

CORROSION RESISTANCE OF TEMPERED HEAT TREATED CARBON STEEL CK45 IN SEA WATER AT DIFFERENT VELOCITIES

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ABSTRACT

The effect of tempering heat treatment on corrosion resistance of carbon steel DIN CK45 is investigated. Test specimens (1.5*1.5*0.3) Cm were prepared according to ASTM G71-30 Tempering Heat treatments at 150, 350 ° C were performed by heating the specimens in electrical furnace to 850 ° C and cooling in water then preheated to 150, 350 ° C and cooled in air. Corrosion tests were investigated by electrochemical potential state cell in prepared salt water (sea water) at multi velocities (1, 2, and 3) m/min where the test specimen represents the positive electrode (anode) pole. Tafel equation was adopted to calculate the corrosion rate. The obtained results show that the heat treatment improves the corrosion resistance by increasing the combination of iron with carbon reducing by that the combination of iron with oxygen which produces rust. On the other hand the increasing of velocity of the media (sea water) contributed in decreasing the corrosion rate because of reducing the assembling of ions on cathode pole.

KEYWORD: Heat treatment, Carbon Steel, CK45, Corrosion Resistance. Sea-Water Velocity.

دراسة تأثير المعاملات الحرارية على مقاومة التآكل لفولاذ كاربوني DIN CK45 وبتعرض ماء البحر الى سرع مختلفة .

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الخلاصة

تم دراسة تأثير المعاملات الحرارية (تقسية، مراجعة) على مقاومة التآكل لفولاذ كاربوني DIN CK45 اذ تم تصنيع عينات اختبار التآكل بابعاد (3, 1.5*1.5*0.3) سم وفق مواصفة ASTM G 71-30. اجريت معاملة حرارية تضمنت تسخين المعدن في فرن كهربائي الى درجة حرارة 850 م° والتبريد بالماء ثم تم اعادة التسخين الى درجة حرارة (150,350) م° ثم التبريد بالهواء. تم إجراء اختبار التآكل بواسطة جهاز مثبت الجهد وباستخدام المحلول الملحي (ماء البحر) ذو سرع (3,2,1) متر / الدقيقة آذ مثلت العينات القطب الموجب وتم حساب معدل التآكل باستخدام معادلة تافل للاستقطاب. ومن النتائج التي تم الحصول عليها تبين ان المعاملة الحرارية ساهمت في تحسين مقاومة التآكل من خلال زيادة اتحاد الكاربون مع الحديد والذي سيققل من

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اتحاده بالاكسجين الذي سيولد الصدا .ومن جهة اخرى فان زيادة سرعة الوسط (ماء البحر) يساهم في زيادة مقاومة التآكل بسبب تقليل تجمع ايونات الحديد على قطب الكاثود.

INTRODUCTION

Corrosion of metal is a major problem in construction company .oil and ship building and other engineering firms, Where medium carbon steel is particularly used. Corrosion can be defined as the destruction of a metal by chemical or electrochemical reaction with its environment. In cooling systems, corrosion causes two basic problems. The first and most obvious is the failure of equipment with the resultant cost of replacement and plant downtime. The second is decreased plant efficiency due to loss of heat transfer. Corrosion occurs at the anode, where metal dissolves. Often, this is separated by a physical distance from the cathode, where a reduction reaction takes place. An electrical potential difference exists between these sites, and current flows through the solution from the anode to the cathode. This is accompanied by the flow of electrons from the anode to the cathode through the metal.

Temperature is one of the critical environmental parameters in corrosion studies because of its severe effects on physicochemical and electrochemical reaction rates. For that Corrosion resistance of steels is strongly connected to their microstructure obtained after heat treatments that are generally performed in order to achieve good mechanical properties. For that reason, there is currently a strong interest in the effect of the heat treatment on the corrosion resistance which is affected by the changes in the microstructure [1] [2]. Many studies investigated the effect of heat treatment on the microstructure and mechanical properties, **M.B.Ndaliman** [8] study this under two different quenching medias (water and palm oil) achieving that best proprieties in strength and hardness in water is better than palm oil.

Adnan Calic [3] shows that in different cooling rate we can obtain different microstructure and improved it by varying the cooling rate . Thus; heat treatment is used to obtain desired proprieties of such as improving the toughness, ductility or removing the residual stresses, etc.

He compared this study with literature survey as, **Bangaru and Sachdev**, [5] show that oil quenching produce ferrite-martensits phases and thin film of retained austenite. By slow air cooling the results in a large amount in retained austenite in addition to the ferrite and martensite. on the other hand with the applied cooling rate increasing the transformed structure evolve s from granular bainite, lower bainite, self tempred martensite, to finally martensite without self-tempering **Qiao etal** [9] .Among them, self-tempered martensite obtained in the transformed specimens cooled with rates of 25-80 C/min, exhibits the highest hardness values due to the precipitation of fine carbides.

W. R. Osório [10] investigate the effects of four different and conventional heat treatments (i.e., hot rolling, normalizing, annealing, and intercritical annealing) on the resulting microstructural patterns and on the electrochemical corrosion behavior of low carbon steel, it was found that The normalizing and the annealing heat treatments have provided the highest and the lowest corrosion resistances, respectively. And this is due to the residual stress from the martensite formation.

On the other hand corrosion behavior of metals in sea water is affected by many environmental factors such as water temperature, dissolved oxygen content and velocity

The effect of water velocity on metals corrosion behavior has got a great interest by researchers, **Kamilia Gruskevica** [7] study the effect of water velocity on corrosion resistance of steel pipes finding that the corrosion resistance decreased in low or medium flow media by a percentage between 20-50% than rapid flow.

The aim of this paper is to examine the effect of phases which obtained by heat treatment of medium carbon steel CK 45 at different velocities on corrosion resistance

EXPERIMENTAL WORK

Metal Selection: medium carbon steel CK45 according to DIN specification were chosen because of its wide range of engineering applications such as shafts, molds, connecting rods and its chemical analysis indicated in table 1 which was conducted by ARL Spectrometer.

Fabrication Of Specimens: test specimens for corrosion test were fabricated as (1.5*1.5*3) cm according to the ASTM G 71-30.

Categorization Of Test Specimens: after the manufacturing of the test specimens were categorized into groups as shown in the **Table 2**.

Heat Treatment: the heat treatments were performed on the specimens shown in **Table 2**. the process consist of heating the specimens of symbols (B, C) to 850°C for 0.5 hour and water cooling., then Samples (B) and (C) were preheated to 350 °C for (B) and 150°C for (C) then cooled in air respectively.

TESTS AND EXAMINATION:

Microstructure Test: test of microstructure on specimens groups in table 2, the specimens were prepared as follows:

The specimens are treated with emery paper of grades 120,350,500,800.

They were polished with cloth and alumina Al₂O₃ solution.

Aqueous treatment using Nital Solution composed of 2% nitric acid and 98% metheyl alcohol.

Optical examination of samples was performed using optical microscope equipped with camera and connected to a computer. The microstructure is shown in **Figure1**.

ELECTROCHEMICAL TESTS

The prepared specimen is fixed with in the holder the reference electrode was fixed about (1 mm) apart from the surface of the specimen to be tested. The reference electrode used in this study was Saturated Calomel Electrode (SCE). The auxiliary electrode used in the electrochemical was platinum type. The specimen holder (working electrode) , together with the reference and auxiliary electrode were inserted in their respective position in the electrochemical cell used for this purpose than can fit all these electrodes as shown in **Figure 2**

Constant potentials (anodic or cathodic) can be imposed on the specimen, By using the potentiostat (Mlab200 of bank Eleck. Germany). This potentiostat is able to induce a constant potentials ranging from (-1 + 1v) the potentials of the standard reference electrode used in this study (SCE).

The potential difference between the working and reference electrode (WE – RE) and any current passing in the circuit of working electrode were auxiliary electrode can be measured by using the SCI Computer Software.

Any potential difference between the working and reference electrodes circuit can be automatically recorded. The result and plots were recorded using window xp. The scan rate can be selected also.

Polarized resistance tests were used to obtain the micro cell corrosion rates. In the tests, cell current reading was taken during a short, slow sweep of the potential. The sweep was taken from (-100 to +100) mv relative to (OPC).

Scan rate defines the speed of potential sweep in mv/sec. In this range the current density versus voltage curve is almost nearly linear. A linear data fitting of the standard model gives an estimate of the polarization resistance, which used to calculate the corrosion current density (I_{corr}) and corrosion rate.

The tests were performed by using a WENKING MLab multi channels and SCI MLab corrosion measuring system from Bank Electronics – Intelligent controls GmbH, Germany 2007, as shown in **Figure 2**. The result of electrochemical corrosions shown in **Table 3** by using [4]

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$$\text{Tafel Eq. (C.R}=0.13*i_{\text{cor}}* \text{ eq. Wt/d)} \quad (1)$$

Corrosion rate (C.R) = $0.43 * i_{\text{cor}}$

Where

mpy = milli – inches per year

i_{cor} = corrosion current density ($\mu\text{A}/\text{cm}^2$)

d = density of corroding species (g/cm^3)

C.R= corrosion rate

wt.= weight

RESULTS AND DISCUSSION

Figure 1 shows the microscopic tests that the microstructure of medium carbon steel as presented by specimens of groups (A, B, and C).

Specimens group (A) consist of ferrite and pearlite and the microstructure of the specimens groups (B, and C) consist of cementite which forming with ferrite a matrix called martensite. Baianite in group (B) while sample (C) consist of tempering martinsied.

These results agree with the results obtained by Adnan Calic [8] which study the cooling rate of the microstructure. This microstructure has affected on the results of the corrosion rates.

Figure 3 shows the relationship between the cathode and anodic behavior after polarization test, the corrosion results are shown in **Table 3**

we see an increasing in corrosion rate of all specimens group at velocity (1m/min) this is because the ferrite which combined with the dissolved oxygen in sea water causes iron oxide which known as rust while this rate decreased as the velocity increased to (2 and 3) m/min, this is because the movement of the liquid prevents the formation of deposits and ions gathering on cathode pole where corrosion can easily develop [6].

Corrosion rate for specimen (C) gives the best corrosion resistance because of the transformation of returned Ustaniate by quenching to Cementite. while specimen (B) gives higher corrosion rate comparing with (C) because of the tempering temperature (350°C) and slow cooling was higher than the tempering of specimen (C) tempering temperature(150°C) which causing forming of Ferrite which contributed in corrosion forming

CONCLUSIONS

1- Heat treatment improves the corrosion resistance by increasing the combination of iron with carbon reducing by that the combination of iron with oxygen which produces rust.

2- Tempering by re-heating at 150°C for 1 hour then cooling in air gives better results in corrosion resistance than re-heating at 350°C or quenching heat treatment because all returned Ustaniate by quenching to Cementite

3- Increasing of sea water velocity contributed in decreasing the corrosion rate because of reducing the assembling of ions on cathode pole

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Table 1 Chemical analysis of CK45

wt%	C	Si	Mn	P	S	Cr	Mo	Ni
Standard Value	0.4-0.5	0.4	0.5-0.8	0.035	0.035	0.4	0.1	0.04
Actual Value	0.42	0.02	0.573	0.002	0.002	0.051	0.018	0.077

Table 2 categorization of test specimens

Specimen symbol	Condition of specimens
A	Base metal
B	Re-heating at 350°C for 1 hour and cooling in air (Tempering)
C	Re-heating at 150°C for 1 hour and cooling in air (Tempering)

Table 3 corrosion test result

Specimen	Velocity m/min	E core (mv)	I core $\mu\text{A}/\text{Cm}^2$	Corrosion rate (m.p.y.)
A	1	-619.1	49.65	21.846
A	2	-627.4	36.28	15.96
A	3	-646.1	20.11	8.87
B	1	-618	26.12	11.49
B	2	-610.5	22.31	9.81
B	3	-606.3	20.36	8.95
C	1	-518	8.25	3.36
C	2	-519.3	3.79	1.744
C	3	-560	2.34	1.0296

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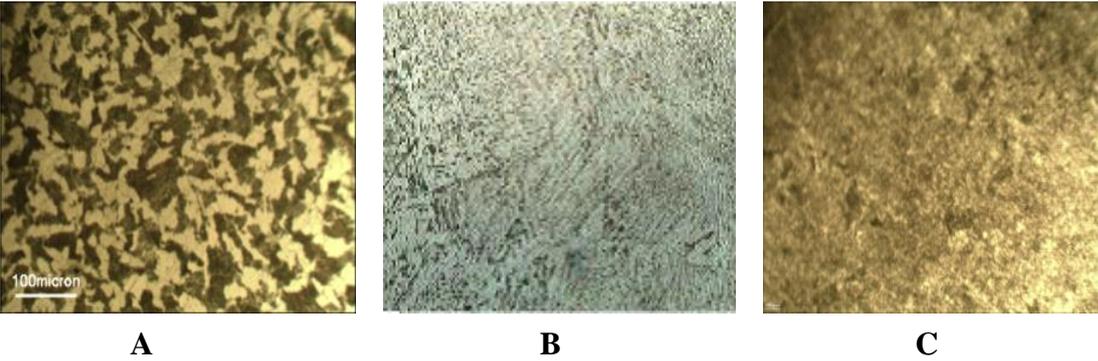


Figure 1 Microstructure of test specimens

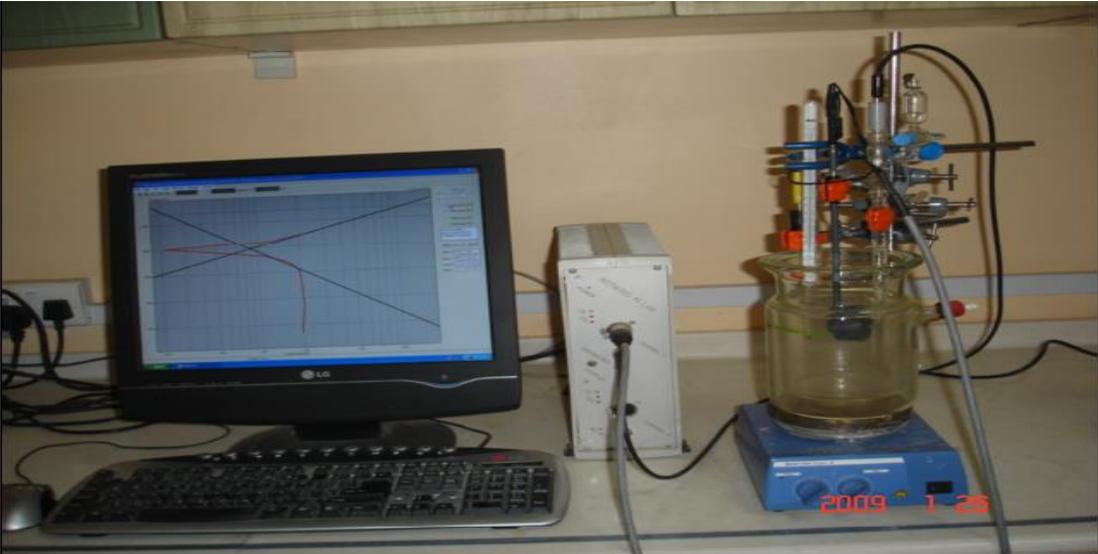


Figure 2 the electrochemical corrosion unit

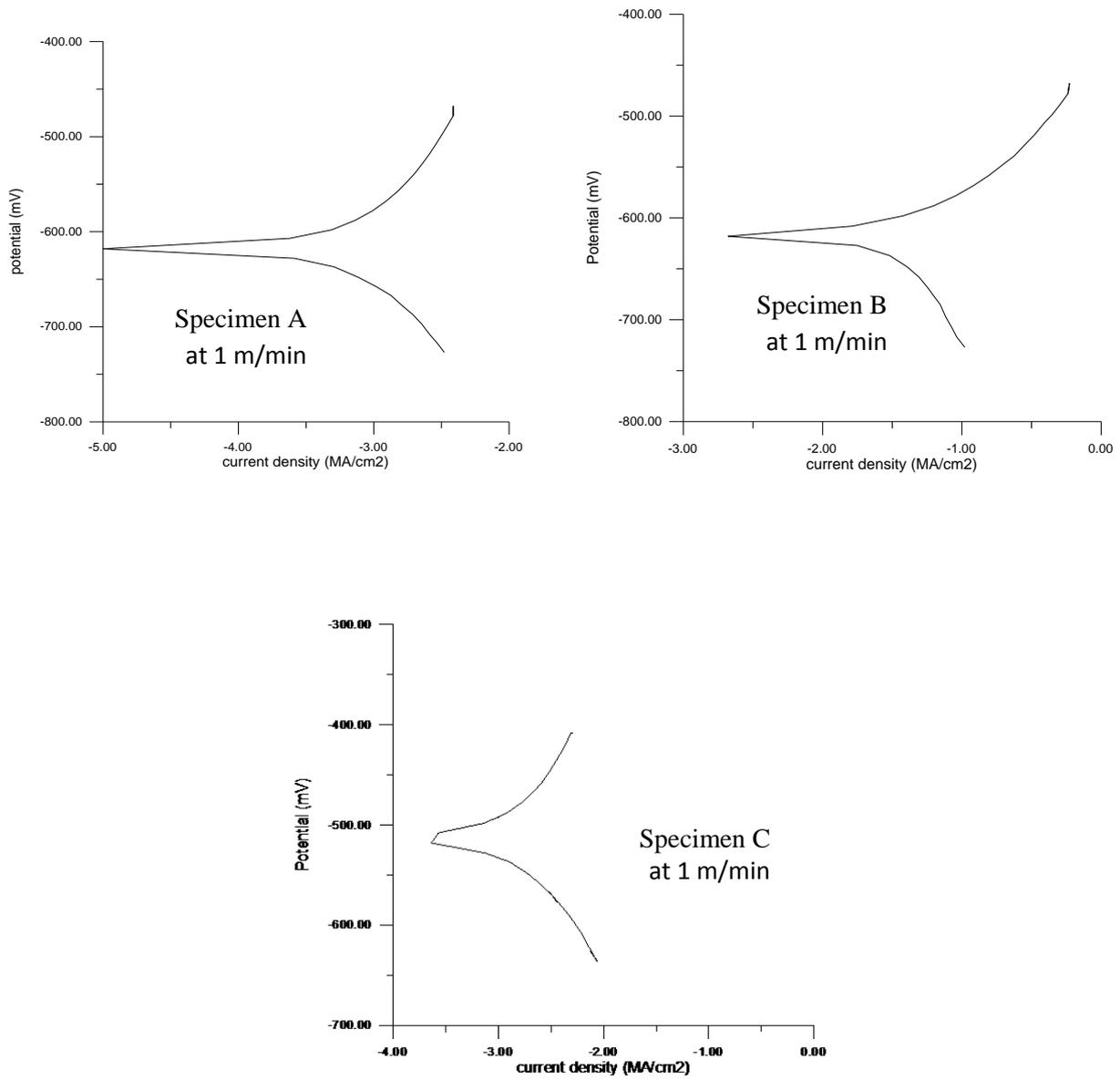


Figure 3 electrochemical behavior polarization for all specimens at (1)m/min.

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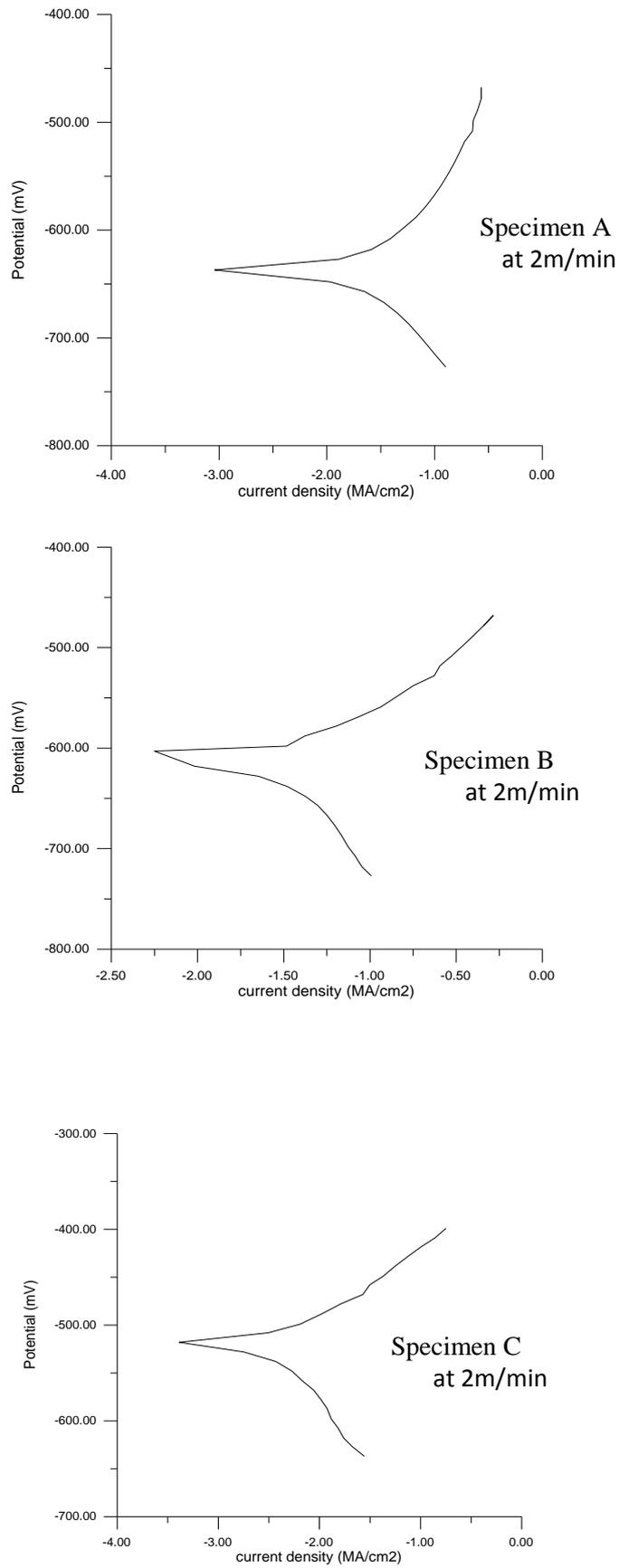


Figure 3 Electrochemical behavior polarization for all specimens at 2 m/min.

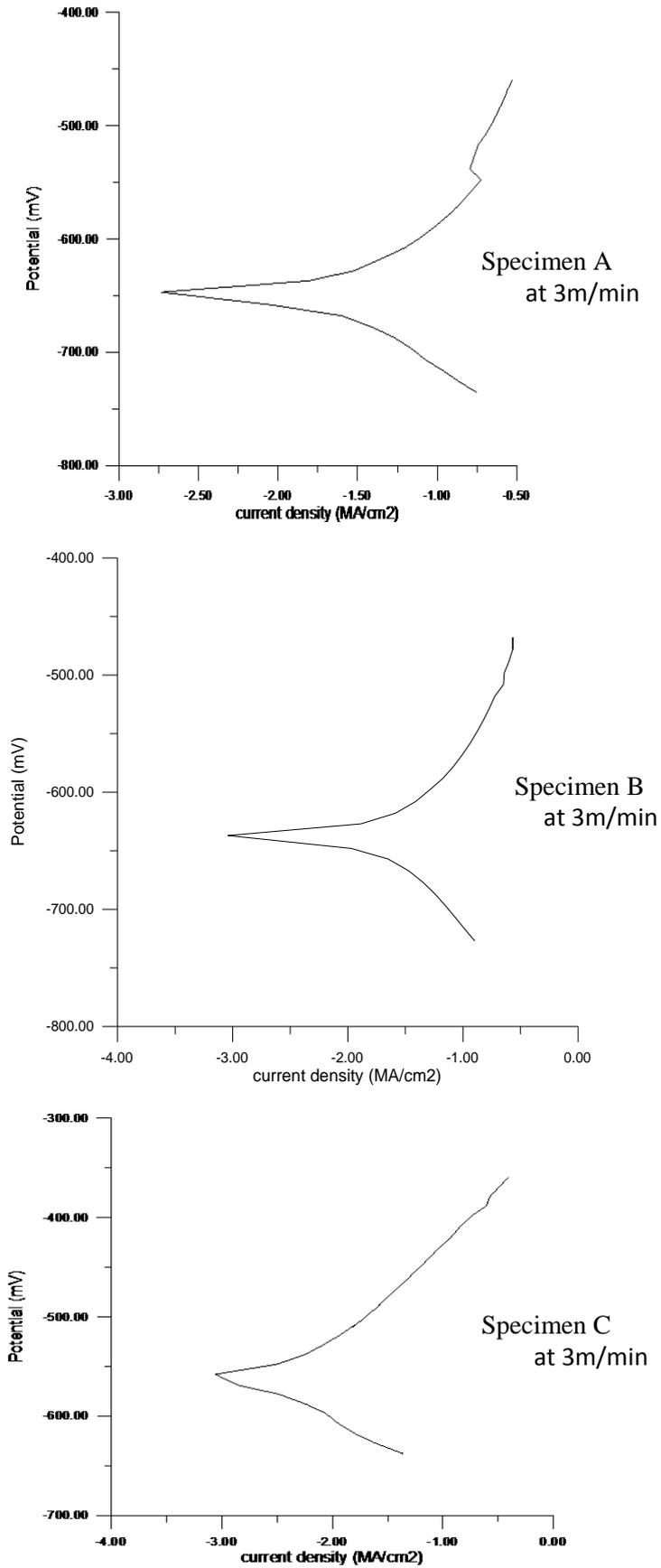


Figure 3 electrochemical behavior polarizations for all specimens at 3 m/min.