (AE). The dimensions of the specimen and the arrangement of the bars embedded in them are shown in the last figure 1.

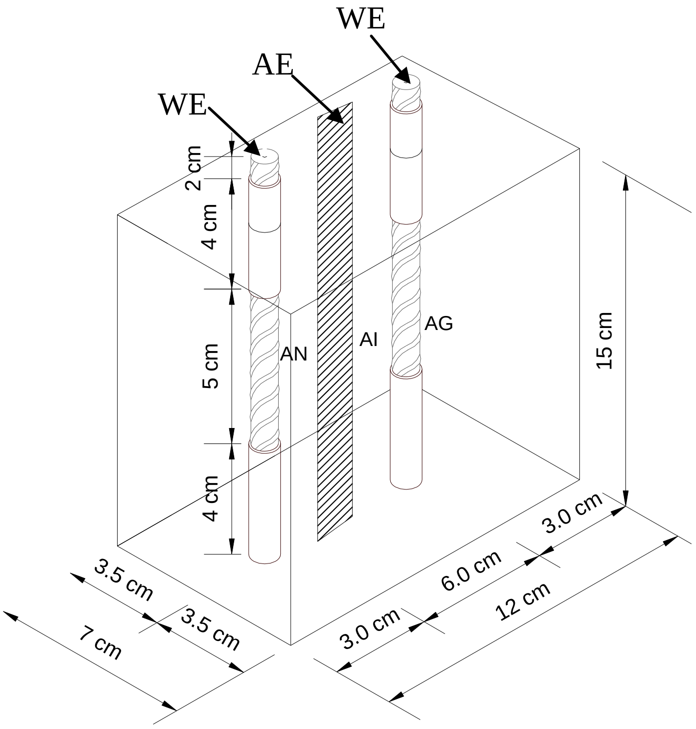

Figure 1. Dimensions of test specimens.

The rods of AISI 1018 carbon steel and galvanized steel were cleaned to remove any impurities that might have been present on them [38], then define the area to be evaluated and the remainder was covered with an anticorrosive paint according to the literature [39,40], see Fig. 2.

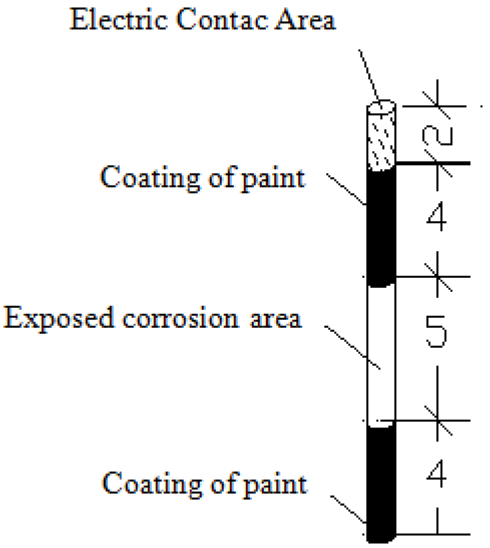

Figure 2. Characteristics of steel bars (cm).

The manufacture of the test specimens was performed as indicated in the standard test method NMX-C-159-2004 [41]. Each of the specimens is assigned a nomenclature, depending on the variables indicated in table 2.

Table 2. Nomenclature of test specimens.

Used nomenclature							
A60RG	A60RN	B61RMG	B61RMN	C62RMG	C62RMN	D63RMG	D63RMN
A60RSG	A60RSN	B61RSMG	B61RSMN	C62RSMG	C62RSMN	D63RSMG	D63RSMN

Where:

A, B, C and D refer to the specimen.

The 6 indicates the ratio water/cement = 0.65 (f´c= 250 kg/cm^2).

0, 1, 2 and 3 show the percentage of magnesium sulphate in the sand or environment of exposure.

R and RS, indicates the type of cement mixtures: R=CPC 30R y RS=CPC 30R RS.

The M indicates that the percentage of pollutant corresponding to magnesium sulphate.

The latest data indicates the steel to be evaluated G = galvanized steel and N = AISI 1018 carbon steel.

Specimens having been mixed and the scaffolding removed were subjected to curing stage for 28 days as indicated by the standard.

After the humidity lost step, the specimens were placed in the sea sand contaminated with 0, 1, 2 and 3% of magnesium sulphate, to be used as an environment of exposure. The specimens were evaluated for a period of time of 266 days by electrochemical techniques of corrosion potential (E_{corr}) and corrosion kinetics (I_{corr}). The experimental arrangement was elaborated according to the standard ASTM G59-97, this arrangement consider an Reference Electrode $Cu/CuSO_4$ (RE), Auxiliary Electrode (AE) and Working Electrode (WE), which together form an electrochemical cell.

To determine the type of soil in which the specimens were to be located, the physical characterization was formulated and replicated so as to constitute a soil sample with sand wrong graduated of symbol SP according to SUCS [42].

3. RESULTS

3.1 Corrosion Potential

Monitoring and interpretation of corrosion potentials (E_{corr}) were performed based in the standard test method ASTM C876-09, considering an extra range according to literature [43], see Table 3.

Table 3. Corrosion potential in reinforced concrete.

Corrosion Potential (mV vs Cu/CuSO$_4$)	
< - 500	Severe Corrosion
< -350	90% Probability of Corrosion
-350 a -200	Uncertanty
> -200	10% Probability of Corrosion

The figure 3 represents the results of the monitoring of (E$_{corr}$) corrosion potential, the specimens are ratio w/c=0.65 (f´c = 250 kg/cm^2), consisting of two types of cement, as well as two types of reinforcement, AISI 1018 carbon steel and galvanized steel. This simulating of reinforced concrete elements is consistent with the methods of many other researchers [44-46].

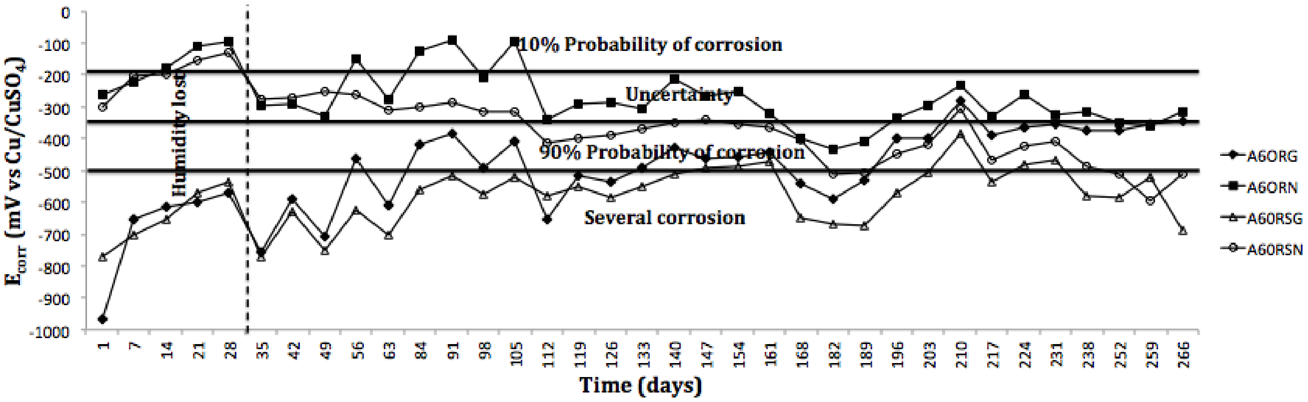

Figure 3. E$_{corr}$, specimens in SP soil with 0% of magnesium sulphate.

Figure 3 shows the results of the corrosion potential, E$_{corr}$, of specimens prepared with relation w/c = 0.65. In the case of specimens with CPC 30R and CPC 30R RS cement and steel reinforcement AISI 1018 (A60RN y A60RSN), it must be the first presents in the day 29 to 50 potentials in the range of 10% of probability corrosion, for two days 56 to final day of exposition in the aggressive environment, to present potential values of -200 a -300 mV, in the case for the specimen made with CPC 30R RS cement, this present a poorer behavior, presenting from the first day of exposure to the environment to day 112, potential between -200 mV and -300 mV, to stay until the day after 250 in an area 90% probability of corrosion and present in last days, 260-270, indicating severe corrosion potential with E$_{corr}$ of -500 and -700 mV.

Specimens with galvanized steel embedded in concrete made with CPC 30R and CPC 30R RS cement (A60RG and A60RSG), this exhibit unstable behaviour from the start of their exposure until day 112, with values of E$_{corr}$, indicating a 90% probability of corrosion for the specimen A60RG, and several corrosion severe in the specimen A60RSG, after the day 120 the specimen A60RG, it performs better, passing of the 90% Probability of Corrosion to an area of uncertainty at the end of the evaluation period, however, the corrosion potentials of specimen A60RSG range in values indicating 90% Probability of Corrosion to values of severe corrosion, presenting at the end of monitoring a trend toward more negative values of -500 mV. The benefit of sulphate resistant cement is not observed in steels, however if you can identify the benefit of using galvanized steel.

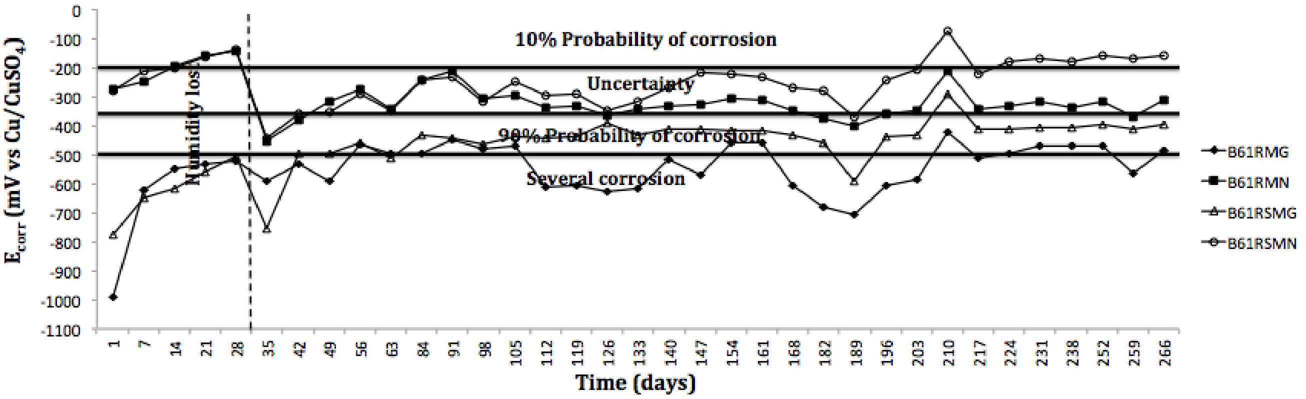

Figure 4. E_{corr}, specimens in SP soil with 1% of magnesium sulphate.

Figure 4 shows the corrosion potentials of the specimens exposed to soil type SP with a concentration of 1% de $MgSO_4$, specimens are made with cement CPC 30R and CPC 30R RS with steel AISI 1018 (B61RMN and B61RSMN respectively) and specimens with galvanized steel (B61RMG and B61RSMG). It can be seen in the first two specimens, that upon contact with contaminated soil present values of E_{corr} indicating 90% Probability of Corrosion for both (B61RMN y B61RSMN), then go to values indicant uncertainty, until day 100, it is when the effect is evident due to the type of cement, presenting a better performance the specimen made with resistant cement sulphates B61RSMN, with values of E_{corr} indicating 10% probability corrosion, while the specimen B61RMN present E_{corr} values indicating uncertainty throughout the period of study. In the case of specimens galvanized steel reinforced, B61RMG and B61RSMG, the same behavior occurs, with E_{corr} values more negative to most positive over time when exposed to corrosive environment, this for both types of cement, for later, the benefit of cement CPC 30R RS is identified, introducing the specimen B61RSMG, E_{corr} values until the end of the monitoring what indicate a 90% probability corrosion, however, the specimen B61RMG presents E_{corr} values of severe corrosion in day 105 to 210.

Figure 5 shows the electrochemical behavior of specimens exposed to soil SP with 2% of $MgSO_4$, the specimens C62RMN y C62RSMN, made with cement CPC 30R and CPC 30R RS (resistant to sulphates) and AISI 1018 steel reinforced, is observed the benefit of utilizer sulphates resistant cement, best performance due to against corrosion of the specimen C62RSMN, with E_{corr} values indicating during the 270 days of exposure to soil with 2% $MgSO_4$ a 10% of probability corrosion, with E_{corr} values more positive than -100 mV, however the specimen C62RMN, made with cement CPC 30R (Normal Cement), present a activation period of 98 to 133 days, with E_{corr} values that indicate up to 90% probability of corrosion, to present in the period of 133 to 270 days E_{corr} values indicating a uncertainty of corrosion. In the case of specimens with galvanized steel C62RMG y C62RSMG, as to those discussed above, the specimen that presents the best performance it is made with sulphate resistant cement, C62RSMG, with E_{corr} values indicating a 90% probability corrosion during the 270 days of the exposition to aggressive environment, it is unlike the specimen C62RMG present E_{corr} values of severe corrosion after the 98 days to exposition, when the specimens are exposed to soil with 2% $MgSO_4$, the benefit of using sulphate resisting cement in concrete is evidence, presenting the AISI 1018 steel and galvanized a better performance against corrosion caused by sulphate soils.

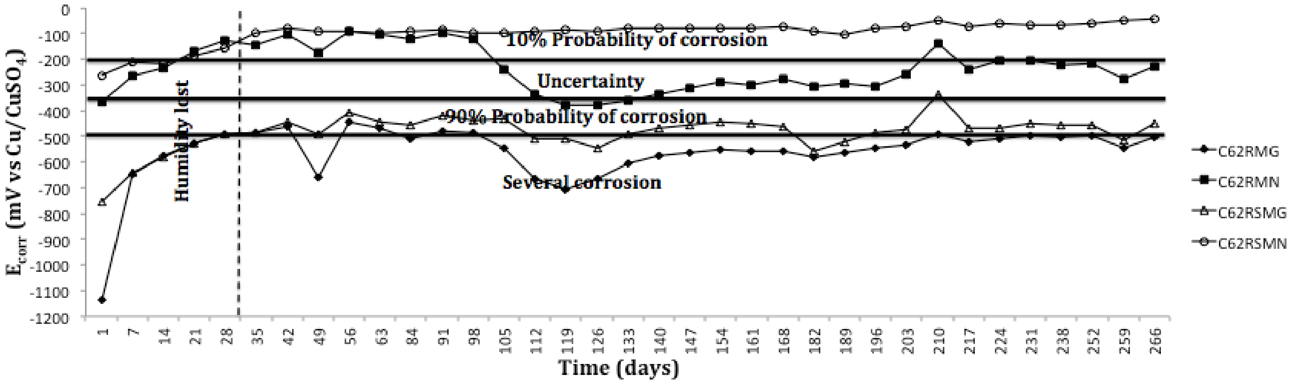

Figure 5. E_{corr}, specimens in SP soil with 2% of magnesium sulphate.

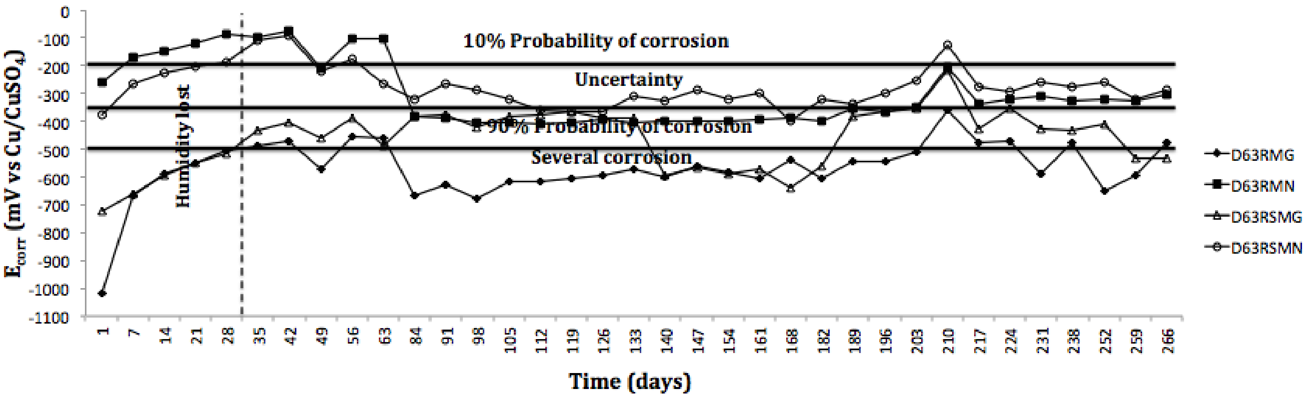

Figure 61. E_{corr}, specimens in SP soil with 3% of magnesium sulphate.

Figure 6 presents the monitoring results of E_{corr} about the specimens D63RMN and D63RSMN, elaborated with common cement (CPC 30R) the first one, and with sulphate-resistant cement (CPC 30R RS) the second one, both were reinforced with steel bars AISI 1018, in the case of the specimens D63RMG and D63RSMG were elaborated with the same types of cement, changing its reinforcement with galvanized steel, the four specimens were exposed to a SP soil, contaminated with 3% of $MgSO_4$. It can be concluded from Figure 6, that the difference between the specimens exposed to a 1 and 2% of $MgSO_4$, and the specimens elaborated with common cement and sulphate-resistant cement, including the steel 1018 and the galvanized steel, is the contamination percentage, because it is a factor in corrosion levels in all the specimens, showing an increased likelihood of corrosion compared with similar specimens exposed to a soil with lower concentrations of $MgSO_4$.

Some studies have reported similar results to those discussed in the previous figures, corrosion potentials (E_{corr}) of concrete specimens exposed to sulphate solutions for 6 months what indicating a 10% probability of corrosion [47], where its variable influencing better performance against corrosion was the addition of silica fume to the concrete mix, Assaad [48] reported that corrosion potential (E_{corr}) of concrete specimens exposed to over a year in sodium sulphate solution, they had values of -250 and

-350 mV, indicating a 90% % probability of corrosion, in that studio they were evaluated different concrete mixtures with additions of silica fume, fly ash and ratios water/cement, it can be seen the influence of each of the variables in the corrosion of reinforcing steel when the concrete is exposed to aggressive environments with presence of sulphates as in the present investigation.

It is known that the analysis of the potentials as indicated is a probably based method by which can be used to the analyse the kinetics of corrosion, and may corroborate the benefit of use of the CPC 30R RS sulphate-resistant cement and galvanized steel when the reinforced concrete is exposed in a sulphated soil as simulated in this research.

4. DISCUSSION

4.1 Corrosion Kinetics

The linear polarization resistance (LPR), is an electrochemical technique that is widely used for monitoring the instantaneous corrosion rate in plant [49], and commonly used within the scientific community for laboratory tests [50]. The corrosion kinetics of specimens was evaluated at based on the standard ASTM G 59-97(2009), and for collected date using a typical scanning range of ± 20 mV around the E_{corr}, with scan speed of 10 mV/min, the equipment used for this was a Gill AC Potentiostat/Galvanostat/ZRA ACM instruments with a reference electrode of copper-copper sulphate ($Cu/CuSO_4$). The criterion used for the interpretation of the results was noted in the Manual DURAR Network [51], which indicates four levels of corrosion; see in table 3.

Table 3. Level of corrosion in accordance to the $I_{corr.}$

Corrosion Rate (I_{corr}) μA/cm^2	**Level of Corrosion**
< 0.1	Despicable
0.1 – 0.5	Moderate
0.5 – 1	Elevated
> 1	Very high

Figure 7 presents the I_{corr} corrosion kinetics of concrete specimens, elaborated with two types of cement and two reinforced steels, AISI 1018 and galvanized steel, for being exposed in a soil from Veracruz State, type SP according to the SUCS. The specimens A60RN and A60RSN match to the specimens reinforced with AISI 1018 steel and the Concrete specimens elaborated with common cement (CPC 30R) and sulphate-resistant cement (CPC 30R RS) respectively, and in the case of the specimens reinforced with galvanized steel there are A60RG and A60RSG. It can be seen that after the curing step and to initiate contact with the aggressive medium, is presented in the four of them an unstable period in the corrosion rate, that period covered day 29 to day 120 with peaks and troughs in the levels of moderate to high corrosion, presenting day 120 to 160 all of them a stable period with high corrosion values, higher than 0.5 μA/cm^2, except the specimen A60RG, that on the last 100 days presented a moderated corrosion level according to the literature with values below 0.5 μA/cm^2. Is not observed any benefit against the corrosion by using a sulphate-resistant cement, to being exposed to this medium (SP soil type), it is observed and could be identified, the best benefit of using galvanized steel for better performance against the corrosion.

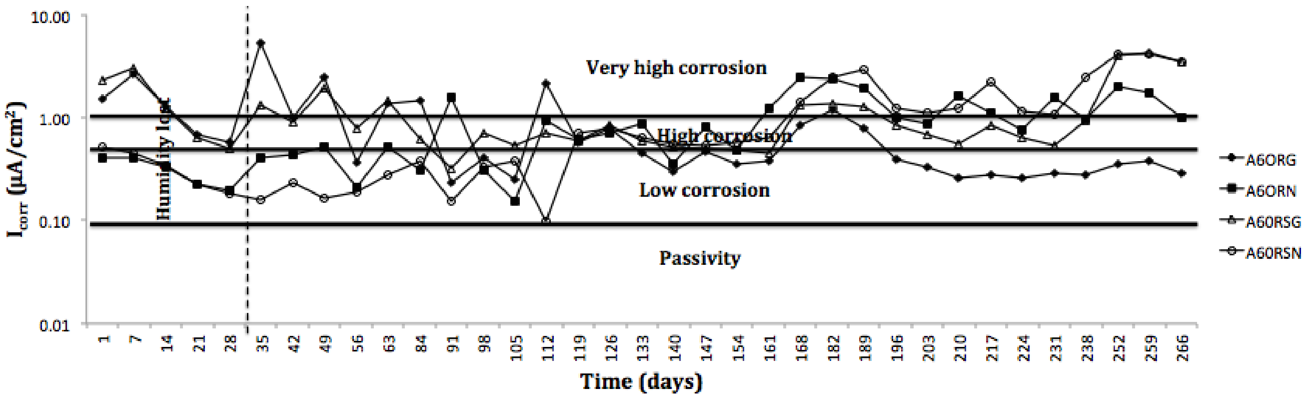

Figure 72. I_{corr} specimens in SP soil with 0% of magnesium sulphate.

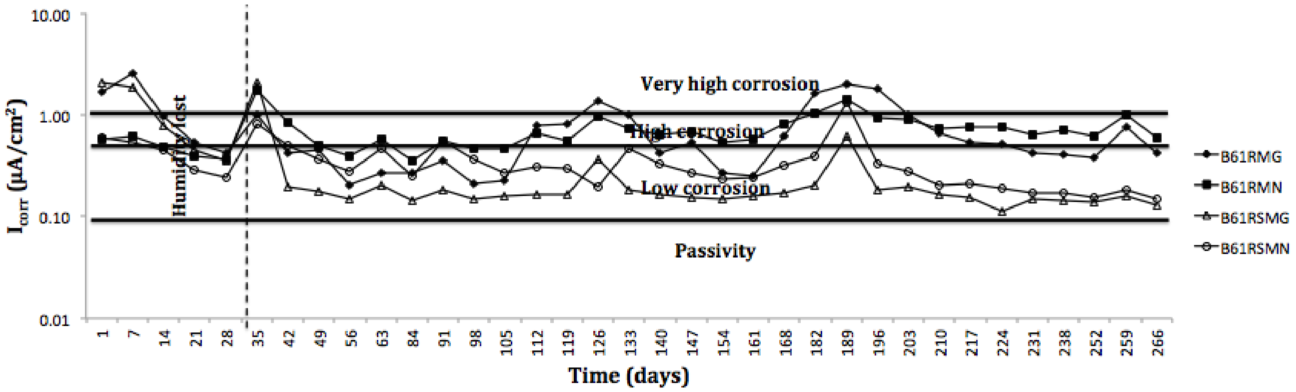

Figure 83. I_{corr} specimens in SP soil with 1% of magnesium sulphate.

In case of Figure 8, there are the results of the I_{corr} corrosion kinetics of concrete specimens, similar to those discussed in Figure 7, exposed at the same soil type SP but now contaminated with a 1% of $MgSO_4$ with respect to its weight as an aggressive agent, as indicated for specimens analysed in Figure 8, for processing were used two types of cement and two reinforced steels, the specimens B61RMN and B61RSMN match to the reinforced with steel AISI 1018 with common cement CPC 30R and sulphate-resistant cement, CPC 30R RS, respectively, in the case of specimens with galvanized steel, their "names" are B61RMG and B61RSMG, it is observed for all of them, a period to day 29 to 120, more stable compared with that observed in the soil without the addition of $MgSO_4$.

Analysing the I_{corr} results in Figure 9, where the change is respect to the specimens analysed in Figures 7 and 8, it is that in this case are exposed to a SP soil with 2% of $MgSO_4$, it is has that the specimens with AISI 1018 steel, with different type of cement, common and sulphate-resistant (C62RMN and C62RSMN), are presenting a behaviour along the study period (270 days), where it could be identify the efficient of the sulphate-resistant cement, presenting the specimen C62RMN after the first 90 days of being exposed to an activation of reinforced steel with an increased in the I_{corr} of values below 0.1 $\mu A/cm^2$ to values up of 1 $\mu A/cm^2$ which indicate a very high level of corrosion to day 120 and continue like that until the end of the experimentation in securities of 0.7 $\mu A/cm^2$ to 0.4

µA/cm^2, instead of the elaborated with sulphate-resistant cement, specimen C62RSMN, reported since the beginning of exposure to soil with 2% of $MgSO_4$ until the end (day 29 to day 270), an I_{corr} who has a despicable corrosion level, with values below 0.1 µA/cm^2; In the case of specimens with galvanized steel C62RMG and C62RSMG is seen the benefit of using the sulphate-resistant cement, presenting specimen C62RSMG a better performance than the elaborated with common cement, with an I_{corr} below 0.5 µA/cm^2 from the day 66 to day 270 of the exposure with a moderated corrosion level.

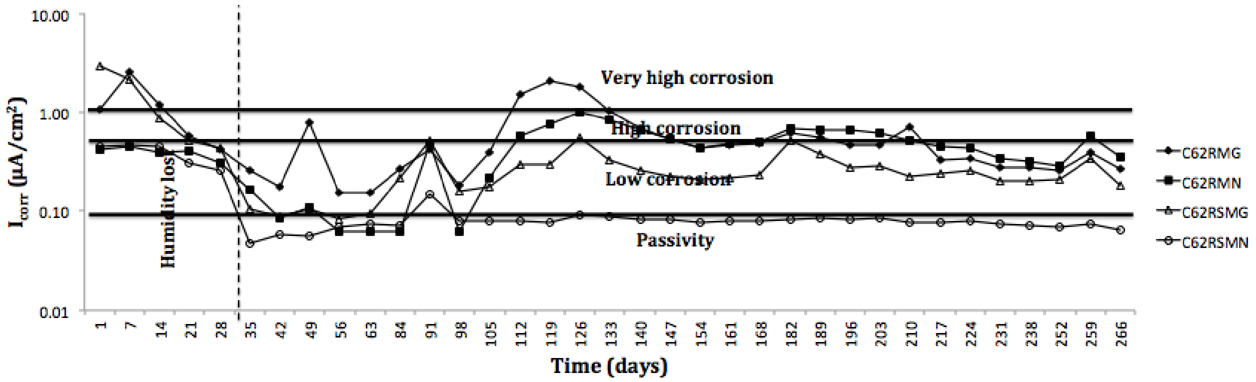

Figure 94. I_{corr} specimens in SP soil with 2% of magnesium sulphate.

By increasing the concentration of $MgSO_4$ to 3%, the statement that is not enough the use of sulphate-resistant cement, to have a better performance against the corrosion of reinforced steel, is confirmed because as it can see in the results of Figure 10, after an instable period that is presented in all the specimens since the day 30 to day 95, increased corrosion speed of all specimens is observed, presenting those who were made with common cement CPC 30R , reinforced steel AISI 1018 and galvanized steel (D63RMN and D63RMG), I_{corr} higher values above 0.5 µA/cm^2, with a high corrosion level from the day of exposure 100 until the last monitoring, unlike the D63RSMN and D63RSMG, who were made with sulphate-resistant cement with AISI 1018 steel and galvanized steel, respectively, presenting specimen D63RSMN I_{corr} values that shows a moderated corrosion level up of 0.4 µA/cm^2, having the best performance specimen D63RSMG, reinforced with galvanized steel and sulphate-resistant cement, with I_{corr} values between 0.1 and 0.3 µA/cm^2.

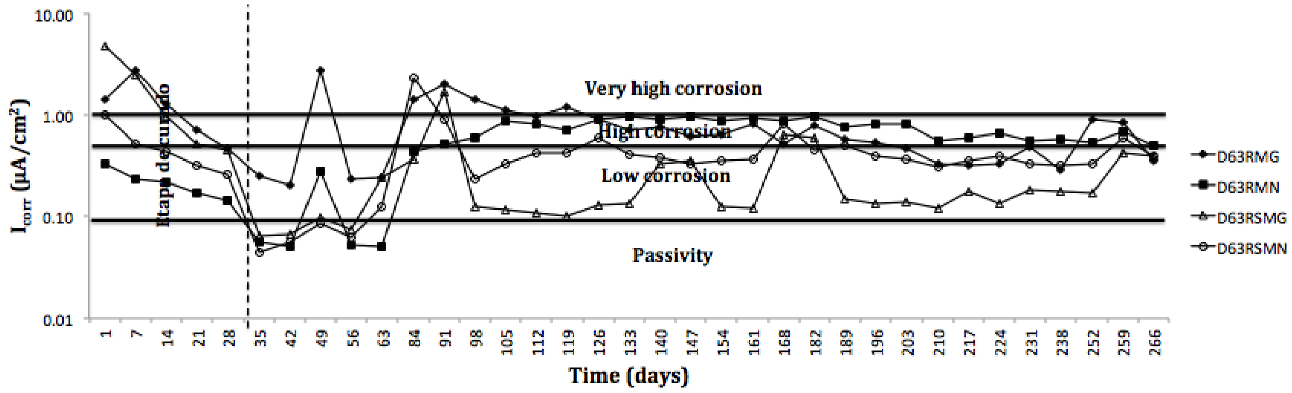

Figure 10. I_{corr} specimens in SP soil with 3% of magnesium sulphate.

The results discussed in the previous figures overlap with those reported in the literature, for example Jarrah [52] when he evaluated concrete specimens exposed to solutions of sulphate, chloride–sulphate, found that immersed in the solution containing only sulphates showed passive corrosion after two and a half years of exposure, unlike specimens exposed to chloride-sulfate solution, where I_{corr} presents values 0.1 and 0.6 $\mu A/cm^2$, such as those presented in Figure 8, indicating that the influence of sulphate if in the process of corrosion of reinforcing steel is very important, the above also coincides with Baghabra´s reported [53], when it analyzed, among other important points, the role of sulphates ions in reinforcement corrosion and the influence of the types of cement used in concrete mixtures, finding a benefit of using sulphate resistant cements, coinciding with some obtained in this investigation results, as the good performance of the specimens made with the CPC 30R RS cement, another interesting work that demonstrated the effect of sulfate ions in the corrosion of reinforcing steel and it helps to give certainty to the results obtained in this investigation, they were reported by Abd El Haleem [54], concluded what the rate of oxide film thickening in $Ca(OH)_2$ solutions devoid of and containing Cl^- and SO_4^{2-} ions follows a direct logarithmic law as evident from the linear relationships between the open-circuit potential and the logarithm of immersion time and threshold concentrations of both Cl^- and SO_4^{2-} anions decrease the rate of oxide film thickening and finally cause the destruction of passivity and initiation of visible pits.

Given the limited information on the reinforced concrete corrosion caused by soil contaminated with sulphates, compared to the vast information exists on the effect of chloride ions, it is of great interest to continue studying the effect of sulphate ions in the corrosion of steel reinforcement of concrete structures, because so far this study is not conclusive.

5. CONCLUSIONS

From the results of this investigation showed that when the concentration of $MgSO_4$ on a soil type SP of marine environment is of 1 to 2%, the corrosion resistance of reinforced concrete specimens of ration water/cement = 0.65 ($f'c=250\ kg/cm^2$), It is higher in the specimens prepared with sulfate-resistant cement CPC 30R RS and reinforced with galvanized steel rods, presented during the 260 days of exposure the best performance against corrosion, I_{corr} values that indicate a level of despicable to moderate corrosion. However, when the soil type SP has a concentration of 3% $MgSO_4$, all specimens after 130 days have activation kinetics corrosion, presenting I_{corr} values that indicant a level of high and moderate corrosion until the end of monitoring, with the exception of the specimen made with sulphate-resisting cement and reinforced with galvanized steel, which presents periods of activation and passivation, which at the end of 266 days, it presents I_{corr} values indicating a moderate level of corrosion coinciding with the other specimens, this shows the effect of 3% concentration of $MgSO_4$ as aggressive agent on the studio soil, we can say that with a concentration of 3% of $MgSO_4$ on the soil, the resistance to corrosion of the specimens prepared with sulfate-resistant cement and reinforced with galvanized steel is significantly reduced.

According with the last, we can say that the soil where reinforced concrete foundations are built and are supported by civil infrastructure, as bridges, buildings, pavements, docks, retaining walls, etc., it should also be considered an aggressive environment and conducive to the development of corrosion of reinforcing steel that can lead to premature deterioration of these structures, and that the results of this investigation are such that the magnitude of the problems of corrosion of reinforcing steel of structures exposed to soils, it depends largely on the concentration of aggressive agents such as sulphates, carbonates, chlorides, presents in that soil. While there are options that can help reduce the problem is, as the use of sulfate resisting cement or the use of galvanized steel reinforcement, as it proposed in this research, to have 3% $MgSO_4$ concentration in soil, the concrete made with this type of cement and reinforced with galvanized steel did not offer adequate protection against corrosion.

According to the global context of sustainable development of our societies, the study and development of sustainable concrete is recommended, concrete having higher durability and corrosion resistance when they exposed to very aggressive soils, concrete base substitutions partial Portland Cement as alternative materials as silica fume, fly ash, ash bagasse and reinforcing steel greater corrosion resistance, as the stainless steels 304, 316, 316L.

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References

1. S.D. Cramer, B.S. Covino Jr., S.J. Bullard, G.R. Holcomb, J.H. Russell, F.J. Nelson, H.M. Laylor, S.M. Soltesz, *Cem. Concr. Compos.* 24(2002)101.
2. H.K. Gerhardus, M.P.H. Brongers and G. Neil, Thompson-CC, Dublin, Ohio, Y. Paul Virmani, Turner-Fairbank, J.H. Payer Case, "Corrosion Costs and Preventive Strategies in the United States" PUBLICATION NO. FHWA-RD-01-156, 2006.
3. M. Maslehuddin, M.M. Al-Zahrani, M. Ibrahim, M.H. Al-Mehthel, S.H. Al-Idi, *Constr. Build. Mater*., 21(2007)1825
4. Erhan Gu neyisi, Turan Ozturan, Mehmet Gesog lu, *Cem. Concr. Compos*., 27(2005)449.
5. Pin Gu, S. Elliot, J.J. Beaudoin and B. Arsenault, *Cem. Concr. Res*., 26(1996)1151.
6. H. Saricimen, M. Mohammad, A. Quddus, M. Shameem, M.S. Barry, *Cem. Concr. Compos*., 24(2002)89.
7. F.H. Estupiñán-López, F. Almeraya-Calderón, R.G. Bautista Margulis, M.A. Baltazar Zamora, A. Martínez-Villafañe, J. Uruchurtu Ch., C. Gaona-Tiburcio, *Int. J. Electrochem. Sci.*, 7(2012)9825.
8. Ahmet Raif Bog, Ilker Bekir Topçu, *Constr. Build. Mater*, 31(2012) 258.
9. G. Santiago-Hurtado, E.E. Maldonado-Bandala, F.J. Olguin Coca, F. Almeraya-Calderón, A. Torres-Acosta, M. A. Baltazar-Zamora, *Int. J. Electrochem. Sci., 6(2011)1785.*
10. N Gowripalan1and H.M Mohameda, *Cem. Concr. Res*. 28(1998)1119.
11. Ming-Te Liang, Ji-Jie Lan, *Cem. Concr. Res*., 35(2005)540.
12. G. Santiago-Hurtado, M.A. Baltazar-Zamora, A. Galindo D, J.A. Cabral M, F.H. Estupíñan, P. Zambrano Robledo, C. Gaona-Tiburcio, *Int. J. Electrochem. Sci*. 8(2013)8490.
13. V. Elias, K.L. Fishman, B.R. Cristopher and R.R. Berg, "Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes", U.S. Department of Transportation Publication No. FHWA-NHI-09-087, Federal Highway Administration, Washington D.C. 2009.
14. A. Shamsad, *Cem. Concr. Compos.,* 25(2003)459
15. Ki Yong Ann, Ha-Won Song, *Corros. Sci*., 49 (2007) 4113.

16. S.T. Leea, H.Y. Moonb, R.N. Swamyc, *Cem. Concr. Compos.*, 27(2005)65.
17. A.I.M Ismail, A.M El-Shamy, Appl. Clay Sci. 42(2009)356.
18. R.A. Gladstone, P.L. Anderson, K.L. Fishman and J.L. Withiam, *Journal of the Transportation Research Board*, 1975 (2006) 49.
19. Manu Santhanam, Menashi D Cohen, Jan Olek, *Cement and Concr. Research.* 31(2001)875.
20. Obada Kayali, Stephen R. Yeomans, *Cem. Concr. Compos*. 22(2000)459.
21. M.A. Baltazar Zamora, Tesis de Maestría, U.A.CH., Chihuahua, México, 2000.
22. M.A. Baltazar-Zamora, Tesis Doctoral, CIMAV, Chihuahua, México, 2005.
23. G. Ebell, A. Burkert, J. Lehmann and J. Mietz, *Mater. Corros.*, 63 (2012) 791.
24. Cheng, R. Huang, J.K. Wu, C.H. Chen, *Construction and Building Materials*, 19(2005)404.
25. T. Bellezze, M. Malavolta, A. Quaranta, N. Ruffini, G. Roventi, *Cem. Concr. Compos*., 28(2006) 246.
26. Omar S. Baghabra Al-Amoudi, *Cem. Concr. Compos.*, 24(2002) 305.
27. David Darwin, JoAnn Browning, Matthew O'Reilly, Lihua Xing, and Jianxin Ji, *ACI Materials Journal*, 106 (2009) 176.
28. E. E. Maldonado-Bandala, V. Jiménez- Quero, F. J. Olguin-Coca, L. G. Lizarraga M, M. A. Baltazar-Zamora, A.Ortiz-C., F. Almeraya C., P. Zambrano R., C. Gaona-Tiburcio, *Int. J. Electrochem. Sci*., 6(2011)4915.
29. Nuntachai Chusilp, Chai Jaturapitakkul, Kraiwood Kiattikomol, *Constr. Build. Mater*, 23(2009)3352.
30. Guilherme Chagas Cordeiro, Romildo Dias Toledo Filho, Luís Marcelo Tavares, Eduardo de Moraes Rego Fairbairn, *Cem. Concr. Res*., 39(2009)110.
31. Tayyeb Akram, Shazim Ali Memon, Humayun Obaid, *Constr. Build. Mater*, 23(2009)703.
32. K. Ganesan, K. Rajagopal, K. Thangavel, *Cem. Concr. Compos*. 29(2007)515.
33. G.C. Cordeiro, R.D. Toledo Filho, L.M. Tavares, E.M.R. Fairbairn, *Cem. Concr. Compos*. 30(2008)410.
34. Nuntachai Chusilp, Chai Jaturapitakkul, Kraiwood Kiattikomol, *Constr. Build. Mater*, 23(2009)3523.
35. ASTM C 876-09, Standard Test Method for Corrosion Potentials of Uncoated Reinforcing steel in Concrete, ASTM Volume 03.02, 2009.
36. ASTM G 59-97(2009), Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements, ASTM Volume 03.02, 2009.
37. ACI. Proporcionamiento de Mezclas, Concreto normal, pesado y masivo ACI 211.1, Ed. IMCYC, México, (2004).
38. G. Santiago-Hurtado, C.M. Hernández-Domínguez, M.A. Baltazar-Zamora, presented at SMEQ 2012. 5th Meeting of the Mexican Section of the ECS, Toluca, Estado de México, México. 11 – 15 de Junio del 2012.
39. G. Santiago-Hurtado, M.A. Baltazar-Zamora, presented at SMEQ 2012- 5th Meeting of the Mexican Section of the ECS, Toluca, Estado de México, México. 11 – 15 de Junio del 2012.
40. C.M. Hernández-Domínguez, G. Santiago-Hurtado, M.A. Baltazar-Zamora, presented at presented at SMEQ 2010-3th Meeting of the Mexican Section of the ECS, Zacatecas, Zacatecas, Méx., Junio del 2010.
41. NMX-C-159-2004, "Industria de la construcción – concreto- Elaboración y curado de especímenes en el laboratorio", ONNCCE S.C., 2004.
42. Braja M. Das, Principio de Ingeniería de Cimentaciones, Ed. Thomson, México, (2006).
43. Ha-Won Song, Velu Saraswathy, *Int. J. Electrochem. Sci*., 2(2007)1.
44. Ki Yong Ann, Ha-Won Song, *Corros. Sci*. 49(2007)4113.
45. S.U. Al-Dulaijan, M.M. Al-Zahrani, H. Saricimen, M. Maslehuddin, M. Shameem, T.A. Abbasi, *Cem. Concr. Compos*. 24(2002)139.
46. S. Sathiyanarayanan, Panjali Natarajan, K. Saravanan, S. Srinivasan, G. Venkatachari, *Cem.*

Concr. Compos. 28(2006)630.

47. Corral-Higuera R., Arredondo-Rea S.P., Neri-Flores M.A., Gómez –Soberón J.M., Almeraya Calderón F, Castorena-González J.H, Almaral-Sanchéz J.L., *Int. J. Electrochem. Sci.*, 6(2011)613.
48. V. Assaad, J. Jofriet, S. Negi, G. Hayward., *Agricultural Engineering International: the CIGR Ejournal,* 7(2005) 1.
49. Almeraya Calderón F, Zambrano Robledo P, Borunda T A, Martnez Villafañe A,Estupiñan L F. H., Gaona Tiburcio C., *Corrosión y preservación de la infraestructura industrial. Barcelona, España:OmniaScience*, 207-224. (2013).
50. J. A. Cabrera-Madrid, M. Balancán-Zapata, A. A. Torres-Acosta, P. Castro-Borges, *Int. J. Electrochem. Sci.,* 9(2014) 8211.
51. Red DURAR, *Manual de Inspección, Evaluación y Diagnóstico de Corrosión en Estructuras de Concreto Armado*, CYTED Program, Rio de Janeiro, (1997).
52. Nezar R. Jarrah, O. S. Baghabra A., M. Maslehuddin, O.A. Ashiru, A.I. Al-Mana, *Constr. Build. Mater*, 9(1995)97.
53. O. S. Baghabra Al-Amoudi, *Build. Environ*, 33(1998)53.
54. S.M. Abd El Haleem, S. Abd El Wanees, E.E. Abd El Aal, A. Diab, *Corros. Sci*., 52 (2010)292.