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The Corrosion Resistance of The Ukrainian Steel Embedded in Concrete after and before quenching

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Abstract

The corrosion resistance of the Ukrainian structural steel(0.22%C) and dual-phase steel which produced from it and embedded in concrete was carried out in this investigation, a test specimens of the Ukrainian steel was prepared and heated to a different temperatures (730 .760 , 790 , 820 , 850, 860 , and870^{0}C) for (50 min) holding time and then quenched in water , a dual-phase steel with a different volumetric fraction of martensite (4.5, 12.6 , 21.4 , 43.2 , 64.8 ,85.3 ,and 100%Ms) was produced respectively .

Test specimens of Ukrainian steel and of dual-phase steel were initially curing in different mediums (Kufa river water, 3.5%NaCl solution, and Arabian gulf water) for (21 Days) , to know the effect of the volumetric fraction of martensite on the corrosion resistance, also another specimens of Ukrainian steel and of (21.4%Ms) dual-phase steel immersed in concrete which conforming to (Bs 532: Part 2: 1990) and after (1 Day) cured in water for (7) days ,to find the effect of the embedded in concrete on the corrosion resistance were cured to the same above test .

Corrosion rates were measured by using a modified Tafel extrapolation corrosion test technique (ASTM G 109) , which entails voltage control and current quantifications. In addition, the (CMS-105) system was employed for daily observations on steel bars immersed in similar curing conditions . The parameters measured included corrosion potential (E_{corr}), corrosion current (I_{corr}), polarization resistance (R_p), and corrosion rate (R_{corr}.) for all specimens .

The experimental results showed that all the dual-phase steel rebar, embedded or not embedded in concrete, have more times corrosion resistant than Ukrainian structural steel for all used mediums (Kufa river water, 3.5%NaCl solution, and Arabian gulf water), because dual-phase steel contains no carbide and most of the carbon atoms are trapped in the martensite structure , and the Ukrainian steel contains the eutectoid carbide that is susceptible to pitting corrosion , and because of the presence of pearlite phase in the microstructure , also there was an effective for the martensite ’s volume percentage (%Ms) on the corrosion resistance of dual-phase steel embedded in concrete ,when it was increased the corrosion resistance increased also

Introduction

The reinforced concrete structures must have a long service lives and have high strength under the influence of various loads and conditions, but some of these structures fail after a few time . One reasons of these failure leads to the corrosion that gets in the rebar rods embedded in the reinforcement, and to improve the corrosion resistance of these rebar rods follow several ways, including improving the concrete quality by adding a material which works to improve the corrosion resistance of these rods [1], or by using materials coating to cover these bars such as epoxy or galvanized reinforcing steel bars [2,3], and there is another way to improve the corrosion resistance of the rods rebar by conducting heat treatment for the commercial low carbon steel to product these bars and get a dual-phase steel which have high corrosion resistant [4,5] . Dual-phase steel contains mainly of two phases ferrite (Fe-α) and martensite (Ms), in addition to the presence amounts of carbides and small amounts of bainite , pearlite(Fe-β) and retained austenite (Fe-γ), . In fact, dual-phase steel was developed in the 1970s and used to produce the high strength low alloy steel (HSLA) in industry [6].

The present research aims to find out the corrosion resistance of the Ukrainian reinforcement steel which produced by (Arceio Nittal) company conforming to (IQS2091 / 1999) and compared it with the corrosion resistance of dual-phase steel which produced from it by heat treatment in which specimens exposed to different mediums (Kufa river water , 3.5%NaCl solution , and Arabian gulf water) to study the corrosion resistance of dual-phase steel which produced from the ukrainian steel reinforcement that containing different volumetric fraction of martensite (4.5, 12.6, 21.4 , 43.2 , 64.8 , 85.3 ,100 % Ms) and compare them with the corrosion resistance of the ukrainian reinforcement steel, corrosion rates of these specimens were monitored by using corrosion testing technique (Tafel) conforming to (ASTM G109). The microstructure of specimens had been studied after and before the exposure corrosion process.

The experimental study

1. Metal preparation and conduct heat treatment

The knowledge of the chemical composition of ukrainian steel reinforcement which produced by (Arceio Nittal) company conforming to (IQS2091 / 1999) is very important to identify the actual lower and upper intercritical temperatures (Ac_1) (Ac_3) respectively, and to find out the suitability of it to produce a dual- phase steel, Ark Spark Spectrometer Analysis was carried out by using the device (METALSCAN 1650-ARUN), and this method has been determine the chemical composition as shown in Table1. Based on the chemical composition of carbon (0.22%C) and using an equation suggested by (Andrew, 1965) [5], the actual lower and upper intercritical temperatures (Ac_1) (Ac_3) for used material are (839 ^{0}C) and (723 ^{0}C) respectively .Simple tensile test specimens were manufactured conforming to (ASTM100) and a simple tensile test carried out by using Avery Dension tensile machine and gave the results shown in Table 2, and the image in Fig. 1 illustrates the used tensile specimens during and after the test . A specimens of (25mm) diameter and (50mm) length had been prepared and heated to a different intercritical temperatures (730,760,790,820,850,860,and 870 ^{0}C) by using an electrical oven furnace type (Carbolite) its maximum temperature (1200^{0}C), for (50 min) and then quenched in water(its temperature about(25^{0}C) to transform the austenite in to martensite.

2.Metallographic Analysis

After the above heat treatment , specimens were prepared for microscopic examination to conduct smoothing operations and refinement, then conducted the process of manifestation of the specimens using etching solution (2% Nital , 98% Alcohol) and all microstructure were filmed by using a device (Optika Microscopes-Italy) as illustrated in the Figs. 2 → 8 , then the volume fraction of the phase constituents was analyzed for martensite by image analyzer , the part of martensite was calculated by using Point Counting Method and the relationship between the heat treatment temperatures (^{0}C)and volumetric fraction of martensite maintained and gave the results shown in Fig.9.

3-Immersion in concrete process

The Portland cement conforming to (BS12: 1989) ,naturally river- washed quartz sand (NORQS) passing through ASTM sieve No. 4 , and crushed granite stones to(7mm) size approximately , was used in this research.

A castings of concrete had been prepared according to (Bs 532: Part 2: 1990) with (200x200x100mm)dimensions and flooded the bars of Ukrainian steel reinforcement which produced by (Arceio Nittal) company and others of the prepare (21.4 % Ms) dual- phase of (25mm) diameter , so that stray ends a distance of not less than (25 mm) from the end of the concre te and the length of the submerged part in the concrete (100 mm) and less than the thickness of the concrete surrounding the penis (25 mm), which are left in the armed concrete castings for one day (1Day) then placed in cold water ,its temperature about (25 ^{0}C) for (7 Days). [7]

4. Corrosion Test

A corrosion rate test was carried out by a modified(ASTMG109) corrosion test technique for the specimens that have been submerged after the surface of the concrete prism clean .A plastic tube with(50 mm) diameter was positioned and sealed on the top of the concrete prism surface . To measure the corrosion rate ,corrosion solutions (Kufa river water , 3.5%NaCl solution , and Arabian gulf water) the analytical components were illustrated in Table 3 , were poured into the plastic tube . The steel rods (working electrode) and graphite (counter electrode) of the specimens were connected to the positive(+) and negative(-) terminals of the potentiate respectively as shown in Fig. 10 . All tests were conducted at room temperature and recorded readings every day and regularly for a period of (21 Days) .The effect of volumetric fraction of martensite (Ms%) on corrosion rates (R_{corr}) for the different mediums were illustrated in Tables 4,5 and in Fig.11 . The corrosion rate was measured by using Tafel Extrapolation and gave a curves as shown in Fig.12 [8,9] .

Results and Discussion

1 - Microscopic Composition

Fig. 2 shows a smooth and accurate structures of ferrite (Fe-α) and pearlite (Fe-β) after normalized heat treatment process was conducted, so the thermal treatment is necessary in order to eliminate the martensite structure of the ukrainian steel before doing the suitable thermal treatment. [10]

Figs 3 →8 show the microstructures of dual-phase steel , which was obtained from heating the Ukrainian steel to different intercritical heat treatment temperatures (730,760,790,820,850,860,and870^{0}C)for(50min)and then quenched in water. Dual-phase steel consists of martensite and ferrite. The martensite usually forms as an island-like shape at the ferrite grain boundaries. The volumetric percentage fraction of martensite in dual-phase steel is affected by the variation of heat treatment temperature ,the higher the intercritical temperature ,the higher the volumetric percentage fraction of martensite in dual-phase steel on the grain boundaries of ferrite as shown in Figure 9, which means that there is a linear relationship between the intercritical heat treatment temperature and the volumetric percentage fraction of martensite, which increases until it reaches (100%Ms) when heats to a temperature higher than (870^0C) temperature, which is higher than the upper critical temperature of this steel (Ac_3) , and that means all the microstructure transforms to austenite when heating to the upper critical temperature ,and when quenched in water transforms to(100%) martensite, but in the (730^0C) temperature, the volumetric fraction of martensite be low when the analysis due to the increased proportion pearlite(Fe-β) dramatically ,which is in agreement with the finding of [11,12].

2 - Electrochemical Corrosion Test (Tafel - Extrapolation)

This test involves the use of Computer-Controlled Potentiostat at a (1mV / sec) scan rate [13,14] . The measured results are summarized in Tables 4and5.

From table 5 it can be shown that the corrosion potential (Ecorr.) of the (21.4% Ms) dual-phase steel less corrosion effort than the ukrainian steel in all the used mediums (Kufa river water, 3.5% NaCl solution, Arabian gulf water).The potential values of dual-phase steel were (-273.8mV) in Kufa river water , (-258.2mV) in (3.5% NaCl solution) and (-246.9 mV) in Arabian gulf water compared to (-529mV) in Kufa river water , (-497.5mV) in (3.5% NaCl solution) and (-360.3mV) in Arabian gulf water for the ukrainian steel, and the corrosion current density (Icorr.) for (21.4% Ms) dual-phase steel is lower than the ukrainian steel. corrosion current density (Icorr.) values ($0.382x10^{-6}A/cm^2$) for Kufa river water compared to ($6.56\ x10^{-6}A/cm^2$) for ukrainian steel and at the same medium , while the corrosion current for dual-phase steel (Icorr.) was ($0.409x10^{-6}A/cm^2$)in(3.5%NaCl solution) and ($7.49x10^{-6}A/cm^2$)for the Ukrainian steel, while in Arabian gulf water was corrosion current density(Icorr.) ($0.823x10^{-6}A/cm^2$)for dual-phase steel compared to ($9.24\ x10^{-6}A/cm^2$) for the ukrainian steel. In this case, it appears clear that the ukrainian steel has high erosion rate than dual-phase steel for all the used mediums , also from table 5 it can be shown that the corrosion rate for the Arabian gulf water medium is higher than corrosion rate of the (3.5% NaCl solution) and Kufa river water, which is in agreement with the finding of [11,13].

The corrosion rate values for the (21.4%Ms) dual-phase steel, which were calculated by the Tafel extrapolation method ranged in between(0.513 → 0.871m p y), while (2.88 → 4.02 m p y) for the ukrainian steel, which were calculated by the same way, which were times the corrosion rate values of (21.4% Ms) dual-phase steel because the presence of pearlite phase in the microstructure of the ukrainian steel ,which contains the eutectoid carbide that is susceptible to pitting corrosion , in the other hand , the carbon in the microscopic structure of the dual-phase steel as a carbon atoms which are trapped in the martensite structure , and this is consistent with the findings of the researchers [14,15].

3. The effect of the volumetric fraction of martensite on corrosion resistance

Fig. 11 shows that when the percentage volumetric fraction of martensite increased , so that the corrosion rate (R. corr) decrease in general and for all the mediums due to the decrease in the pearlite phase(Fe-β) which leads to a decrease eutectic carbide in microstructure which decreases the pitting Corrosion, as well as the microstructure of the dual-phase steel contains no carbides and most of the carbon atoms are trapped in and distributed wildly in the martensite phase , and it is clear that the corrosion resistance of the dual-phase steel, higher than the ukrainian steel ,and the result of the presence of the pearlite phase(Fe-β) in the microstructure of the armature the ukrainian steel which generates eutectoid carbide , which promotes corrosion pitting , and in the other hand, the dual-phase steel has high corrosion resistance because it does not contain carbides in the microstructure and most of the carbon thawed and distributed wildly in the martensite phase, and this is consistent with the findings of the researchers [15,16].

Conclusions

From the results of this research it can be concluded the following

1 - Dual-phase steel which produced from the ukrainian steel has higher corrosion resistance rates than the Ukrainian steel which embedded in concrete and for all exposure conditions.

2 - The corrosion rates of steel dual is affected by the percentage of the volumetric fraction of martensite which were in between (0.513 → 0.871 mpy),while the corrosion rates for the Ukrainian steel in (2.88→4.02mpy).

3 - The corrosion rates of the dual and the Ukrainian steels were both affected by the aggressive medium , and the highest rate of erosion happened in Arabian gulf water medium.

4 - Dual-phase steel can be considered as suitable for use in the mediums (Kufa river water, 3.5% NaCl solution , Arabian gulf water).

5 – Increasing the heat treatment temperature causes increasing the percentage of the volumetric fraction of martensite .

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Table 1: The chemical composition analysis of the ukrainian (0.22% C) steel (IQS2091/1999), Arceio Nittal company . Materials Engineering Dep. Laboratory , University of Technology , Baghdad **.**

Element	S	Mn	Si	C	P	Other	Fe
wt%	0.05	1.00	0.4	0.22	0.05	0.3	Rem.

Table 2: The mechanical properties of the ukrainian (0.22% C) steel (IQS2091/1999), Arceio Nittal company .

Metal	**Ultimate Tensile Strength б UTS (N\mm^2)**	**Yield Stress бy (N \ mm^2)**	**Elongation % El**
As specified	<600	<400	8
As tested	645.5	416.16	14.8

Table 3 : The analytical component of the Kufa river water and Arabian gulf water, Central Laboratory of Al Najaf water office (Feb . 2015).

Type of test	NTU	Temp. ^0C	PH	EC µ S/ m	ALK p.p.m	T.H p.p.m	Ca^{+2} p.p.m
Kufa river water	5.8	17	7.2	1637	150	572	115.7
Arabian gulf water	13.4	25.4	8.4	2317	258	814	400
Type of test	**Mg^{+2} p.p.m**	**Cl^- p.p.m**	**SO_4^{-2} p.p.m**	**T.D.S p.p.m**	**T.S.S p.p.m**	**K p.p.m**	**Na^+ p.p.m**
Kufa river water	69.7	181	468	1044	56	7.2	140
Arabian gulf water	$1.3x10^3$	$1.8x10^4$	$2.6x10^3$	$1.34x10^3$	$3.2x10^3$	380	$1.1x10^4$

Table 4: The effect of the volume fraction of martensite (Ms%) on the Corrosion rate (R corr.) (m p y) for the Ukrainian (0.22% C) steel (IQS2091/1999), Arceio Nittal company .

Volume fraction of martensite (Ms%)	Corrosion rate (R corr.) (m p y)		
	Kufa river water	3.5% NaCl solution	Arabian gulf water
0	2.88	3.74	4.02
4.5	1.022	1.832	2.123
12.6	0.735	0.829	1.208
21.4	0.513	0.647	0.871
43.2	0.324	0.523	0.756
64.8	0.0231	0.0451	0.1218
85.3	0.0109	0.0346	0.065
100	0.0082	0.0051	0.0073

Table 5: Comparison of Tafel Results between Dual-phase steel (21.4% Ms) and The Ukrainian (0.22% C) steel **.**

Type of test	The Ukrainian (0.22% C) steel			Dual-phase steel (21.4% Ms)		
	Kufa river water	3.5% NaCl solution	Arabian gulf water	Kufa river water	3.5% NaCl solution	Arabian gulf water
Corrosion potential $E_{corr.}$ (mV)	-529	-497.5	-360.3	-273.2	-258.2	-246.9
Corrosion current (I_{corr}) (A/cm^2) $x10^{-6}$	6.56	7.49	9.24	0.382	0.409	0.823
Polarization Resistance (R_p) (Ohm cm^2) $x10^4$	2.74	2.06	12.01	18.2	17.3	11.1
Corrosion rate ($R_{corr.}$ (m p y)	2.88	3.74	4.02	0.513	0.64	0.871

a

b

Figure 1: Tensile Test specimens (a :through , b :after) test

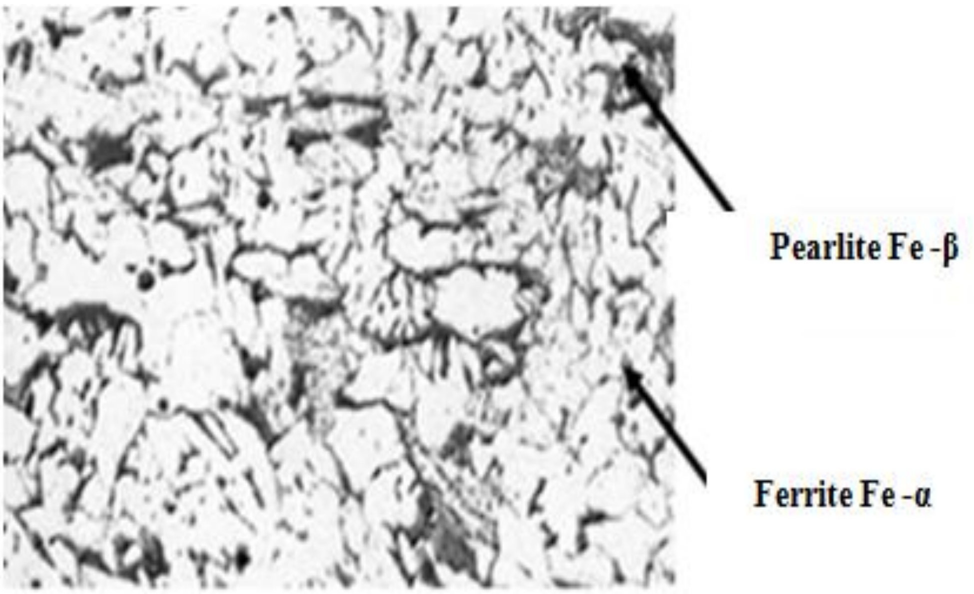


Figure 2: The microstructure of the Ukrainian (0.22% C) steel (X200) .

Figure 3: The microstructure of the surface layer for the Ukrainian (0.22%C) steel (X200)

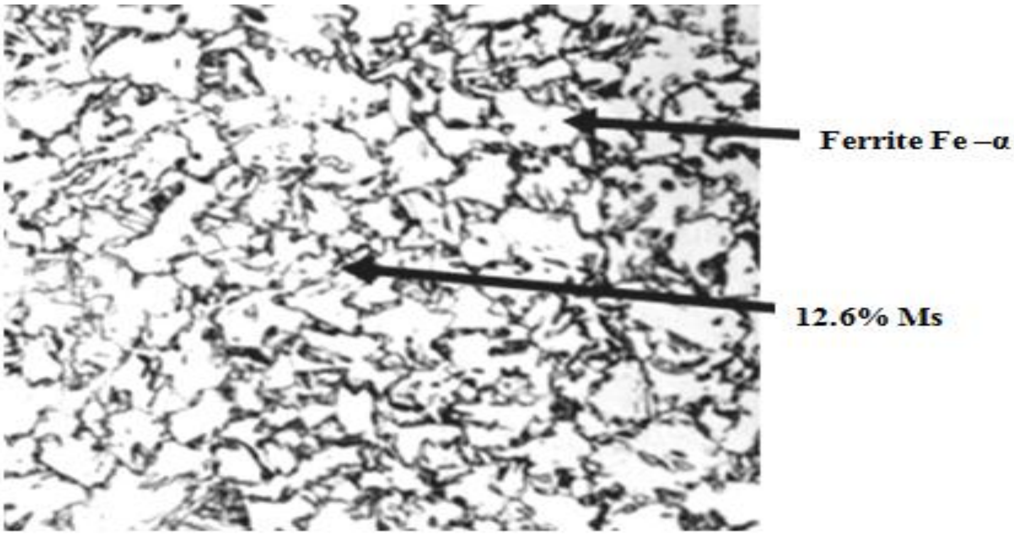


Figure4:.The microstructure of the Dual-phase steel ,(760^{0}C) annealing temperature , (X500) **.**

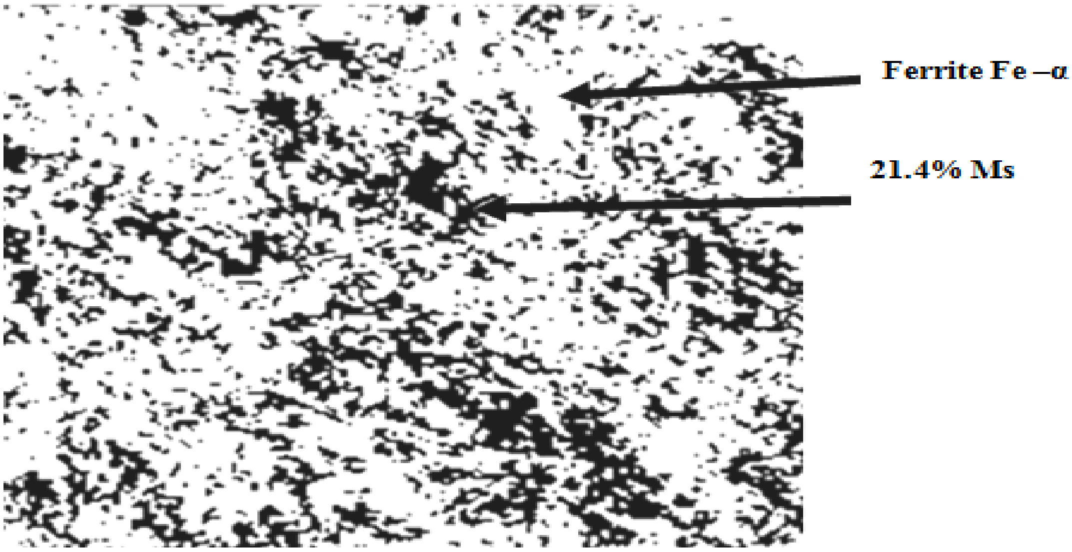


Figure 5: The microstructure of the Dual-phase steel ,(790^{0}C) annealing temperature , (X1000) .

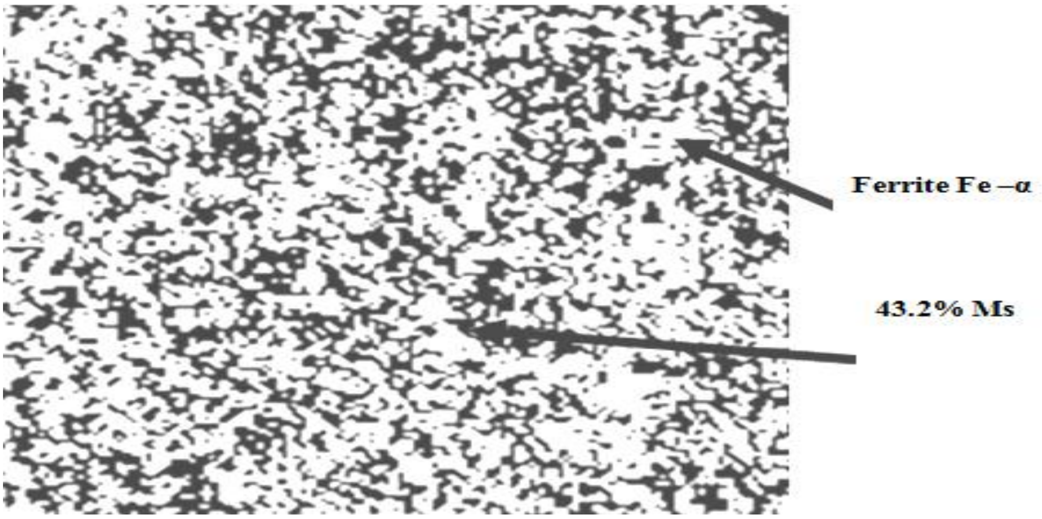


Figure 6: The microstructure of the Dual-phase steel ,(820^{0}C) annealing temperature , (X1000) **.**

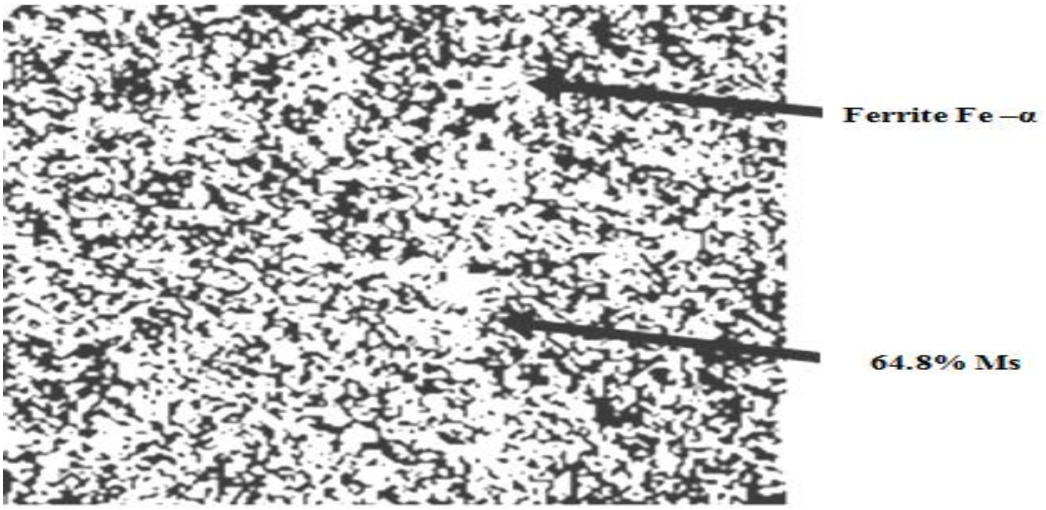


Figure 7: The microstructure of the Dual-phase steel ,(850^{0}C) annealing temperature , (X1000) .

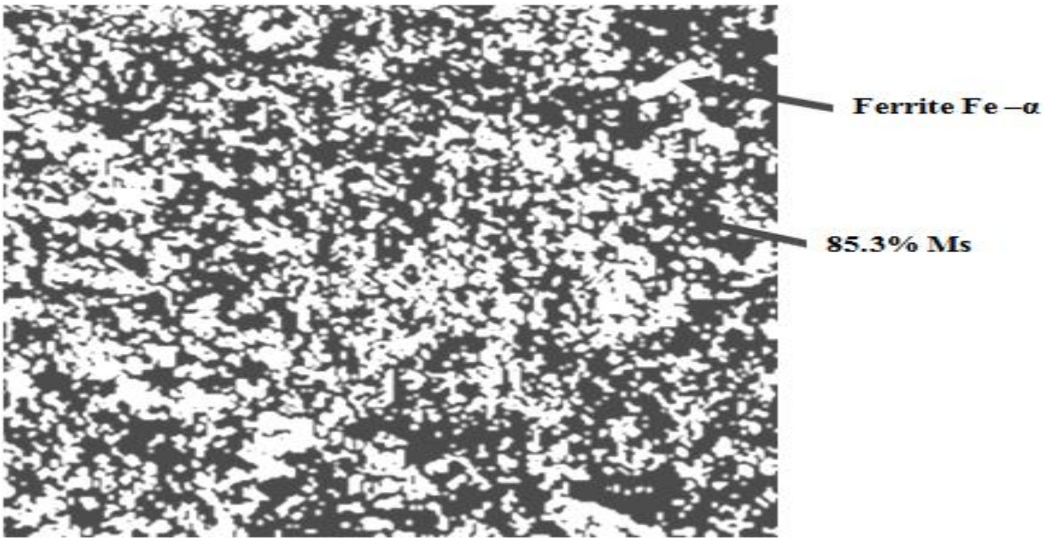


Figure 8: The microstructure of the Dual-phase steel ,(860^{0}C) annealing temperature , (X1000) .

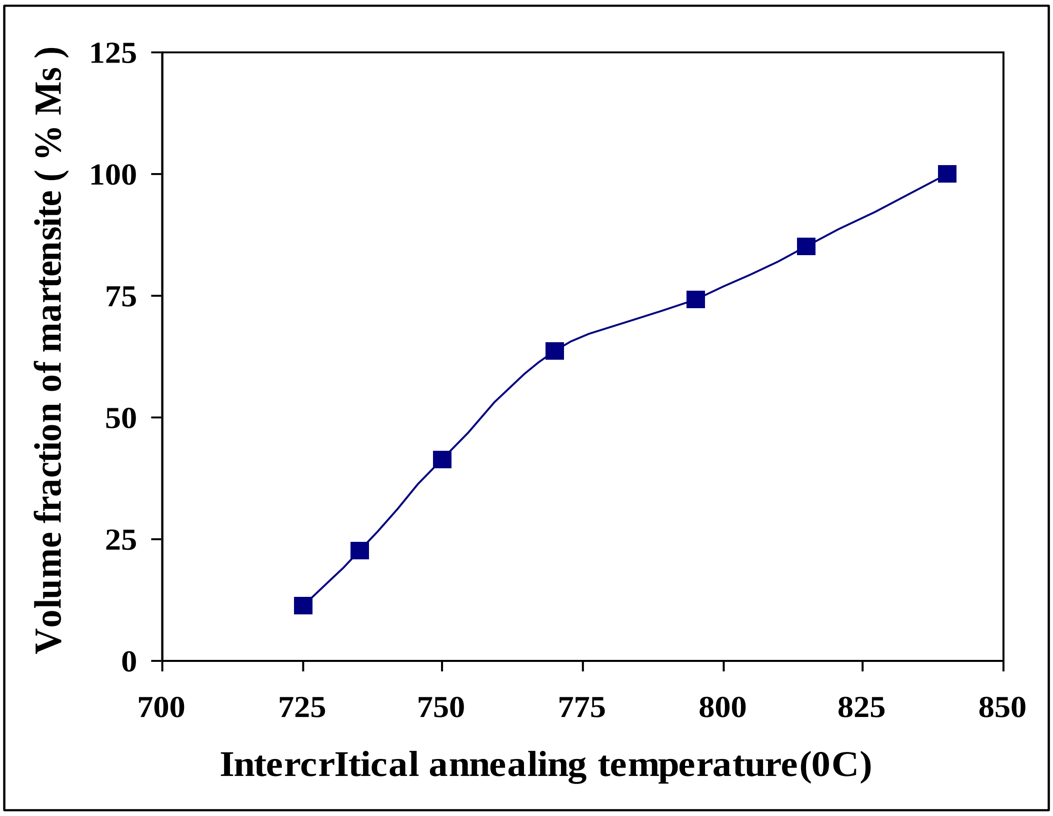


Figure 9: Percentage of volume fraction of martensite vs intercritical annealing temperature (^{0}C) for the Ukrainian (0.22%C) steel .

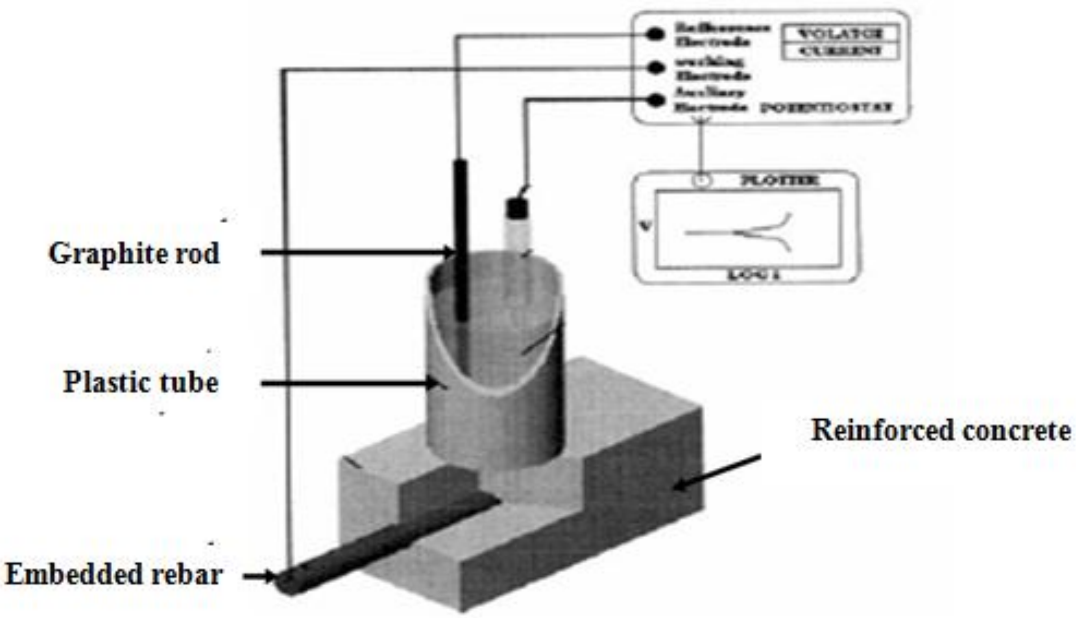


Figure 10: Schematic of the connection between the potentiostat and the three electrodes to the DC corrosion measurement software [11] .

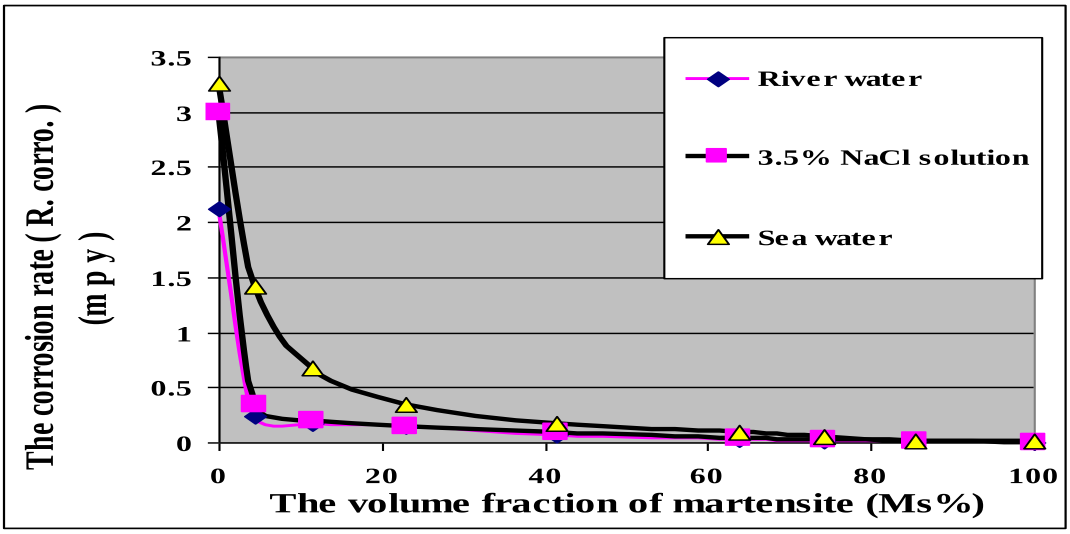
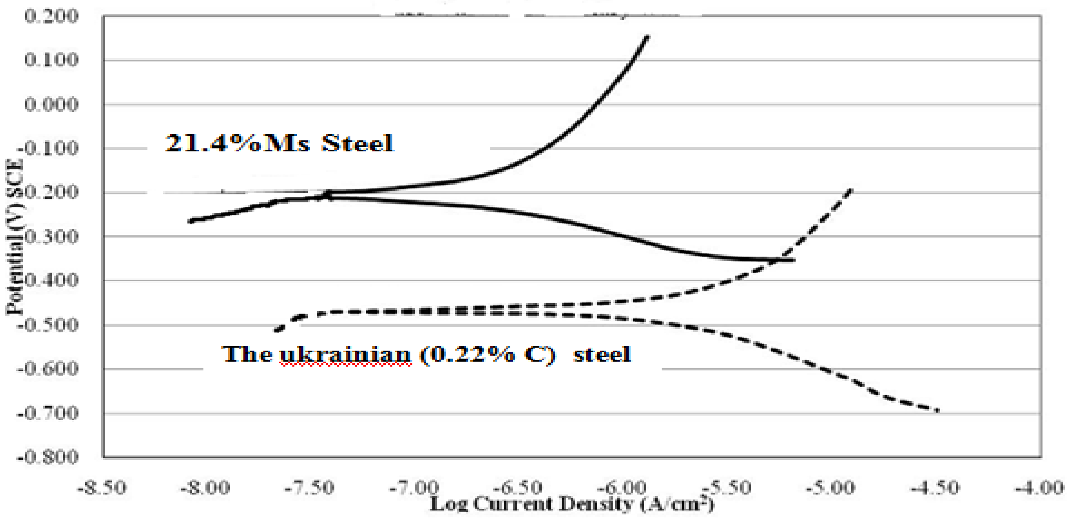
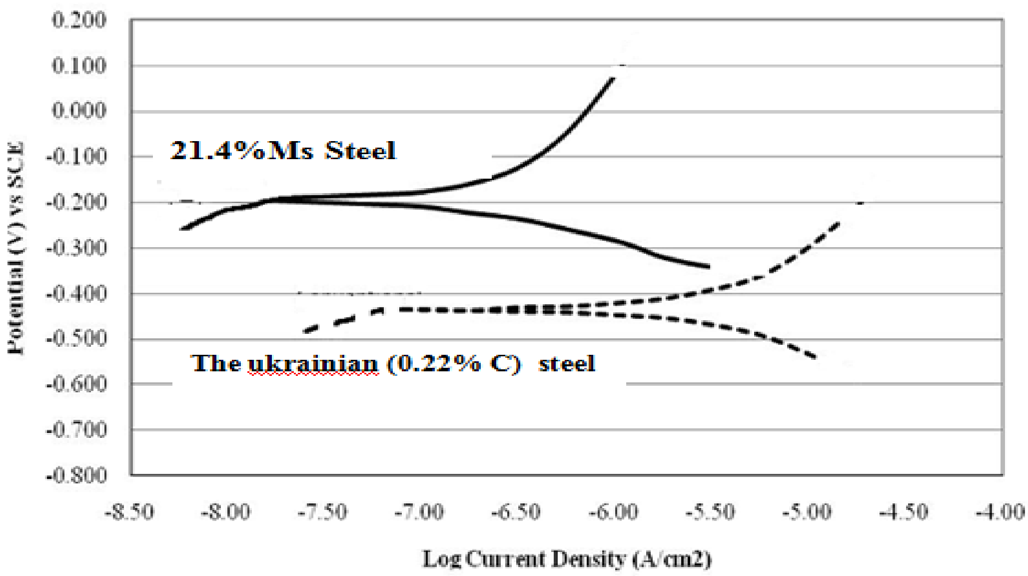


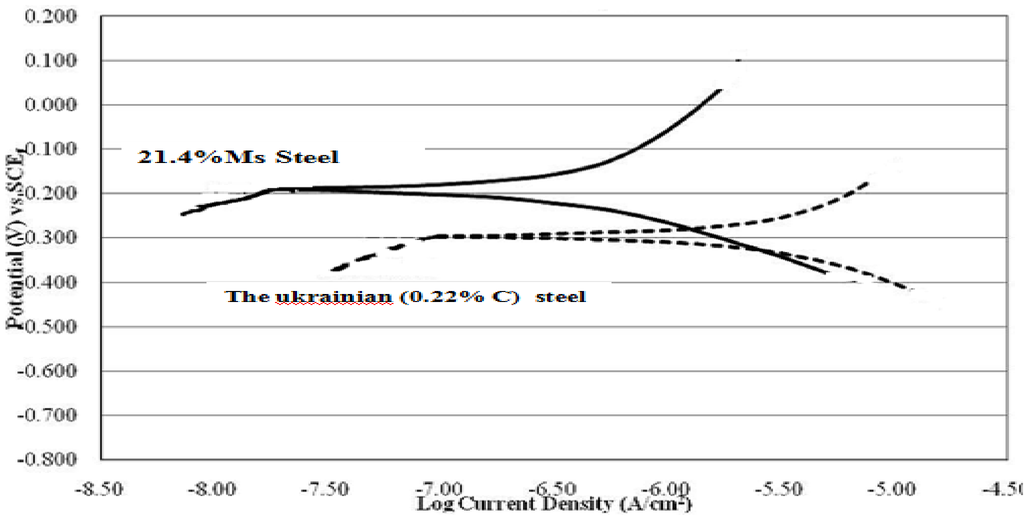
Figure 11: Percentage of volume fraction of martensite (Ms%) vs corrosion rate($R_{corr.}$)(m p y) , for different mediums .



A :Kufa river water



B : 3.5% NaCl solution



C : Arabian gulf water

Figure 12: Tafel Extrapolation curves (A : Kufa river water , B : 3.5% NaCl solution ,and C : Arabian gulf water) .

مقاومة للتآكل من الصلب الأوكرانية جزءا لا يتجزأ في الخرسانة بعد و قبل التبريد

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الخلاصة :

تم في هذا البحث دراسة مقاومة التآكل لحديد التسليح الاوكراني المنشأ C%0.22)) وللصلب ثنائي الطور المحضر منه و المغمورين في الخرسانة الكونكريتية ، حيث تم تحضير عينات من حديد التسليح وتسخينها لدرجات حرارية مختلفة (7300 , 760 790 , 820 , 850 , 860. 870 C) ولزمن (50 min) ثم الإخماد بالماء ومن ذلك أمكن الحصول على صلب ثنائي الطور ذو جزء حجمي للمارتنسايت بنسب مختلفة (100 , 85.3 , 64.8 , 43.2 , 21.4 ,12.6 , Ms%4.5)على التوالي.

لقد غمرت عينات من حديد التسليح ومن الصلب ثنائي الطور المحضر في أوساط تآكل مختلفة (ماء نهر الكوفة ، محلول NaCl%3.5 ، ماء الخليج العربي) ولمدة (21 Days) وذلك لمعرفة تأثير الجزء ألحجمي للمارتنسايت (Ms%) على مقاومة التآكل, ولتوضيح تأثير الغمر في الخرسانة على مقاومة التآكل, اجري نفس الاختبار أعلاه لعينات أخرى من حديد التسليح ومن الصلب ثنائي الطور (21.4 Ms%) بعد أن غمرت أولا في الخرسانة الكونكريتية المحضرة حسب المواصفة (Bs 532: Part 2: 1990) وتركت لمدة يوم واحد ثم غمرت بعد ذلك في الماء لمدة سبعة أيام (7 Days).

اجري اختبار معدل التآكل لجميع العينات باستخدام تقنية اختبار التآكل المعدل (Tafel) وحسب المواصفة (ASTM G 109) وذلك من خلال السيطرة على التيار الكمي والجهد وذلك باستخدام نظام (CMS-105) للمراقبة اليومية على جميع العينات المغمورة في حالات مماثلة , كما تم قياس جهد التآكل (Ecorr.) وتيار التآكل (Icorr.) ومقاومة الاستقطاب (Rp) ومعدل التآكل (Rcorr).

أظهرت النتائج بأن مقاومة التآكل لكافة أنواع الصلب ثنائي الطور المنتج أعلى بعدة أضعاف منها لحديد التسليح سواءا كانت مغمورة أو غير مغمورة في الخرسانة وذلك لان الصلب ثنائي الطور لا يحتوي على الكاربيدات ومعظم الكربون فيه مذاب وموزع بصورة عشوائية في التركيب المارتنسايتي هذا من جهة و من جهة أخرى فان وجود البرلايت في التركيب ألمجهري لحديد التسليح والذي يكون كار بيد اليوتكتويد والذي يشجع بدوره على التآكل بالتنقر (Pitting Corrosion) ويقلل من مقاومة التآكل لحديد التسليح ، كما أن هنالك تأثير كبير للنسبة المئوية للجزء ألحجمي للمارتنسايت (Ms%)على مقاومة التآكل للصلب ثنائي الطور حيث تزداد مقاومة التآكل بزيادتها.