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THE CORROSION EFFECT OF SULFUR-REDUCING BACTERIA ON REINFORCED HIGH STRENGTH CONCRETE

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ABSTRACT: This study deals with the ability of the sulfur reducing bacteria to cause corrosion in reinforced concrete .The susceptibility of those bacteria to cause corrosion in reinforced concrete has been tested by using models manufactured in laboratory of construction tests of the college of engineering University of Diyala. where they were studying the effect of bacteria on the high strength concrete mix by using ordinary and sulfate-resistant cement and reinforced iron of 16 mm in different positions. The corrosion effort of reinforced concrete has been measured using a half-cell potential equipment. The effect of sulfur reducing bacteria on the high strength concrete mix with the use of sulfate-resistant cement has been less than its effect on the high- strength concrete mix with ordinary cement by 13%. This is due to the little amount of Mono ammonium tri-silica in high strength concrete and the paucity of porosity in the high strength concrete mix which leads to interference of effect between them and restricts the activity of the bacteria. Then, samples of mild iron have been used and the capacity of bacteria to cause corrosion have been studied with help of electronic scanning microscope.
Keywords: sulfur reducing bacteria**,** reinforced concrete**,** biocorrosion.

INTRODUCTION:

corrosion is defined as spoiling of certain material or of its properties as a result of interaction with external or internal influences or is defined as the damage that is caused by the interaction of two or more substances or components with the availability of conducive environment such as heat and humidity. Corrosion occurs in foundations slowly but cause unimaginable damage or loss economically and materially, including human related health issues, which affects him (ALAgha. 2006). Whereas, micro-biologically influenced corrosion is an electro-chemical process and in most cases the electrochemical interaction depends on the difference in potential , which causes the movement of electrons from the positive electrode (anode) to the negative electrode (cathode) which result in cathodic depolarization leading to pitting of the anode (Juzelinuas *et al* , 2006). The latter is defined as corrosion caused by the activity of different microorganisms and their effectiveness among the major ones is sulfur reducing bacteria (SRB). However, SRB is not the only one to case corrosion in metals and reinforced iron (Li *et al*, 2006) . Moreover, the essential character of this SRB is that it is found as obligate anaerobic communities of bacteria. It is also effective in the use of sulfates as a final recipient of electrons during anaerobic respiration and it is able to generate sulfide hydrogen from the reduction of sulfate (Boetius *etal* , 2000 Sahrani *etal* , 2008). This type is the main that causes the failure to many industries as it happens in the corrosion-induced transfer of cooling water systems in many workstations. It accounts for about 20% of the damage caused by this type of corrosion, which is a very complex process resulting from the overlap of many types of microorganisms such as bacteria and non- microscopic ones as fungi (Jafa Herdashti., 2009). The biofilm contributes to citation of corrosion on the metal surface and its continuous development accelerates metal damage and corrosion (Teng *et al*, 2008). Immediately after being immersed in the aquatic environment, a metal develops corrosion. The biofilm thickness ranges (20-28 nm) and thus works to provide anaerobic conditions that boost the growth of sulfur-reducing bacteria and thereby increases the incidence of corrosion as it caused it in the first place (Vieldela and Herrera 2005) .

MATERIALS AND METHODS

1. **Mix culture for sulfur reducing bacteria (SRB):** - were obtained on mix culture depositions of the Tigris River, passing through the village of Zamnboor Khalis district of Diyala province.
2. **Samples of mild iron**: in corrosion tests samples of mild iron were used processed locally from the Department of Mechanical Engineering - college of Engineering - University of Diyala , with dimensions of (10 × 5) mm .
3. **Test of the ability of sulfur reducing bacteria on the corrosion of metals**.

Corrosion tests were conducted on mix culture sulfur reducing bacteria, and for different periods of time to study the feasibility of such bacteria on the corrosion of metals and is as follows:

Corrosion by using mix culture

Mild acetone-polished steel samples have been cleaned to remove grease, and then placed in a beaker filled with acid Hydraulic (N2) for 30 minutes to remove the protective layers and to become clean and predestined for corrosion. Thereafter, the samples are weighed accurately using sensitive balance and sterilized by burning on flame lamp of Bunsen. Next, they are placed in glass bottles containing 100 ml of liquid culture, sterilized media API. Each vial is vaccinated with 10 ml of mix culture stimulant (3 days old) undiagnosed of sulfur reducing bacteria. Bottles are incubated at 37 °C and the experiment lasted 84 days distributed over the time periods (28, 42, 56, 70, 84) days. Meantime, control samples are prepared using glass bottles containing only culture media and metal. The whole process is done using gas to get rid of aerobic conditions (Booth and Wormwell, 1961).

The method followed (Lim and Bell, 1981) to remove the corrosion product, as it samples washed well with hot water and placed in a glass beaker containing icy acetic acid for 30 minutes to remove the corrosion product then washed with distilled water and dried using filter paper, a method is used **(Greene and Fontana, 1978)** in the calculation of corrosion according to weight loss. And has also been using the scanning Electron Microscope to conduct tests on the sample of mild steel surface and study the changes that took place in which.

4. **Materials used in the concrete mix: -** The use of two types of ordinary and sulfate resistant cement produced by Al-Jisser, the aggregate is equipped with the rubble of the north of Iraq and the water used is drinking water.
5. **reinforced concrete samples:-** The concrete samples were made in constructional laboratory of research of the Department of Civil Engineering - college of Engineering - University of Diyala , has been designed concrete mix with a high strength to resist compression 45.51 Mega Pascal as comprising the mixture of different materials as in the table (1) and that the molds used for casting samples are prisms ranging dimensions (6 × 6 × 10) cm with arming the form using rebar in different positions, and during the casting process has been modeling on your Electrovibrators Vibration to introduce air bubbles from the sample and settled in the template then saved samples at room temperature for 24 hours where they were extracted from the template for use in experiments testing the speed of corrosion in reinforced concrete by sulfur reducing bacteria and Figure (1) illustrates the modeling of reinforced concrete used.

6 **- Test the effect of sulfur reducing bacteria on the corrosion of reinforced concrete**

sulfur reducing bacteria has been tested of causing corrosion in reinforced concrete through the design of a small environment for the growth of these bacteria and the development of the form of the concrete inside, where they were using plastic cans capacity of 1500 ml for the purpose of completing the work of the implant and the lap of sample inside as suggestive in Figure (2). The experience has been done several times Features included the first time a concrete sample was not sterilize where it was planted directly considering the use of gases and provide anaerobic conditions and in return control samples were made for the purpose of comparison, the second plant included sterilization concrete sample in a autoclave under a degree of 121°C for half-hour , but plastic cans were sterilized in alcohol 70% and has been planting the same way with the presence of control samples as well and samples incubated under room temperature and for a period of two months where they were measuring by half-cell potential (corrosion potential) using a half cell equipment provided by can in company and by the time periods prescribed (0,28,60) days.

7- Examine samples of concrete using a half cell potential

This device is used to measure the potential on the surface of the concrete to give an idea of the state of rust in the mild steel as it has been to prepare samples of concrete measured by wetting the surface analogy several times to get enough moisture, solution to examination is copper sulphate solution , which brings by melting 40 grams of that substance in 100 ml of distilled water , which is placed inside electrolid of the device , which connects directly to the device and on the other hand there is a pole last connecting point of the device and the other end connects to the mild steel in the sample and once you put on the wet surface electrolid device starts reading and recording the score at reading stability and measured by MV. If the reading is less than -200 mV means the likelihood of low-lying for the occurrence of rust and as shown in Figure 3 However, if the voltage difference between the -200 to -350 mV mean rust effective but is uncertain if either the voltage difference is greater than -350 mV mean a high probability for the occurrence rust, taking into account that the size ratio of the voltage to the pole Cu / cuso4 record (chansuriyasak *et al*, 2010).

RESULTS AND DISCUSSION

1- Corrosion of mild steel samples.

The results showed that the corrosion rate using the weight method is directly proportional to the time period of exposure since the mix culture experienced highest loss of weight of 0.1289 grams over 84 days compared with the control samples , which amounted to the loss of 0.0440 grams. This means that the corrosion rate increases with time as shown in Figure (4). While, corrosion in control samples is due to chemical corrosion by the components of the media and the availability of ions n chloride. All results reported were identical as (Dong) said and others in (2011). They have shown that corrosion by sulfur reducing bacteria increases with the time period of exposure. This also is in line with the study of (Guiamet and Saravia 2005) that proves that the mild steel samples subject to a series of inorganic biological reactions when immersed in medias containing sulfur reducing bacteria, leading to the formation of Biocorrosion. Further, the adhesion of microbial surfaces affects the systems of various industrial like water-cooling systems and oil industry and thermal power plants and other industrial processes. The corrosion of sulfur reducing bacteria depends on the composition of electrochemical cells and physical nature and chemical to corrosion product and the internal dynamics between the components of the media and metabolic products such as sulfide and sulfide Ferrous then that bacteria is working to remove the polarization of hydrogen in the areas of deposition sulfide Ferrous leading formation pitting compared with the surface of the metal itself and the result was identical as (Munoz) and others in (2007) said as well as the matching of what (Widdel, 1992) which indicated sulfide ferrous associated with biocorrosion product available in 81 % of cases of severe corrosion and 54 % of cases of medium corrosion and 46% cases of light corrosion indicating a high rate of corrosion of these bacteria.

(Wang) and others in (2011) said that the availability of sulfur reducing bacteria leads to obtain corrosion in anodic areas sought refuge get the transition several electrons from the anode to the cathode presence of water or culture media .(Daumus) and others in (1993) also noted that the substrate used by the sulfur reducing bacteria and products metabolic events resulting from interference in the occurrence of mechanical biocorrosion then that layer of sulfur compounds that work for Electron receptors play an important role in the occurrence of acid differentiation and this explains the lack of fermented bacteria producing acids stimulate pitting corrosion as sulfur reducing do. They also showed the results of the current study is a thin black layer on samples denote be biofilm and this result was identical (Castaneda and Benetto) (2008). said (Saravia) and others in (2003) also noted that the increase in the proportion of corrosion that occurs due to sulfur reducing bacteria back to the exposure of sulfide, which leads to the sulfide membrane (sulfide film) on the metal surface , thereby hindering the hydrogen molecules on its surface , and this encourages the Galvanic cells . The results of the examination using scanning electron microscope SEM samples mild iron exposed bacteria to a period of 84 days, note the appearance of cracks and clear and large in comparison with control samples, which did not show it as it goes back and there are those cracks in the protective layer of the samples of mild iron to the effectiveness Sulfur reducing bacteria. and that cracking protective layer exposed metal to rust and this result confirmed by (Starosvetsky) and others in (2008) as the protective layer of mild steel be high stabilized pH alkaline ph = 9 and this value when less, this layer begins to weak and break-up, which will accelerate steel rust and because of the culture media ph = 7.2 is alkaline, the protective layer breaks up directly and this is what the results showed. And also noted which was cuddling the availability of dark spots explain the availability of iron sulfate and other corrosion products, which produces about the effectiveness of the bacteria. while white spots appeared in the form of a nods, it shows the forming biofilm because of it lies the susceptibility of sulfur reducing bacteria of making corrosion in the samples mild steel and this was identical to (Cantaneda and Benetto) (2008) said. also the results of the current study was identical to (Xu) and others said in (2007) ensured that the black spots indicate the availability of sulfates and phosphates and chlorides , which produces of components for the media and cause corrosion on the surface of the samples as it gets in control samples and also shown in Figure (5) .

2-comparison of corrosion potential of samples with control samples:

2-1 corrosion in high- resistance concrete mix samples using ordinary cement with steel 16 mm.

The results of the current study showed that the half- cell potential sample of the concrete **B1** made of concrete mix high resistance and containing steel extended along the template and outside of those on one side reached -520 mV compared with the control sample , which amounted to -309 mV within 60 days , as was the difference between samples -211 mV while at 28 days , bringing the difference -455 mV, and concrete sample **B2** containing steel extending from the middle of the template and the outside of the hand and one reaching potential in -444 mV sample , compared with the control sample , which reached potential in -300 mV , as was the difference between the two samples -144 mV within 60 days either at 28 days was the difference between the two samples -412 mV, while **B3** concrete sample that contains steel extended along the outside of the mold and the two sides reached -530 mV compared with the control sample , which reached potential in -290 mV if the difference between the two models -240 mV within 60 days either at 28 the difference was -292 mV , and as shown in Figure (6). at the comparison among the three samples we note that B3 sample was highest latest potential amounted to -530 mV and then followed the B1 sample potential which reached -520 mV and then followed that B2 sample amounted to -444 mV.

2 -2 corrosion in samples made from high- resistance concrete mix using resistant cement with 16 mm diameter.

The results of the current study showed that the half- cell model potential of the concrete **BR1** made of concrete mix high resistance and resistant cement and containing steel extended along the template and out of hand, and one was -450 as compared with the control sample , which amounted to -244 mV within 60 days as the difference between the two samples either -206 mV at 28 , reaching -381 mV difference while concrete samples **BR2** containing steel extending from the middle of the template and outside the one hand , reaching potential in which -430 mV, compared with the control sample , which reached potential in which -263 mV as the difference between the typical -167 mV within 60 days , either at 28 days was the difference between models -288 mV, while concrete sample **BR3** that contains steel extended along the template and outside of the two sides reached potential in which -490 mV of bacterial culture compared with the control sample , which reached potential in which -305 mV as the difference between the two samples -185 mV through 60 the 28 days of age difference was -216 mV , as shown in Figure (7) . when comparing the three models we note that the form BR3 latest potential reached the top -490 mV then BR1 , which reached a voltage of -450 mV and then followed sample which stood BR2 -430 mV.

We note that the results of the current study, that the concrete mix with high resistance was less than the effected of sulfur reducing bacteria samples with concrete mix with resistance routine as the ratio of water to cement w / c to be less in the concrete mix with a high resistance and to be so porous surrounding iron few thus the reason for the lack of a place to bacteria to work, **(Hansson)** and his colleagues in **(2007)**. also note that the difference among the samples of the implant and samples of control at 28 days for all the samples of concrete mentioned was higher than the difference among the samples of the implant and control at the age of 60 and is due to the activity of the membrane bio which is more effective at the beginning of the configure, and then decreasing its effectiveness over time, and this result was matching what **(Dong)** and his colleagues said in **(2011)** and also reported **(Videla and Herrera) (2005)** to be a biofilm accelerate corrosion for ways to change the important factors surrounding metal such as pH and oxygen level and pressuring and nutrients , which are the interface between environment and the metal and the change of these factors lead to major changes such as the concentration and type of ions and effort meiosis and pH , which in turn lead to a change in the properties of the positive and negative of the metal , as well as configure the products of corrosion.

3- Comparing potential of the corrosion of the concrete models of the mixture resulting from the high resistance of sulfur reducing bacteria by using the ordinary and resistant cement.

The results of the current study showed that the readings half-cell potential samples ordinary cement (B1=-520, B2=-444, B3=-530) mV were higher compared with the readings resistant cement and respectively (BR1=-450, BR2=-43- , BR3=-490) mV at age of 60 days, as shown in Figure (8). because the results showed that the models made from ordinary cement (B1, B2, B3) showed corrosion potential higher by 13 % compared with the samples of concrete made from resistor cement (BR1, BR2, BR3) respectively. And explain those results that contain the standard cement a large proportion of aluminum composite unilateral three C3A and silica , which in turn reacts with the sulfates and chlorides available in environment, leading to the compound Alatrinkat a larger than the size of its constituent materials causing an increase in porosity in the surrounding area compared with steel compared with resistant cement that contains a small percentage of the compound aluminum unilateral and three silica, which leads to the availability of a small percentage of Alatrinkat also because the availability of sulfate is ineffective by a large margin because it is not available from the interaction with him and thus keeps the concrete sample for a longer period **(Skripkiunas *etal.* , 2013.(**

And the results of this study were identical to what was brought by (**Lopes**) and his colleagues in (**2006**) , as proved that the armature of the most affected by metal- sulfur reducing bacteria which makes concrete more susceptible to corrosion and deterioration over time.

CONCLUSIONS

1. The sulfur reducing bacteria SRB highly influential on the creation of corrosion in reinforced concrete, lay it out in their ability to form biofilm and possession of an enzyme hydrogens which pulls hydrogen ion from the metal surface during anaerobic respiration gallery to metal corrosion environment.
2. The effect of the use of concrete mix with a high resistance with the use of cement, steel to resist corrosion better than the use of concrete mix high strength cement with less effort as usual corrosion rate of 13 %.
3. from the current study concluded that samples of concrete containing steel extended along the template length of 20 cm caused corrosion potential of the top samples containing iron length of 15 cm by 2 % and corrosion potential of the top 14% of the samples containing steel length of 10 cm .
4. a low corrosion potential over time, they were the highest value at 28 days and then decreased at the age of 60 days by 26 %.

REFERENCES

Al Agha,O.M.(2006). Corrosion In Structures.J.AL-Agsa Unv., 10(S.E.):122-144.

Boetius, A. ;Raven Schlag , K. ; Schubert , C.J. ; Ricket , D.; Widdel , F. ; Gieseke , A. ; Amann, R.; Jorgensen , B. B. ; Witte , U. and Pfannkuche, O. (2000) a marine microbial consortium apparently mediationg anaerobic oxidation of methane . Letters to nature, 407: 623 – 626.

Booth, G.H. and Wormwell, F. (1961). Corrosion of mild steal by sulfate reducing bacteria. Effect of different strain of organisms. Cited by Starr, M.P.; Slop, H.; Truper, H.G.; Balows, A. and schegl, H.G. (ed). The Prokaryotes, a handbook of habitats, isolation and identification of bacteria. Vol. 2. Berlin. Springer-verlage.

Castaneda, H. and Benetton, X. D. (2008). SRB-biofilm influence in active corrosion sites formed at the steel-electrolyte interface when exposed to artificial seawater conditions. Corrosion Science 50: 1169–1183.

Chansuriyasak, K.; Wanichlamlart, C.; Sancharoen, P.; Kongprawechnon, W. and Tangtermsirikul, S. (2010). Comparison between half-cell potential of reinforced concrete exposed to carbon dioxide and chloride environment. songklanakarin j. sci. technol., 32 (5), 461-468.

Daumus, S.; Magot, M. and Crolet, J.L. (1993). Measurement of the net production of acidity by sulfate reducing bacterium: experiment checking of theoretical models of pictorially influenced corrosion. Ress. Microbiol, 144: 327- 332.

Dong, Z. H.; Shi, W. ; Ruan , H. M. and Zhang , G.A. (2011). Hetero geneous corrosion of mild steel under srb-biofilm characterized by electrochemical mapping technique. corrosion science , 53 : 2978 – 2987.

Greene, N.D. and Fontana, M.G. (1978). Materials Sicence and Engineering Series. United States of America, Pp.47-67.

Guiamet , P. S. and Saravia, S. G. (2005). Laboratory Studies of Biocorrosion Control Using Traditional and Environmentally Friendly Biocides: An Overview. Latin American Applied Research, 35:295-300.

Hansson, C. M.; Poursaee, A. and Jaffer, S.J. (2007).Corrosion of Reinforcing Barsin Concrete. Pca R&D Serial No. 3013:1-31.

Java Herdashti , R.(2009) . Abrief Review of General Patterns of MIC of Carbon Steel and Biodegradation of Concrete. IUFS Journal of Biology, 68(2): 65-73.

Juzeliunas , E., Ramanauskas R., Lugauskas A., Leinartas ,K., Samulevicien, M.and Sudavicius, A. (2006). Influence of wild strain *Bacillus mycoides*on metals: From corrosion acceleration to environmentally friendly protection. Electrochimi. Acta, 51:6085-6090.

Li,S.Y. ;Kim ,Y.G. ;Jeon,K.S. and Kang ,T.(2001) Microbiologically influenced To anaerobic Soil. Corrosion of Carbon Steel Exposed To Anaerobic Soil. Corrosion, 27(9):815-824.

Lim, C**.** and Bell, R.G. (1981). Corrosion of Mild and Stainless Steel by four Tropical Desulfovibrio Desulfuricans Strains. J. Microbiology, 27: 242-245.

Lopes, F.A.; Morin, P.; Oliveira, R. and Melo L.F. (2006). Interaction of Desulfovibrio desulfuricans biofilms with stainless steel surface and its impact on bacterial metabolism. Journal of Applied Microbiology, 101: 1087–1095.

Munoz, L. D.; Bergel, A. and Basseguy, R. (2007). Role of the reversible electrochemical deprotonation of phosphate species in anaerobic biocorrosion of steels. Corrosion Science, 49: 3988–4004.

Sahrani , F.K. ; Ibrahim , Z. ; Yanya , A. and Aziz , M. (2008). Isolation and Indentification of Marine Sulphate – Reducing Bacteria , Desulfovibrio Spp. and *Citrobacter Freundii* From Pasir Gudang , Malaysia , Science. , 47: 265 – 371.

Saravia, S.G.; Guiamet, R.S. and Videla, H.A. (2003). Prevention and protection of the effects of biocorrosion and biofouling, minimising the environmental impact, Rev. Metal Madrid Vol. Extr. : 49-54.

Skripkiunas, G.; Nagrockienė, D.; Girskasc,G. :Vaicienė, M. and Baranauskaitė, E.(2013).The Cement Type Effect on Freeze – Thaw and Deicing Salt Resistance of Concrete. Procedia Engineering 57:1045 – 1051.

Starosvetsky, J.; Starovetsky, D.; Pokroy, B.; Hilel, T. And Armon, R. (2008). Electro Chemical Behaviour of Stainless Steels in Media Containing Ironoxidizing Bacteria (IOB) By Corrosion Process Modeling. Corrosion Science, 50:540-547**.**

Teng, F.; Guan, Y.T.; and Zhu, W.P. (2008) .Effect of biofilm on castiron pipe corrosion in drinking water distribution system: grrosion scales characterization and microbial community structure investigation corrosion science, 50: 2816-2823.

Videla , H. A. ; Herrera , L. K. (2005). Microbiologically Influenced Corrosion: Looking To the Future. International Microbiology, 8: 169 – 180.WWW.Im-Microbios.Org.

Wang, W.; Jenkins, P. E. and Ren, Z. (2011). Heterogeneous corrosion behaviour of carbon steel in water contaminated biodiesel. Corrosion Science, 53: 845–849.

Widdle, F. ;Finne, R.K.; Prave, P.; Schlingman, M.; crueger.w; Esser, K; Thauer, R. and Wagner, F.(1992).Microbial corrosion. Biotechnology focus 3, fundamentals, Applications, Information. (ed). Oxford Press. New York, 216-299.

Xu,C. ; Zhang, Y. ; Cheng, G. ; Zhu, W. ;(2007). Localized corrosion behavior of 316L stainless steel in the presence of sulfate-reducing and iron-oxidizing bacteria. Materials Science and Engineering, 443: 235–241.

Table (1) illustrates the components of the concrete mix high resistance

Material	m^3/ Kg
Sand	650
Coarse	1120
cement	500
Water	190
plasticizer	100Kg cement/0.6L
w/c	0.38

Figure (2) concrete models before the onset of growth

Figure (1) illustrates the modeling of reinforced concrete used

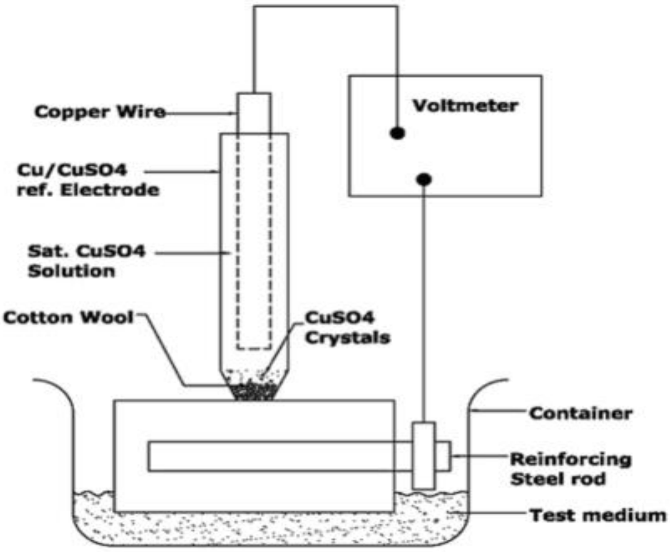


Figure (3) examine the half-cell potential for rebar by using HCP

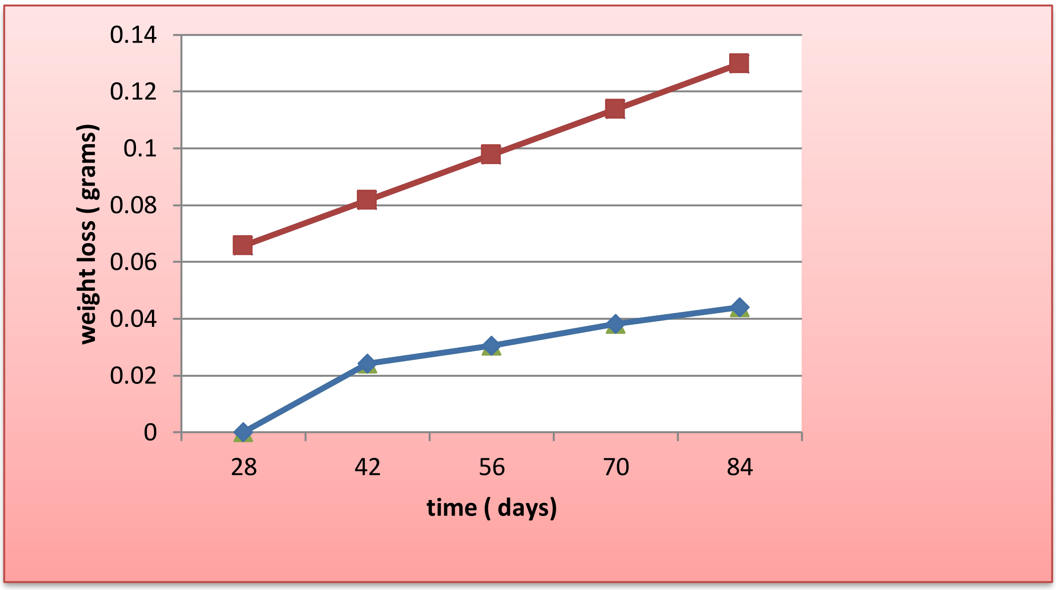
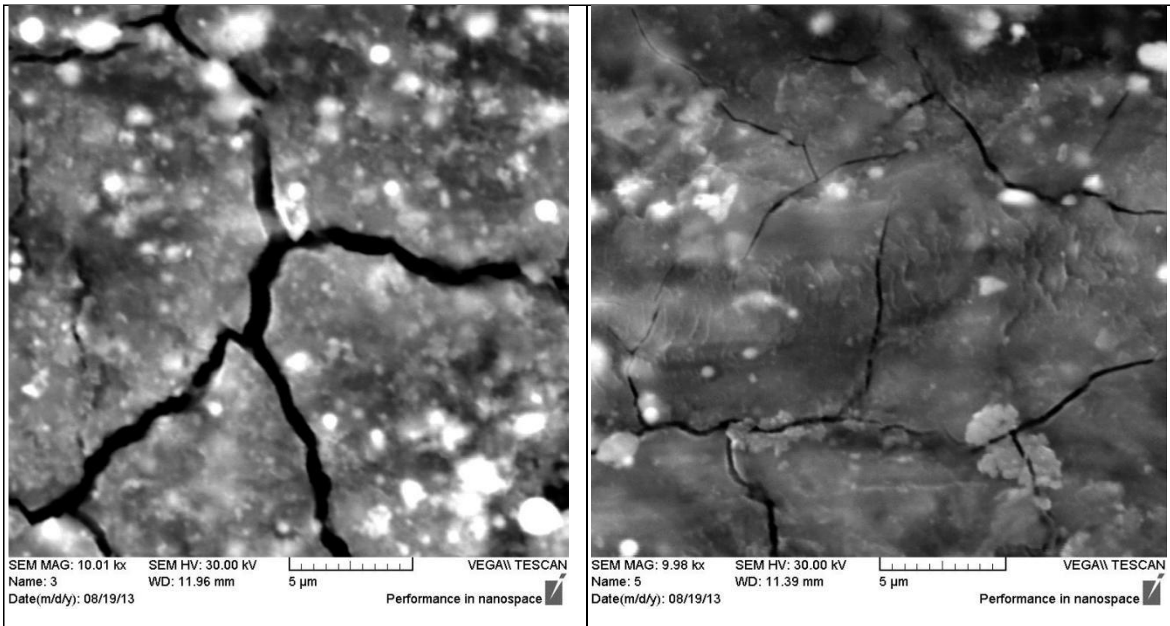


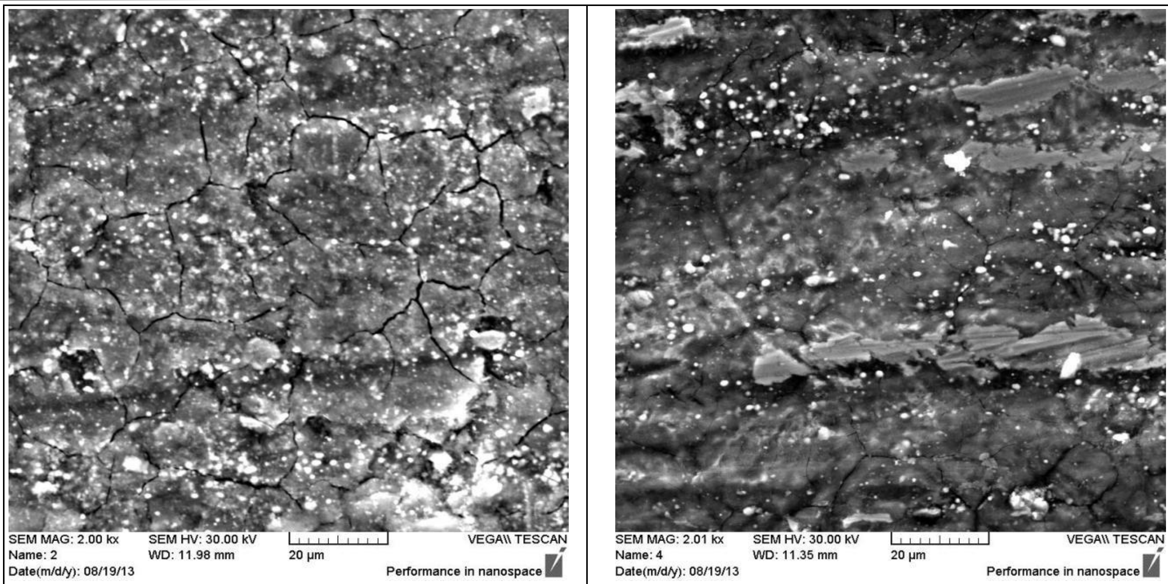
Figure (4) the speed corrosion of samples in bacterial culture compared with control samples during the time periods specified by using the weight method



With SRB

Without SRB

A

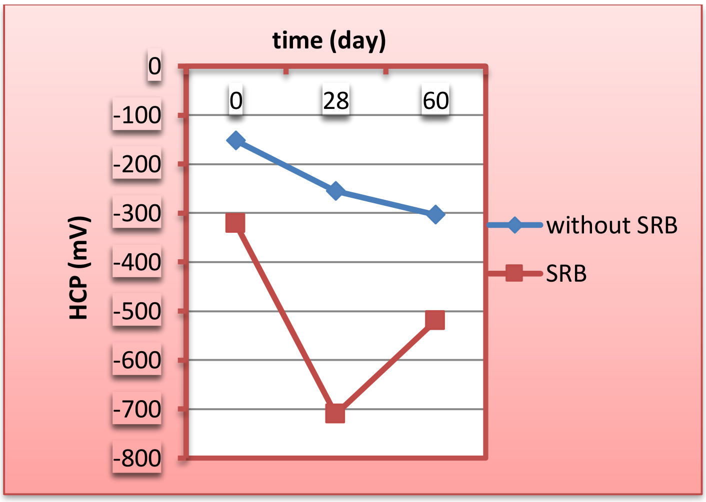


With SRB

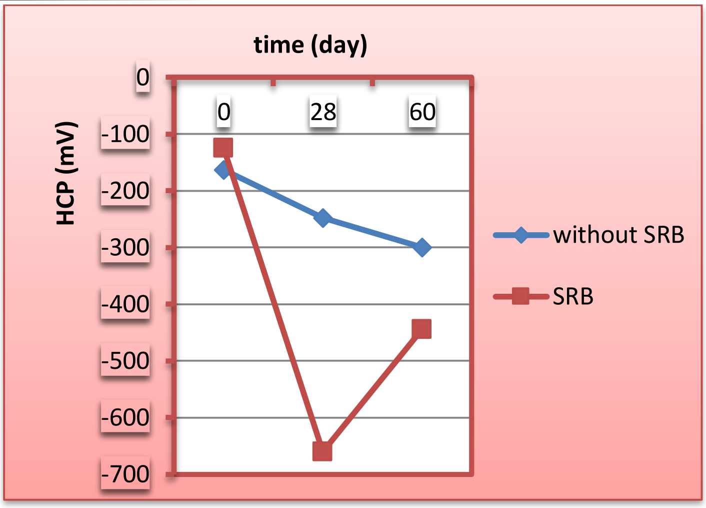
Without SRB

B

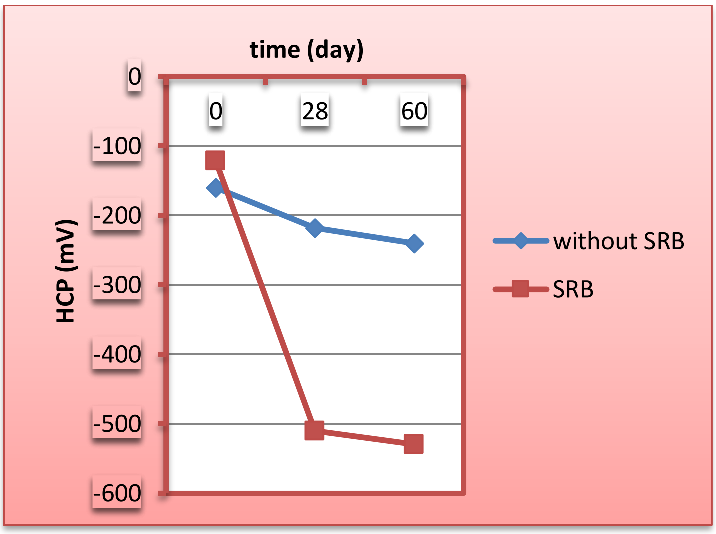
Figure (5) the results of scanning electron microscope examination of the samples of mild iron (A) 5- Microlitar (B) 20- Microlitar.



B1

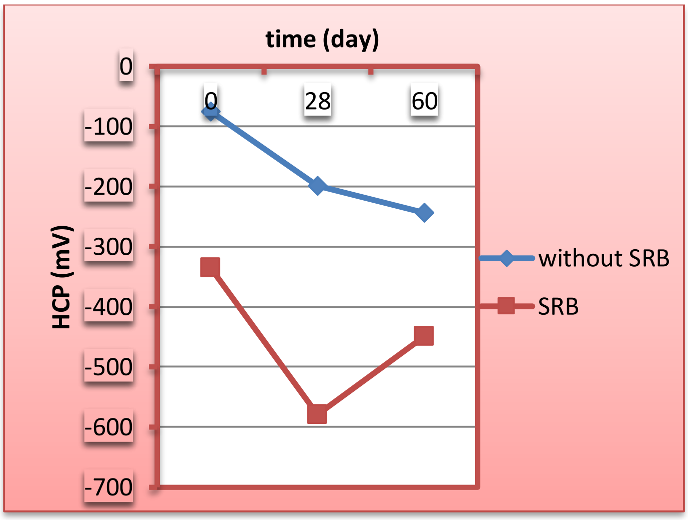


B2

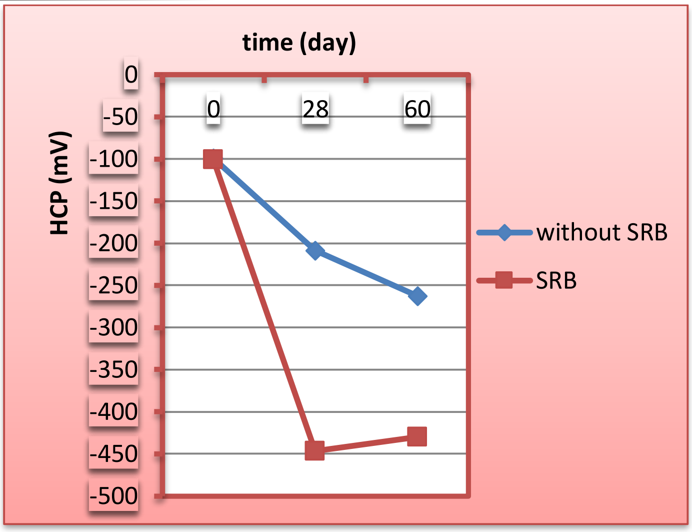


B3

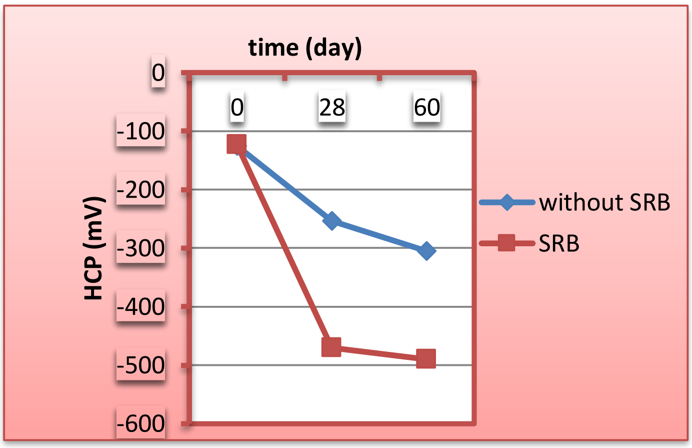
Figure (6): compare the potential of corrosion of the models (B1, B2, B3) by sulfur-reducing bacteria with control samples



BR1

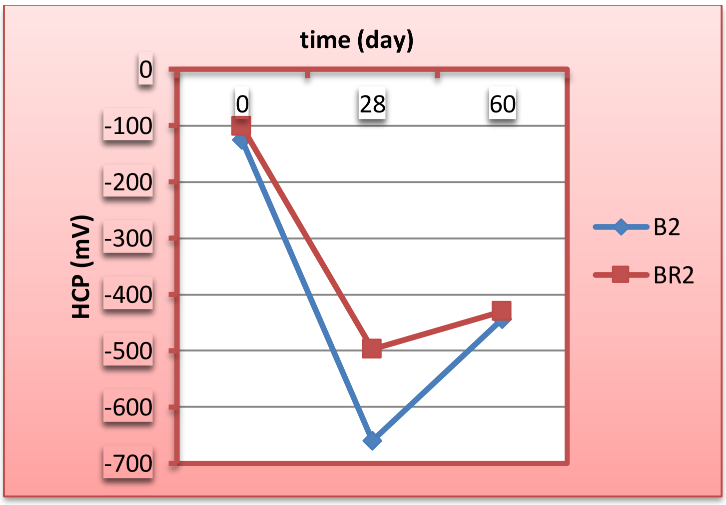


BR2



BR3

Figure (7) compared to the potential of corrosion of the models (BR1, BR2, BR3) by sulfur-reducing bacteria with control samples.



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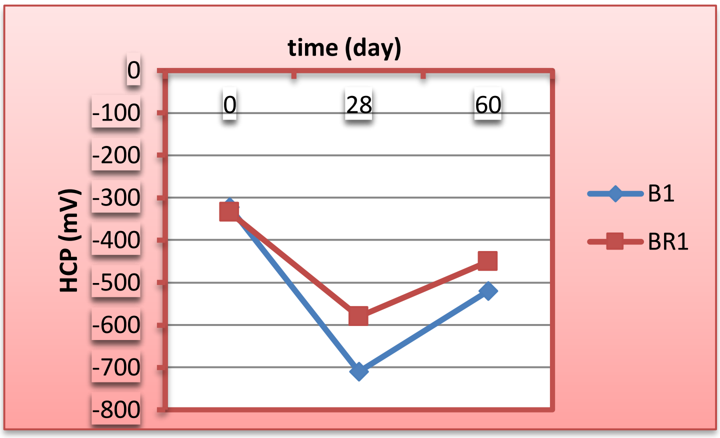
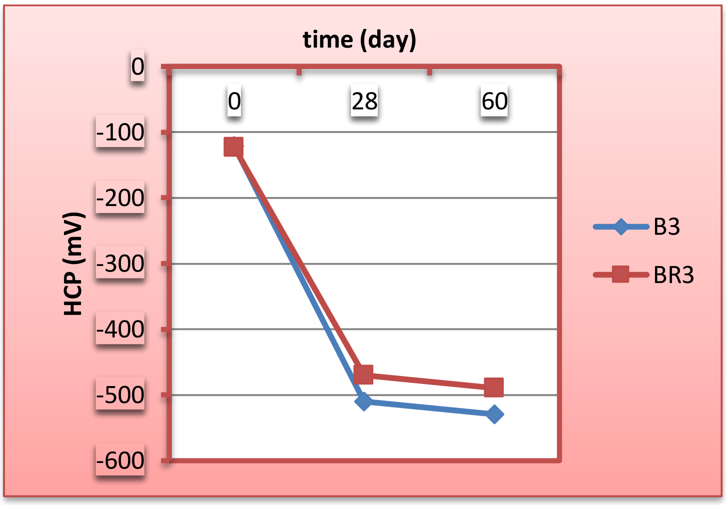
B1 ,BR2



B2 ,BR2



B3 ,BR3

Figure (8) the comparison between the ordinary and resistant cement mix with a high resistance rebar with a diameter of 16 mm