

Galvanic Corrosion Behavior of Aluminum-Carbon Steel Using Rotating Cylinder Electrode

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Abstract:

The galvanic corrosion behavior for Aluminum (Al), Carbon steel metals in aerated 3.5% NaCl solution has been investigated under turbulent controlled flow conditions at different temperatures using a rotating cylindrical electrode unit. Corrosion potential, potentiostatic polarization and galvanic corrosion experiments were carried out at 313,323 and 333 k under rotational speed of 0, 50,125 and 200 r.p.m

Potentiostatic polarization studies have been performed individually for Aluminum and Carbon steel and when they are coupled with an equal area (19.27 cm²), of cathode to anode.

It was found the mass transfer process as measured by the limiting diffusion current density is not affected by the nature of the cathode material.

For coupled metals, it is found that the corrosion process of Carbon steel and Al is under diffusion control since the corrosion rate increases with increasing rotational speed.

The measured corrosion potentials of these metals give no exact information about the galvanic corrosion but only show the direction of current flow.

The zero resistance ammeter has been used to measure the variation of galvanic current with time.

The galvanic current was largely increased with increasing rotational speed (r.p.m.) and temperatures.

The corrosion potential of (Al-Cs) coupled is larger than the corrosion potential of the individual anode member, which means large amount of anodic polarization due to this galvanic coupling.

سلوكية التآكل الغلفاني

للألومنيوم- كاربون ستيل بأستخدام القطب الأسطواني الدوار

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الخلاصة

يهدف البحث الى دراسة سلوكية التآكل الغلفاني للألمنيوم - كاربون ستيل بأستخدام القطب الاسطواني الدوار (RCE) في محلول (3.5%) من كلوريد الصوديوم المشبع بالهواء الطبيعي.

تم استخدام معادن الفولاذ الكاربوني والالمنيوم م على شكل قطب اسطواني دوار لكل منهما وبنفس المساحة السطحية المعرضة للمحلول (19.27سم²).

اجريت التجارب (جهد التآكل, الاستقطاب المنفرد والمزدوج, التآكل الغلفاني عند درجات حرارة مختلفة (313,323,333k) وعند ظروف السكون والجريان المضطرب بمعدل (0,50,125,200) دورة بالدقيقة.

تم قياس التآكل الغلفاني بقياس التيار الغلفاني المتولد بواسطة جهاز قياس التيار الغلفاني (ZRA) وكذلك مراقبة وتسجيل جهد الازدواج (Coupled potential) خلال فترة الاختبار.

تم اجراء الاستقطاب لدراسة ميكانيكية التآكل للمعادن في الحالة المنفردة وفي الحالة المزدوجة (وباستخدام مساحة متساوية من الانود والكاثود) ولمختلف حالات الجريان ودرجات الحرارة. تم الاستنتاج من خلال النتائج بأن تآكل الالمنيوم في حالتيه المنفردة والمزدوجة يكون تحت تأثير سيطرة تفاعل الانتشار للأوكسجين (Diffusion Control) على سطح المعدن ويزداد التآكل بزيادة سرعة الجريان ولوحظ نفس السلوك بالنسبة للكربون الفولاذي . التيار الغلفاني ومعدل التآكل الكلي للأنود يزداد بزيادة سرعة الجريان وزيادة درجة الحرارة. ليس هناك تأثير لنوعية المعدن بالنسبة لتفاعل الاوكسجين على سطح المعدن وقد لوحظ ذلك بالنسبة لتفاعل الاوكسجين وانتشاره على سطح معدن الالمنيوم والفولاذ الكربوني .

Introduction

Corrosion is the undesirable combination of processes by which metals tend to bind chemically with other materials by losing or sharing electrons to or with other elements.

The corrosion of dissimilar metals “Galvanic Corrosion” is one of the most common and most severe type of corrosion .

Galvanic corrosion is the type of corrosion, involves two metals electrically connected in a liquid electrolyte where one metal acts as the anode (corrodes) and the other is the cathode ^[1].

When two different metals are in a corrosive environment , they corrode at different rates ,according to their specific corrosion resistances to that environment ,however, if the two metals are in contact , the more corrosion prone (metal 1) corrodes faster and the less corrosion prone (metal 2 the more noble one) corrodes slower than originally,i.e when no contact existed . The accelerated damage to the less resistant metal is called galvanic corrosion.In galvanic corrosion, the added anodic currents (on metals 1and 2) equal the added cathodic currents (on metals 1and 2). ^[2]

So that:-

$$I_{a.1} + I_{a.2} = |I_{c.1}| + |I_{c.2}| \quad \dots(1)$$

Where, $I_{a.1}$ & $I_{a.2}$ are the anodic current on metals 1,2

$I_{c.1}$ & $I_{c.2}$ are the cathodic current on metal 1,2

Or in terms of current densities and areas

$$i_{a.1} A_1 + i_{a.2} A_2 = |i_{c.1} A_1| + |i_{c.2} A_2| \quad \dots(2)$$

where, A_1 & A_2 are the surface area of metal 1,2 respectively

If $I_{a.1} \gg I_{a.2}$, This equation is reduced to

$$i_{a.1} A_1 = |i_{c.1} A_1| + |i_{c.2} A_2| \quad \dots(3)$$

The fundamental behavior of galvanic couples has been thoroughly discussed by Wesley and Brown^[3]. The more active metal (base metal) ‘anode’ is corroded more rapidly than it would if it were uncoupled in the same medium. The less active metal (noble metal) ‘cathode’ generally corrodes as less than would be the case if it is uncoupled in the same medium or it could be made a resistant to corrosion.This effect is referred to as galvanic or cathodic protection .

The basic requirements necessary for bimetallic (galvanic corrosion) are^[4,5] :

- a- The presence of an electrolyte.
- b- Electrical connection between metals.
- c- A difference in potential between the two metals.

Experimental Work

Throughout this investigation the galvanic current and galvanic potential was studied in 3.5 % sodium chloride solution under various controlled flow rates using a rotating cylinder electrode unit to obtain turbulent flow condition at different temperature .

Experimental Apparatus:

The experimental apparatus used in this work are consists mainly of

- Galvanic corrosion cell.
- Rotating cylinder electrode assembly.
- Constant temperature bath (Memert P21S6).
- Zero resistance ammeter (ZRA).

Galvanic Corrosion Cell:

The galvanic corrosion cell, see Figure (1), consists of a cylindrical glass reaction vessel, working electrodes (Al , Cs) and a thermometer. The reaction vessel (230mm diameter×160mm high) has a capacity of 2 liters.

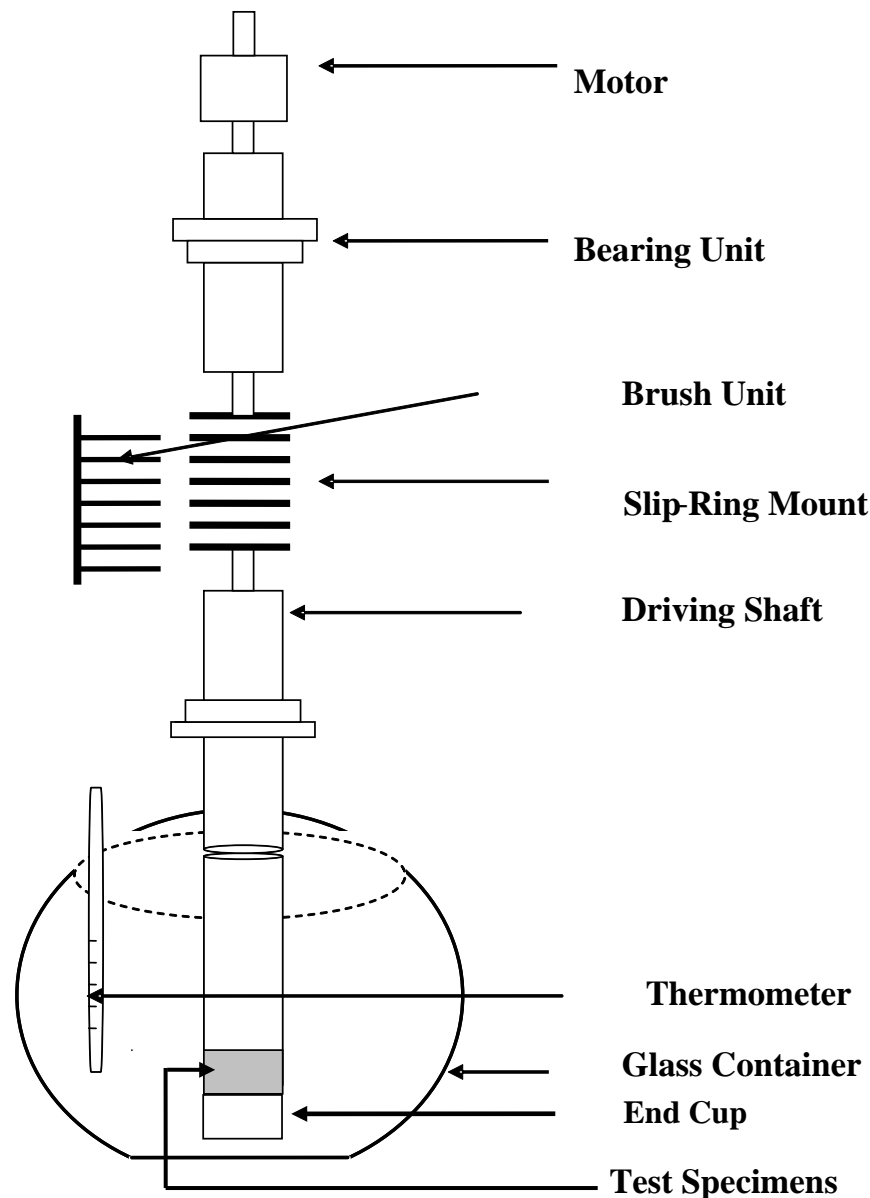


Fig.(1): The Rotating Cylinder Electrode Assembly

Rotating Cylinder Electrode Assembly:

The rotating electrode assembly used in this work consists of the following items as shown in Figure (1):

1. The rotating cylinder electrode shaft.
2. A driving shaft, bearing unit and slip-ring (together described later as the electrode mounting); and
3. A driving unit (motor and speed controller).

The description and design of the rotating electrode assembly are shown below:

1. The Rotating Cylinder Electrode:

1.1 The Working Electrode (Rotating Cylinder):

The rotating cylinder is composed of the carbon steel cylinder, and Aluminum cylinder see Figure (2 and 3), which has the following dimensions

Where: $r_o = 34 \text{ mm}$
 $r_i = 25 \text{ mm}$
 $h = 9 \text{ mm}$

Thus, the surface area of the specimen was 19.27 cm^2 .

The spectrographic analysis of the Carbon steel and Aluminum is given in Table (1) and (2).

Table (1) Spectrographic composition of Carbon steel (wt%)

C	Mn	Si	Ni	S	Cr	Fe
0.1841	0.1434	0.1495	0.0581	0.0233	0.0233	Balance

Table (2) Spectrographic composition of Aluminum (wt%)

Mg	Mn	Ti	Fe	Cu	Cr	Al
1.5	0.18	0.02	0.26	1.45	0.0	Balance

1.2 The Electrode Shaft:

The electrode shaft has the following features.

1. The lower part of the electrode shaft has means to facilitate the attachment and removal of the specimen.
2. A provision for electrical connection to the working electrode (the specimen), and,
3. A provision for mounting the electrode shaft on the driving shaft.

The details of the electrode shaft design for Rotating Cylinder Electrode (RCE) are shown in Figure (2) and (3).

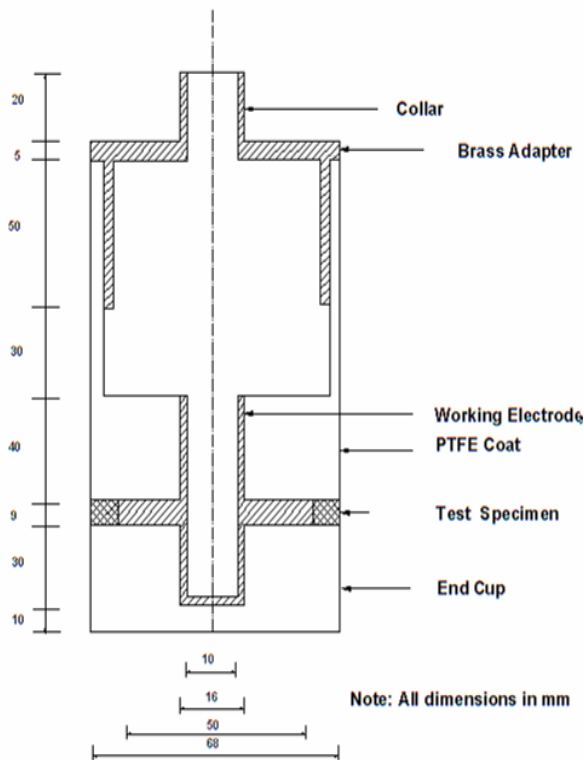


Fig.(2): Rotating Cylinder Electrodes (single metals)

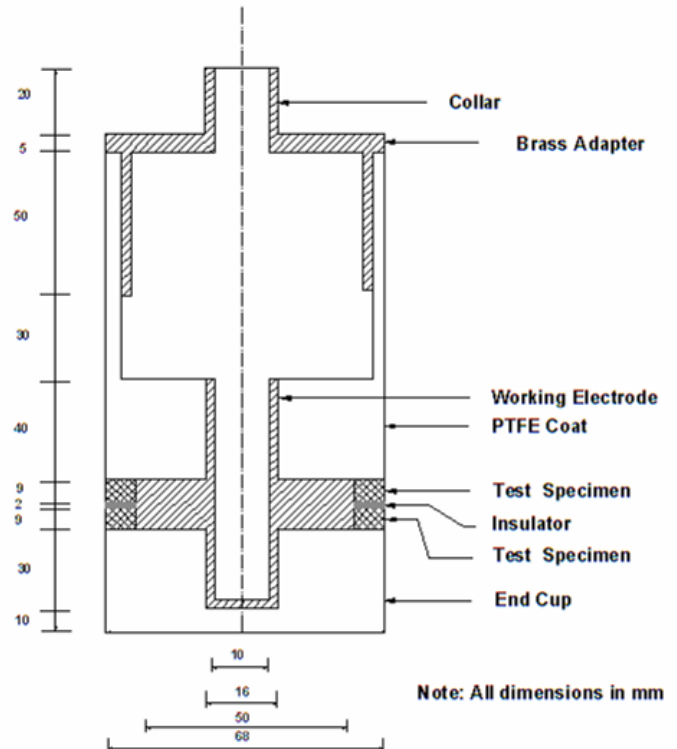


Fig.(3): Rotating Cylinder Electrodes (coupled metals)

Experimental Procedure:

The galvanic corrosion cell was filled with 2 liters of the 3.5 % NaCl solution , and then placed inside a constant temperature water bath supplied with a thermostat to keep the temperature constant within ($\pm 0.5-1C^{\circ}$) until the solution reached the preset temperature .After that, the water bath was raised up using a hydraulic jack , until the RCE was introduced into the solution .The RCE was set in motion at the required r.p.m. by manually adjusting the speed controller. The working (Al,CS), counter and reference electrodes were connected to a potentiostat (Wenking LT.87).

The electrochemical polarization was carried out for single metals (Carbon Steel, -1000mv to -400mv), (Aluminum, -1500mv to -600mv).and for coupled metals (Al & Cs) from (-1100mv to -600mv).

The corrosion potential and corrosion current were checked and read by digital multimeter in the two states above.

The galvanic corrosion current generated between the two metals ,and the galvanic corrosion potential were measured and recorded continuously through the time period (2.25 hour) by using the interface ZRA(zero resistance ammeter) which was constructed by using the circuit of Lauer and Mansfeld ^[6].

Results and Discussion

The results reported are the average values of duplicate experimental runs obtained with satisfactory reproducibility.

Using Zero Resistance Ammeter, the galvanic corrosion current of carbon steel coupled to aluminum was studied under different rotational speeds (ω) and different temperatures, for 2.25 hr. exposure in 3.5 % NaCl solution.

Generally, in the galvanic couple the more active metal (anode) is corroded more rapidly than the less active metal (cathode), and this cathode will be protected in most cases.

Table (3) shows the average galvanic current densities and galvanic potential at different rotational speeds (0, 50, 125 and 200 r.p.m.), and at different temperatures (313, 323 and 333 K).

The behavior of the galvanic current density (i_g) and galvanic potential (E_g) as function of time (for example at $T=313$) can be seen in figures (4 to 7). Several interesting observations can be made from these figures, the initial galvanic current is increasing with time for a maximum value in the early stages of the test then decreases slowly with the time until steady state galvanic corrosion. This maximum value is apparently dependent on the rotational speed and temperature. Because the metal surfaces at the beginning of the test are clean and active for corrosion to ensure but during a later stage corrosion product film will be formed which will decrease the activity of the metal surfaces and impede the diffusion of oxygen. This was noticed with time as the electrolyte colour changed due to formation of corrosion products.

The galvanic current measurements depend upon:

1. Experimental condition.
2. Geometry of the cell.
3. Relative surface of the specimens (samples).

Figure (8) show that the galvanic potential increases with increasing rotational speed at different temperatures. Figure (9) show that the galvanic potential decreases slightly with increasing temperature at different rotational speeds.

Table (3): Galvanic current density (average) and galvanic potential of aluminum coupled with carbon steel in 3.5 % NaCl solution at different rotational speeds and different temperatures.

Temp. (K)	Rotational speed (ω)	Galvanic current density ($\mu\text{A}/\text{cm}^2$)	Galvanic potential (mV)
313	0	116.494	-981.5
	50	184.047	-960.0
	125	253.546	-920.5
	200	408.318	-900.5
323	0	138.136	-1020.5
	50	219.326	-980.0
	125	325.074	-940.5
	200	467.939	-920.0
333	0	198.547	-1040.5
	50	298.975	-999.5
	125	387.836	-960.0
	200	541.572	-939.5

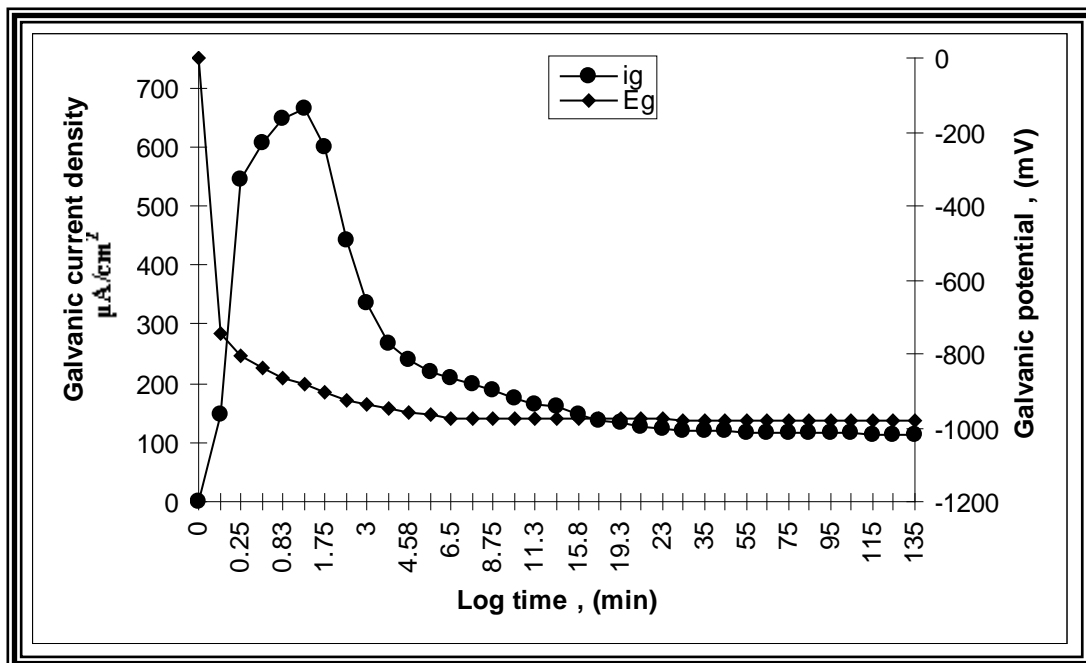


Fig.(4):Variations of galvanic current density and couple potential with time of carbon steel coupled with aluminum in 3.5 % NaCl solution at T=313 K & r.p.m = 0

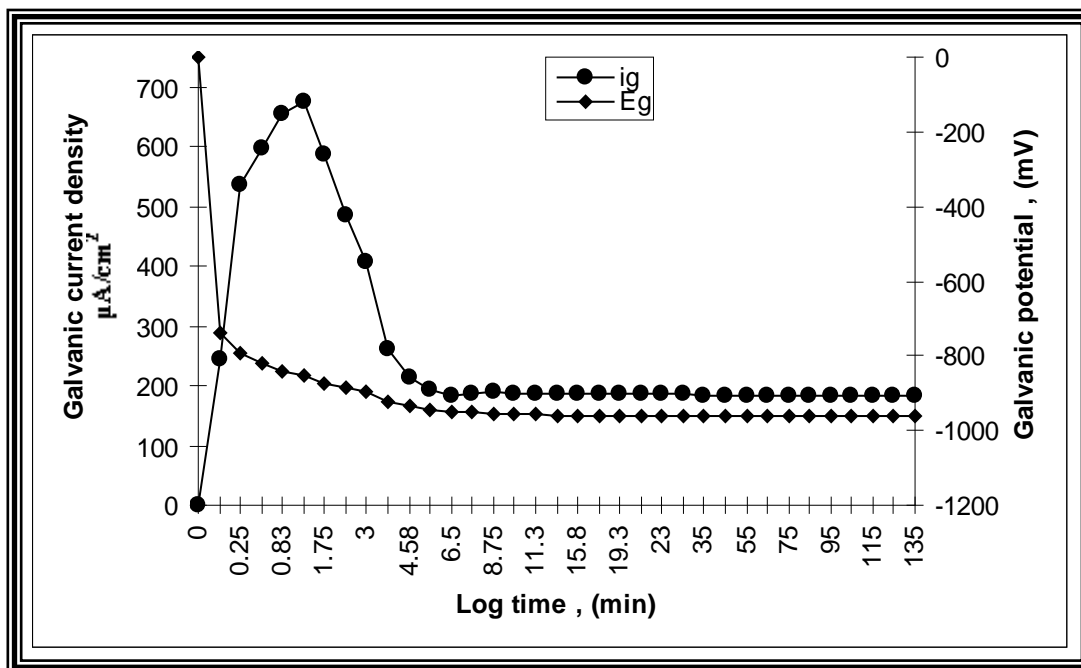


Fig.(5): Variation of galvanic current density and couple potential with time of carbon steel coupled with aluminum in 3.5 % NaCl solution at T=313 K & r.p.m = 50

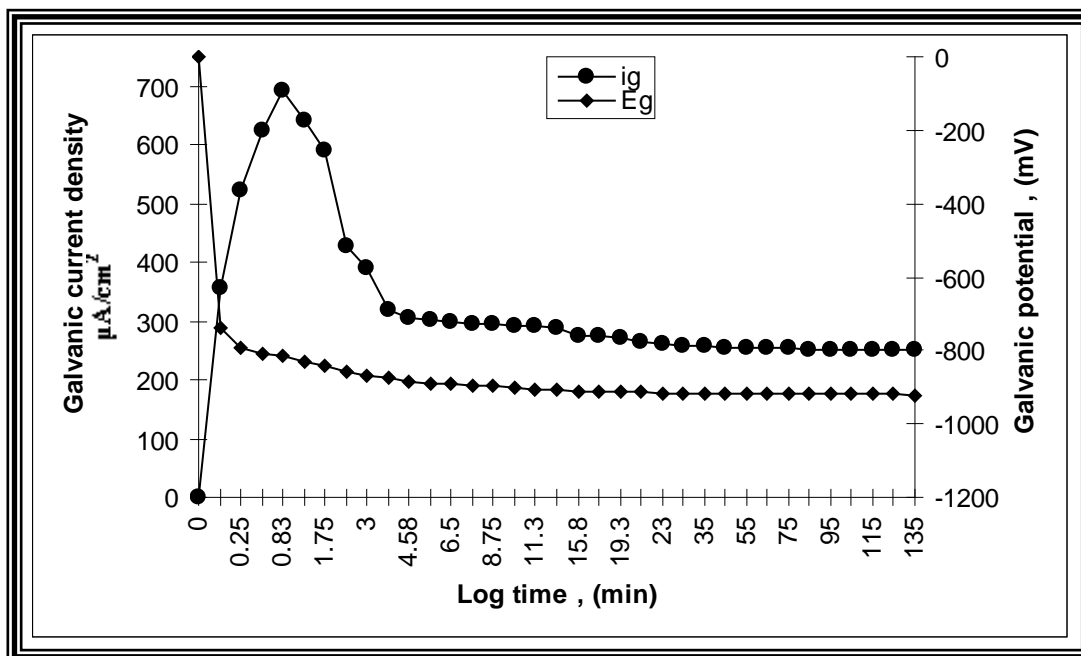


Fig.(6): Variation of galvanic current density and couple potential with time of carbon steel coupled with aluminum in 3.5 % NaCl solution at T=313 K & r.p.m = 125

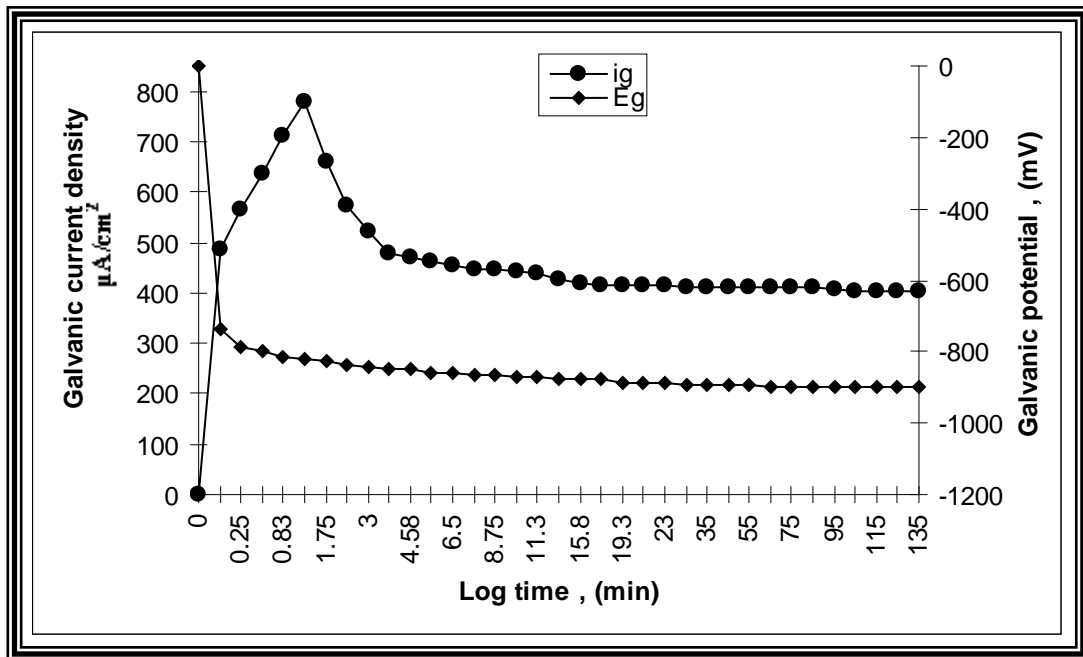


Fig.(7):Variation of galvanic current density and couple potential with time of carbon steel coupled with aluminum in 3.5 % NaCl solution at T=313 K & r.p.m = 200

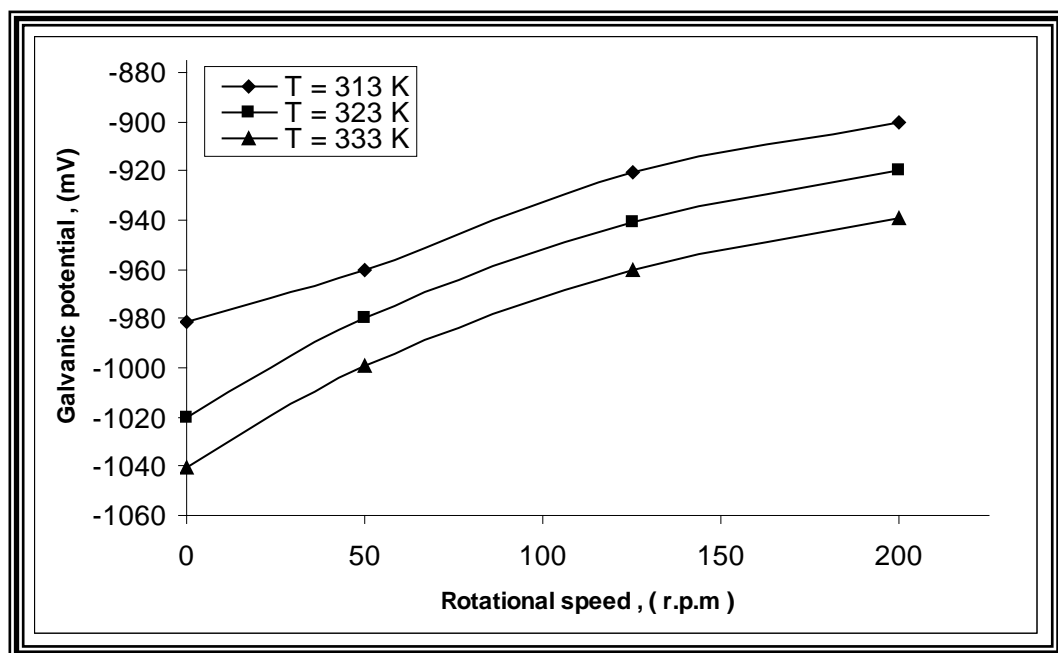


Fig.(8): Effect of rotational speed on the galvanic potential for different temperatures in 3.5 % NaCl solution

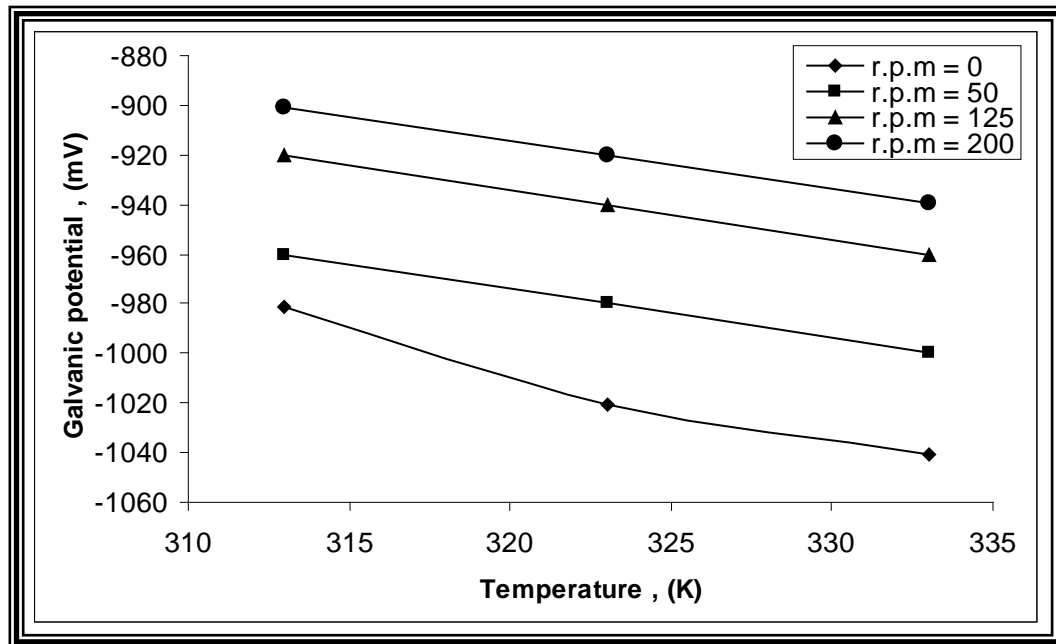


Fig.(9): Effect of Temperature on the galvanic potential for different rotational speeds in 3.5 % NaCl solution

Conclusions

On the basis of the results presented the following conclusions can be drawn:

1. When aluminum and carbon steel are galvanically coupled in aerated 3.5% NaCl solution at different temperatures and different rotational speeds, aluminum effectively protects the carbon steel against corrosion.
2. The galvanic current density increases with increasing temperature and rotational speed, but the galvanic potential increases with increasing rotational speed and decreases with increasing temperature.
3. The greater galvanic current density is at rotational speed = 200 r.p.m and temperature = 333K, but the lower galvanic current density is at rotational speed = 0 r.p.m and temperature = 313K.
4. A continuous recording of the galvanic current with time show sharply decrease in galvanic current and then decrease to steady state condition.

References

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