Study the effect of magnetic field on the corrosion of steel in sodium chloride solution (NaCl)

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Abstract:

In this study we test the effect of magnetic field on the corrosion of Iron in NaCl – solution of different ratios. The samples of Iron were put in the NaCl-solution of different ratios of concentration ranged between (1%, 2%, 3%, 4% and 5%). The magnetic field effect on the hydrogen reduction and on the activation –controlled iron dissolution reaction .Results show that the magnetic field effect on the corrosion of Iron in the NaCl-solutions and increased the corrosion. See the figures(1-7) that represent the corrosion of iron in NaCl-solutions with applying magnetic field and without magnetic field. In control group fig(1), we show the highest loss in weight while in magnetic field group fig(2), we show the lowest weight loss. This can be ascribe to effect of magnetic field on the reduction and oxidation reactions of corrosion.

دراسة تأثير المجال المغناطيسي على تآكل الفولاذ في محلول كلوريد الصوديوم (NaCl)

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الخلاصة:

تم في هذه الدراسة اختبار تأثير المجال المغناطيسي على تآكل الحديد في محلول كلوريد الصوديوم بتراكيز متنوعة. حيث وضعت عينات الحديد في محلول كلوريد الصوديوم بتراكيز من 1% و 2% و 3% و 4% و 5% . أن المجال المغناطيسي كان له تأثير كبير على عمليات الاخترال للهيدروجين وكذلك على تفاعلات تحلل الحديد . وهذا ما لوحظ خلال النتائج التي تم الحصول عليها في الجداول والمخططات البيانية. حيث بينت الرسوم البيانية (من الشكل 1 إلى الشكل 7) تآكل الحديد في محلول كلوريد الصوديوم تحت تأثير المجال المغناطيسي مقارنة مع عدم وجود المجال المغناطيسي. حيث بينت النتائج التي تم التوصل إليها أن المجال المغناطيسي يزيد من تأكل الحديد في محلول كلوريد الصوديوم تحت تأثير المجال المغناطيسي مقارنة مع عدم وجود المجال محلول كلوريد الصوديوم. ونلاحظ في نماذج السيطرة وجود أعلى فقدان بالوزن مقارنة مع النماذج

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الأخرى المعرضة للمجال المغناطيسي حيث يوجد اقل مقدار للفقدان بالوزن وهذا يمكن أن يعزى إلـــى تأثير المجال المغناطيسي على تفاعلات الأكسدة والاختزال في عملية الأكل.

Keyword : Magnetic corrosion, Iron Corrosion, Steel Corrosion, Corrosion of steel

Introduction:

Corrosion is defined as the destructive and unintentional attack of a metal; it is electrochemical and ordinarily begins at the surface. The problem of metallic corrosion is one of significant proportions; in economic terms, it has been estimated that approximately 5% of an industrialized nation's income is spent on corrosion prevention and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions. The consequences of corrosion are common. Familiar examples include the rusting of automotive body panels and radiator and exhaust components. Corrosion processes are occasionally used as advantageous. For example, etching procedures[1], make use of the selective chemical reactivity of grain boundaries or various microstructural constituents. Also, the current developed in dry-cell batteries is a result of corrosion processes.

It has been estimated that yearly corrosion damage costs are currently equivalent to 4.2% of the U.S. gross national product[1]. The direct cost of atmospheric corrosion in metals and alloys has been estimated to be at \$5 million annually [2].

The annual cost of corrosion and corrosion protection in the United States is estimated by the National Association of Corrosion Engineers (NACE) to be in excess of 10 billion dollars. This figure is perhaps less intimidating considering that corrosion occurs, with varying degrees and types of degradation, whenever metallics are used.[2,3]



Figure (1-1) The basic corrosion cell consists of an anode, a cathode, an electrolyte, and a metallic path for electron flow. Note that the corrosion current (z) enters the electrolyte at the anode and flows to the cathode

Corrosion occurs by an electrochemical process[3,4]. The phenomenon is similar to that which takes place when a carbon-zinc "dry" cell generates a direct current. Basically, an anode (negative electrode), a cathode (positive electrode), an electrolyte (environment), and a circuit connecting the anode and the cathode are required for corrosion to occur (see Figure (1-1)). Dissolution of metal occurs at the anode where the corrosion current enters the electrolyte and flows to the cathode. The general reaction (reactions, if an alloy is involved) that occurs at the anode is the dissolution of metal as ions:

Where:

M = metal involved

n = valence of the corroding metal species

e = electrons

Examination of this basic reaction reveals that a loss of electrons, or oxidation, occurs at the anode. Electrons lost at the anode flow through the metallic circuit to the cathode and permit a cathodic reaction (or reactions) to occur. In alkaline and neutral aerated solutions, the predominant cathodic reaction is:

 $O_2 + 2H_2O + 4e^- \rightarrow 4(OH) \dots (2)$

The cathodic reaction that usually occurs in deaerated acids is :

 $2H^+ + 2e^- \rightarrow H_2.....$ (3)

In aerated acids, the cathodic reaction could be

 $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (4)

All of these reactions involve a gain of electrons and a reduction process. The number of electrons lost at the anode must equal the number of electrons gained at the cathode. For example, if iron (Fe) was exposed to an aerated, corrosive water, the anodic reaction would be :

At the cathode, reduction of oxygen would occur :

 $O_2 + 2H_2O + 4e^- \rightarrow 4(OH^-) \dots (6)$

Because there can be no net gain or loss of electrons, two atoms of iron must dissolve to provide the four electrons required at the cathode. Thus, the anodic and cathodic reactions would be:

 $2 \text{ Fe} \rightarrow 2\text{Fe} + 4\text{e} \text{ (anodic)} \dots (7)$

 $O_2 + 2H_2O 4e \rightarrow 4(OH)$ (cathodic)

These can be summed to give the overall oxidation reduction reaction

 $2Fe + O_2 + 2H_2O \rightarrow 2Fe 4(OH) \dots (8)$

After dissolution, ferrous ions (Fe⁺⁺) generally oxidize to ferric ions (Fe⁺⁺⁺); these will combine with hydroxide ions (OH⁻) formed at the cathode to give a corrosion product called rust (FeOOH or Fe₂O₃ X H₂O). Similarly, zinc corroding in an aerated, corrosive water (i.e., Zn \rightarrow Zn⁺⁺ + 2e-) will form the corrosion product Zn(OH)2. The important issue to remember is that anodic dissolution of metal occurs electrochemically; the insoluble corrosion products are formed by a secondary chemical reaction[4,5].

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Almost all corrosion problems and failures encountered in service can be associated with one or more of the eight basic forms of corrosion: general corrosion, galvanic corrosion, concentration-cell (crevice) corrosion, pitting corrosion, intergranular corrosion, stress corrosion cracking, dealloying, and erosion corrosion.[5]

The degradation of materials by corrosion limits their lifetime. This process is in many cases enhanced by the influence of magnetic fields. Additionally the corrosion might be localized by magnetic fields, what can lead to an early failure. Thus, it is important to understand the role of magnetic fields in the corrosion process. The main influence of a magnetic field on electrochemical processes is the introduction of two additional forces into the electrolyte. The Lorentz force, which acts on moving charge carriers, introduces a movement of the electrolyte (so-called magneto hydrodynamic (MHD) effect) and thus increases the mass transport. The field gradient force pulls paramagnetic ions in regions of high flux density, leading to concentration gradients at an electrodes surface. The magnetization of a ferromagnetic electrode in an external homogeneous magnetic field leads to an inhomogeneous stray field in front of the electrode as shown in the left figure. This stray field and its gradients can alter the anodic behavior as well as the free corrosion behavior of the electrode significantly [5,6].

Experimental Procedure:

The commercial iron specimens (purity 99% and diameter of 0.5cm) are molded to a specimen of dimensions (10 cm long and 0.5 cm radius) for experiments. The surface of the specimens was polished with emery cloth down to 2000, immersed for 1 min. in 1 mol dm⁻³ of HCl solution, and attached to the center of glass container (120ml. in size) as shown in fig(1-2). We prepare ten samples using an electric saw, the samples were washed by distilled water to remove the remaining dust and particles then dried and weighted before test. The salt solution prepared by weighting method, by solving 1gm of salt in distilled water so we get a concentration 1% NaCl solution, also by the same way we prepared 2%, 3%, 4% and 5% of NaCl solution.

After weighted the samples of iron, two groups were tested in the same concentration, the first one without any effect of magnetic field (control sample) while the other with the effect of magnetic field. Both groups were immersed in the salt solution by inserting them in glass containers which contain salt solution. The permanent magnetic also inserted inside the containers for the magnetic field group. The containers were labeled and specified information write downs. We should not covered the glass containers in order to allow to oxygen to dissolve in solution. After every specify period of time the samples were cleaned and weighted and the losses in weight were calculated.



Fig(1-2) flow diagram represent the test

The specimens put on the solution as in Fig(1-2) uncovered to allow oxygen to dissolve in the solution for a different periods of time range from (14, 28, 49 and 79 days) which represent (336,672, 1176 and 1896 hour.) respectively. When every time is finish the specimen was out of the solution and left to dry then we take the weight of it to calculate the weight loss during this period of time.

Results and Discussion:

Table (1) Loss in weight for control group

Time (hrs)	Weight loss (gm)						
Time (ms)	1% NaCl	2% NaCl	3% NaCl	4% NaCl	5% NaCl		
0	0	0	0	0	0		
336	0.0112	0.0172	0.0272	0.0244	0.0155		
672	0.028	0.0363	0.053	0.0502	0.0445		
1176	0.058	0.0632	0.095	0.0894	0.0839		
1896	0.1077	0.1081	0.1451	0.1401	0.1341		

Fable ((2)) Loss	in	weight	for	Magnetic	field	group)
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Time (hrs)	Weight loss (gm)						
	1% NaCl	2% NaCl	3% NaCl	4% NaCl	5% NaCl		
0	0	0	0	0	0		
336	0.0288	0.032	0.0318	0.0297	0.0283		
672	0.0582	0.063	0.0596	0.063	0.063		
1176	0.1122	0.106	0.0987	0.1188	0.13		
1896	0.2219	0.16	0.1564	0.202	0.2163		

The corrosion of steel is a chemical reaction of oxygen dissolved in water and iron on its surface. Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface. The amount of

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oxygen that can be held by the water depends on the water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (cold water holds more oxygen). Gas solubility increases with salinity (fresh water holds more oxygen than dose saltwater). Both the partial pressure and the degree of saturation will change with altitude.

As a result, rust is brought forth while oxygen consumed. Once oxygen is consumed in the corrosion, it is supplied from the upper open side of the vessel to recover the equilibrium of oxygen between the vessel and the surrounding. The diffusion time of the oxygen molecule in the water is much longer than the reaction time because its molecular diffusion constant is very small: $D = 10^{-5}$ cm^{-2} / s at 258 °C. So the exists the difference in the concentration of oxygen between the top and the bottom of the vessel which is far from that in equilibrium. When the water is under the action of a gradient of magnetic force, two constituents of water, i.e. the oxygen molecule and the water molecule, are affected differently by this force because the magnetic susceptibility of these molecule is different. This difference is able to produce the magnetic buoyancy force on the water. In the upper part of the vessel, oxygen is rich in amount, so the water is drawn towards the magnetic pole region due to the magnetic buoyancy force. While the water is flowing downwards, oxygen is consumed in the corrosion and becomes reduced in concentration. as a result, the water is drawn out from the magnetic pole region due to the magnetic buoyancy force and ascends to the upper part of the vessel due to incompressibility. This process repeats, leading to the convective flow of water. This steady convection is realized when oxygen is supplied from the upper open side of the vessel after oxygen is consumed in the corrosion. This convection is not a forced but a selfsustained convection because the adverse concentration gradient of oxygen is realized automatically in the experimental condition. The corrosion of a steel plate submerged in water does not only generate a convective flow of water but also serve for its visualization.[4]

It is very clear from the Fig (1) that the highest weight loss achieved in 3% (NaCl+ water) solution. While in Fig (2) we show the lowest weight loss achieved in 3% (NaCl+ water) solution, and it is so clear from figures (3-7) that the presence of magnetic field increase the weight loss for steel. We think that in 3% (for control group) the solution is reaches saturation condition that is all OH⁻ ions are bonded with Na⁺ ions from NaOH which is very powerful base on steel. In 4%, 5% the super saturation condition of solution is reach and NaCl salt being precipitates in the bottom of the vessel. While in magnetic field group the 3% is very dense solution among other ratios therefore the oxygen from atmospheric is difficult to dissolve in solution. The 1% solution has the highest weight loss because the density is low which permit oxygen to inter to the solution.





Fig(2) : weight losses for different NaCl ratio for magnetic group.





Fig(4): Effect of magnetic field on 2% NaCl sample.

Fig(3): Effect of magnetic field on 4% NaCl sample.





Fig(5): Effect of magnetic field on 3% NaCl sample.



Fig(7): Effect of magnetic field on 5% NaCl sample.

References:

- 1. Shreir, L.L. Jarman R.A. and Burstein G.T.," CORROSION", volume 1, Third edition, 2000
- 2. Nestor Perez," ELECTROCHEMISTRY AND CORROSI ON SCIENCE", 2004.
- 3. Fowler, Michael (1997). "Historical Beginnings of Theories of Electricity and Magnetism".
- 4. Tomohei Sasada, Akira Sato, Physics Letters A 266_2000.350-358.

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- 5. Aljourani J., Raeissi K. *, Golozar M.A.," Benzimidazole and its derivatives as corrosion inhibitors for mild steel in 1M HCl solution", Corrosion Science journal, Corrosion Science 51 (2009) 1836–1843.
- 6. David Talbot , James Talbot , " Corrosion Science and Technology " , Library of Congress Cataloging-in-Publication Data, 1998 by CRC Press LLC, P(238-250).
- Hu Q., Y.B. Qiu, Guo X.P. *, Huang J.Y.," Crevice corrosion of Q235 carbon steels in a solution of NaHCO3 and NaCl", Corrosion Science journal, Corrosion Science 52 (2010) 1205–1212.
- 8. William D. Callister, Jr." Fundamentals of Materials Science and Engineering", an Electronic text book , John Wiley & Sons, Inc. Copy right , 2001, p(S-205).
- 9. Chipa A., Wen-Chang Wu, " Influence of the magnetically treated 3% sodum chloride on the corrosion of Iron"; Journal of material science, 31 (1996), p(3821-3825).
- 10.Zhanpeng Lu *, Wu Yang;" In situ monitoring the effects of a magnetic field on the open-circuit corrosion states of iron in acidic and neutral solutions" ; Corrosion Science 50 (2008) 510–522.
- 11.Sueptitz R. *, Koza J., Uhlemann M., Gebert A., Schultz L.;" Magnetic field effect on the anodic behavior of a ferromagnetic electrode in acidic solutions"; Electrochimica Acta 54 (2009) 2229–2233.