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RESEARCH ARTICLE

Investigation on the Effect of Origin of Carbon Steel Reinforcing Bar on the Corrosion Behavior in Artificial Concrete Solution

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Abstract

The corrosion of steel reinforcing bar in concrete is very important point in fractures and damage of concrete building structures, many factors play important role in this problem. This research focuses on the effect of the origin of the carbon steel reinforcing bar on the corrosion parameters in simulate concrete solution (artificial), consisted of (Ca $(OH)_2$ (2gm), KOH (22.44mg), Noah (8mg). Two familiar types in the Iraqi local markets were followed, namely; locally produced sample and Ukrainian imported samples. Tafel plots and cyclic polarization procedures were conducted to estimate the corrosion parameters and pitting susceptibly of the two types using three electrodes potentiostat.The effect of temperature and some thermodynamic functions were measured in the range 20 to 50°C. The microstructure and morphology was imaged using optical and atomic force microscope (AFM) respectively.

Keywords: *Steel reinforcing, Concrete solution, Artificial, Tafel.*

Introduction

Corrosion of reinforcing steel is the major cause of destruction of concrete structures in spite of that concrete itself has a very high alkalinity (pH >10) and produce a very thin passive film which limits the metal loss from the carbon steel surface [1,3]. It is well known that chloride, carbon dioxide and other causing agents, the steel protective passive layer is locally destroyed and unprotected steel areas dissolve and will corrode faster [4,8]. A nether less important factor is the chemical composition of the carbon steel used to fabricate the reinforcing bar, few investigation were published on such factor [9, 10].

This work aimed to follow up the corrosion properties of two types of different manufacturers' origin of carbon steel reinforcing bar (CSRB).

Materials and Methods

Two types of carbon steel reinforcing bars are used in this study, it represent the most familiar types in the Iraq local markets, the first is produced by the ministry of industry of Iraq while the other is imported from Ukraine by private Iraqi merchants. The chemical composition of the the Ukrainian and Iraqi CSRB are tabulated in Table (1) have been determined by the manufacturers.

Table 1: Chemical composition of Iraq CS and Ukraine Bars

RSB Type	C	S	Si	N	Cu	Mn	Ni	Cr	p
Ukraine	0.26	0.031	0.28	0.010	0.28	0.73	0.13	0.12	0.018
Iraqi	0.24	0.026	0.26	0.009	0.26	0.70	0.12	0.14	0.015

The first step of the corrosion measurement procedure is the preparation of the Iraqi and Ukraine CSRB, it pickled with concentrated HCl (37%, Fluka/Switzerland), then rinsed with running water and rinsed with ethanol and dried well, the bar was then covered with adhesive tape except for a known distance which is (16.55cm^2), Fig. (1), and put them in a the three electrode cell and serve as working electrode, the Pt-electrode serve as counter electrode, and Ag/AgCl as references electrode.

Fig.1: Preparation of the Carbon steel reinforcing bars used in this study

The open circuit potential (OCP) was measured and then the two types (Ukraine and Iraqi) were polarized in the artificial concrete solution (Ca (OH) $_2$ (2gm), KOH (22.44mg), NaOH (8mg)). After that, Tafel plots were recorded for corrosion rate measurement by scanning the potentials ±200mv around the OCP with a rate of 2mv/sec. To evaluate the thermodymic and kinetic parameters, the same procedure were repeated at four temperatures namely; 20, 30, 40, and 50^{o}C. The cyclic polarization conducted at 20C starting from few millivolts lower than OCP going up to about 1000mv. The change in the microstructure and morphology of the surface followed by optical microscope (Nikon Eclipse ME 600, Japan) and atomic force microscope (SPM AA3000, Angstrom Advanced Inc., USA) respectively.

Results and Discussion

From Tafel plots (E vs. i), three polarization parameters were used to study the electrochemical corrosion kinetics of the systems under investigations by determining; corrosion current density (i_{corr}) corrosion potential (E_{corr}), anodic Tafel slopes (βa) and cathodic Tafel slopes (βc). Evaluation of these parameters leads to the determination of the polarization resistance (Rp) as in Eq. (1) and (2), the corrosion rate as which is often converted into Faradaic corrosion rate having units of (mm/y) [11]. The corrosion rate measurements of the two kinds of CSRB see Tafel plots Fig. (1) and Fig. (2), reflected small values which attributed to the inert immunity of the concrete solution due to high pH value[12], on increasing the temperature of the concrete electrolyte, the corrosion rate increased for the two types of CSRB but it still small in spite of the Iraqi-CSRB seems to be more sensitive to warm conditions, as shown in Table (2).

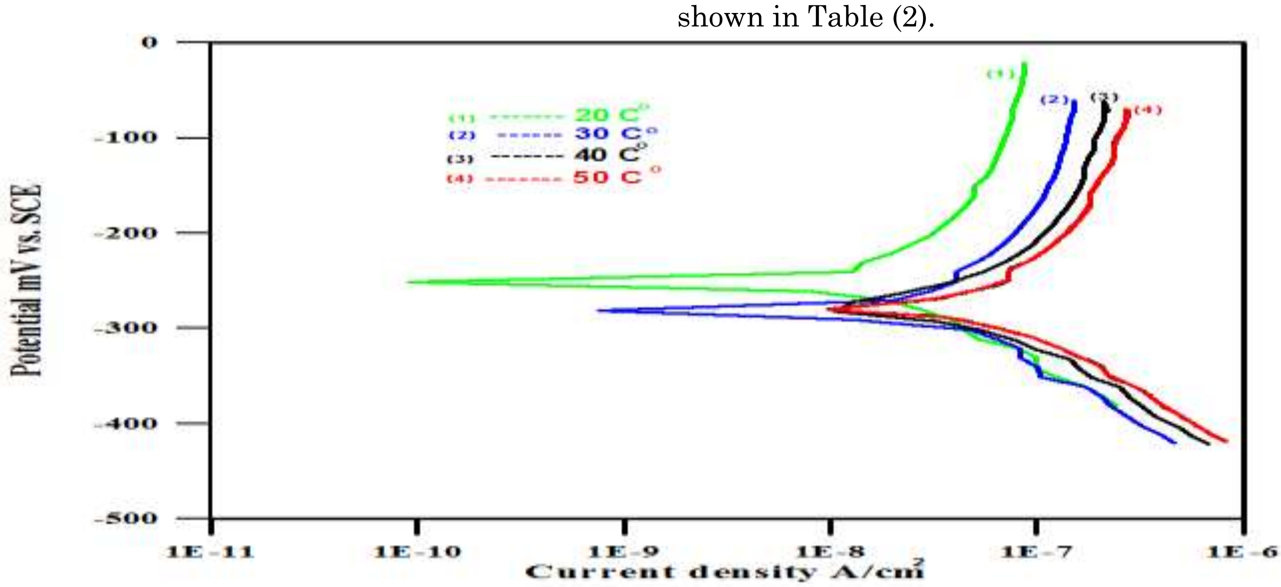

Fig. 1: Tafel plots of Ukrainian CSRB in simulated concrete solution at 20, 30, 40, 50^{o}C

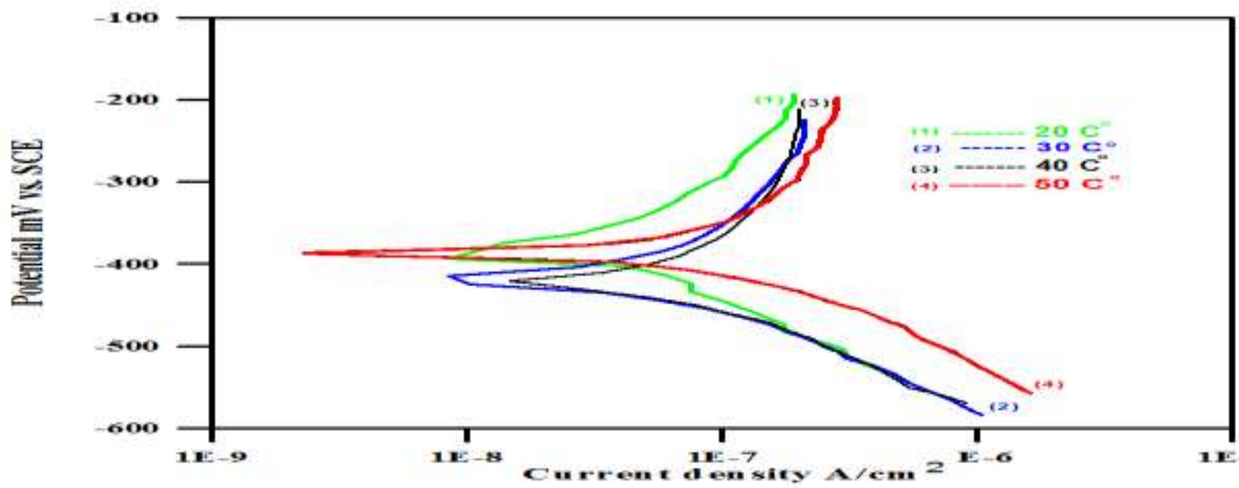

Fig.2: Tafel plots of Iraqi CSRB in simulated concrete solution at 20, 30, 40, 50°C

Table 2: Corrosion rate parameters of Ukraine and Iraqi CSRB in simulated concrete solution at 20, 30, 40, 50°C

sample	T(K)	E_{corr} (mV)	i_{corr} (*10^{-6} A/cm^2)	ßc (mV/Dec)	ßa (mV/Dec)	Rp (Ω.cm^2)	CR(WL) g.m^{-2}d^{-1}	CR(PL) mmpy
Ukraine	293	-340.3	24.20	-121.8	137.1	677.75	6.05	0.281
	303	-379.6	31.47	-129.4	176.8	1020.90	7.87	0.365
CSRB	313	-421.1	39.04	-89.8	166.6	989.12	9.76	0.453
	323	-393.2	61.45	-82.7	186.4	1528.50	15.40	0.713
Iraqi	293	-246.8	12.68	-96.3	124.2	298.65	3.17	0.147
	303	-280.0	25.81	-105.8	162.7	718.49	6.45	0.300
CSRB	313	-273.7	52.39	-136.9	240.6	1984.89	13.10	0.608
	323	-279.7	66.34	-127.1	255.6	2445.285	16.60	0.770

The corrosion current of the Ukraine CSRB is higher than that of the Iraqi one at ambient temperature and 30°C, while over these temperatures, the manner is somehow opposite, Fig. (3). This difference is attributed to main two factors; the first is the history of mechanical treatments of each kind which form different defects [13], the second is the differences in the elemental composition presented in table (1), which also responsible for the differences in the calculated R_p [14].

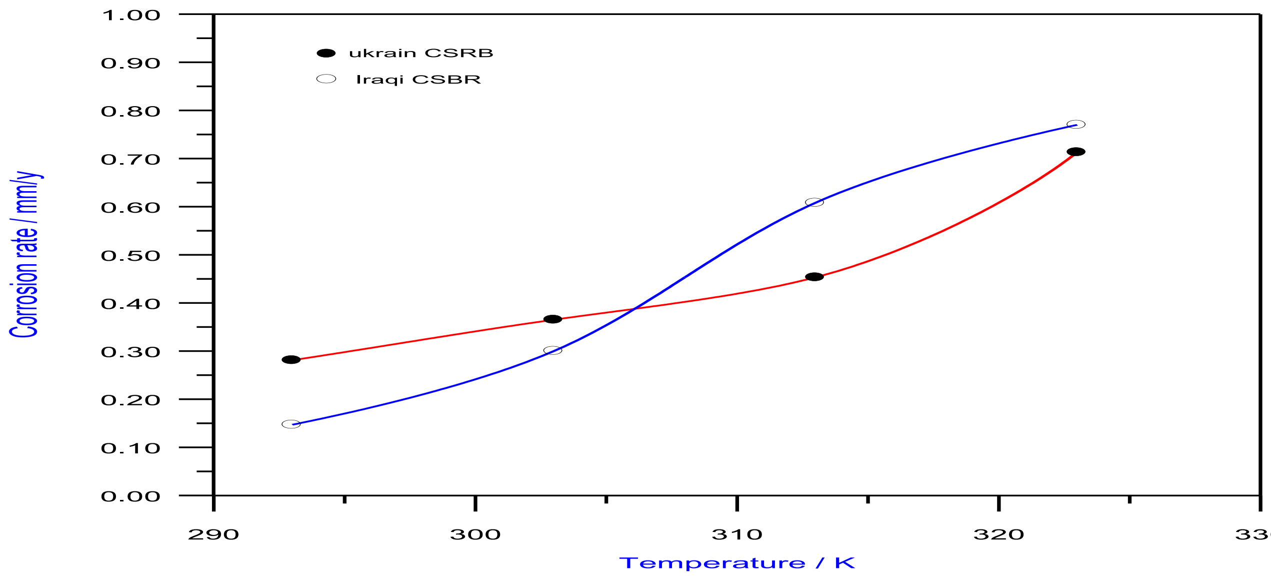

Fig.3: Corrosion rate in (mm/y) against temperature for Ukraine and Iraqi CSRB in artificial concrete solution

The values of individual elements and the carbon equivalent play important role in the corrosion behaviors against environments, this carbon equivalent value C_{eq} can be computed using the following formula [15]:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (1)$$

Where C is the percentage carbon content; Mn is the percentage manganese content; Cr is the percentage chromium content; Mo is the percentage molybdenum content; V is the percentage vanadium content; Ni is the percentage nickel content; and Cu is the percentage copper content.

So for Ukraine CSRB Ceq is equal to 0.43% while for Iraqi CSRB is 0.41%. The thermodynamic properties (Ea, Δ G*, ΔH*, and ΔS*) were calculated using the following relationships [16, 17]:

$$\text{Log CR} = \log A - \frac{Ea}{2.303RT} \quad (2)$$

$$\text{Log}\frac{CR}{T} = \log\left(\frac{R}{Nh}\right) + \frac{\Delta Sa}{2.303R} - \frac{\Delta Ha}{2.303RT} \quad (3)$$

Where R is the universal gas constant (8.314 J mol^{-1} K^{-1}), T is the temperature in K, h is the Plank's constant (6.626176 x 10^{-34} Js), N is the Avogadro's number (6.022 x 10^{23} mol^{-1}), ΔS_a is the entropy of activation and ΔH_a is the enthalpy of activation. Then G can calculated using Eq. (3) [17];

$$\Delta Ga = \Delta Ha - T\Delta Sa \quad (4)$$

Table (2) summarizes thermodynamic properties of CSRB/artificial concrete solution,

Table 2: Thermodynamic parameters of CSRB/ artificial concrete solution

Sample ID	T(K)	E_a (kJ/mole)	ΔH* (kJ/mol)	ΔS* (kJ/mol.K)	ΔG* (kJ/mol)
Ukraine CSRB	293	24.444	15.400	-0.165	64.029
	303				65.688
	313				67.348
	323				69.008
Iraqi CSRB	293	23.244	14.773	-0.166	63.549
	303				65.214
	313				66.879
	323				68.543

The values of the calculated thermodynamic function are very similar of each kind of CSRBs. The microstructures of the two CSRB are shown in Fig. (4), while the morphologies are shown in Fig. (5), the surfaces appeared nearly clean unaffected and in consequences with evaluated corrosion data.

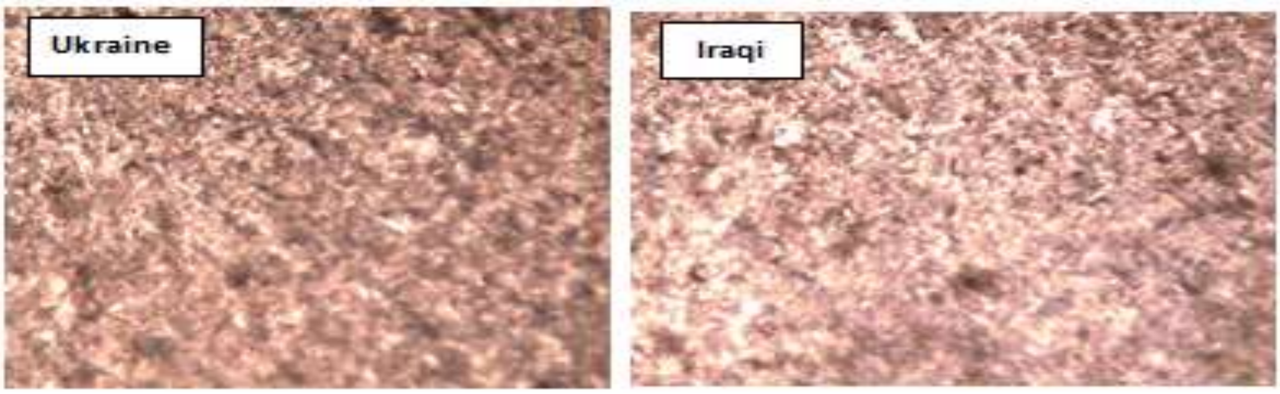

Fig. 4: Optical microscope images of Ukraine and Iraqi CSRB polarized in artificial concrete solution

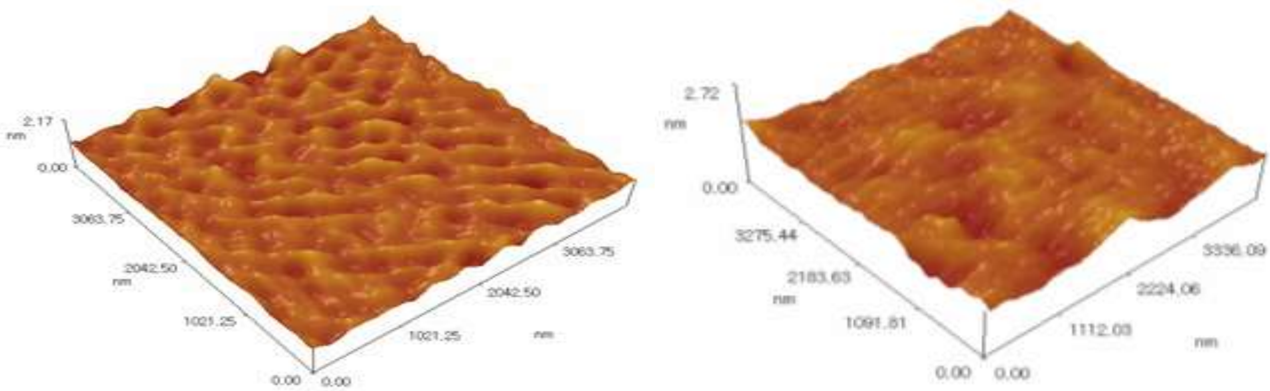

Fig.5: 3D AFM images of of Ukraine and Iraqi CSRB polarized in artificial concrete solution

The reactions of corrosion of CSRB can be written as follows:

At the anode $Fe \longrightarrow Fe^{++} + 2e^{-}$ (5)

At the cathode $2e^{-} + O_2 + H_2O \longrightarrow 4OH^{-}$ (6)

$Fe^{++} + 2OH^{-} \quad Fe(OH)_2 \longrightarrow$ (7)

$Fe(OH)_2 + O_2 + 2H_2O \longrightarrow Fe(OH)_3$ (8)

From these equations it can be seen that oxygen is consumed, but water is regenerated and needed only for the process to continue, Fig. (6). Thus it can be noted that in a completely dry atmosphere no corrosion can take place, most probably below 40% relative humidity. It is also recorded that not much corrosion of reinforcement takes place if concrete is fully immersed in water except when water can entrain air [18, 19], 70 to 80% relative humidity is most-congenial for the development of corrosion of reinforcement. At higher than 80% relative humidity, the diffusion of oxygen is reduced considerably and atmospheric conditions along the steel are more uniform. It has also been observed that the products of corrosion occupy volume about six times the original volume of steel depending upon the oxidation state [20].

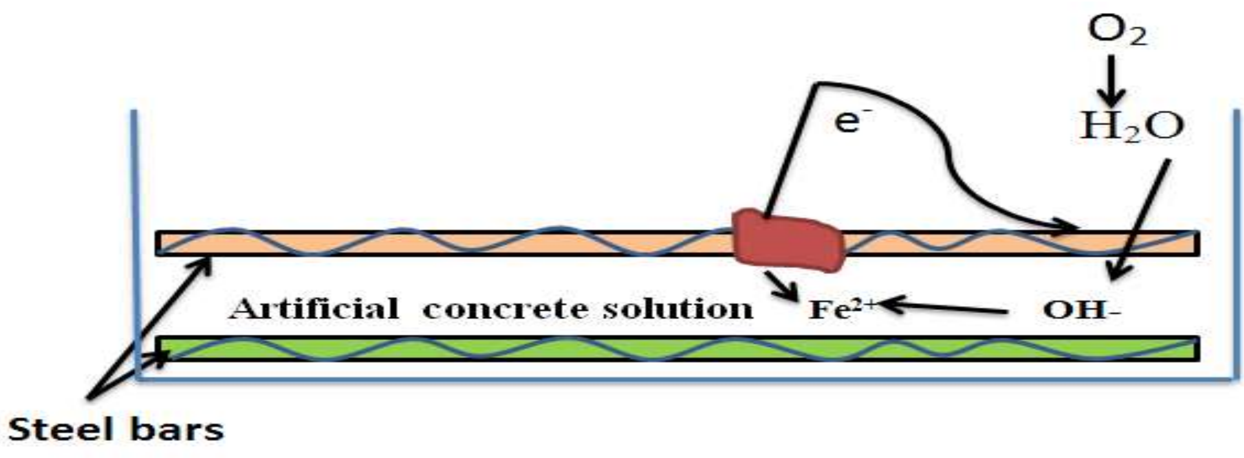

Fig.6: Corrosion of CSRB in presence of oxygen and water

Conclusions

A difference of the corrosion properties of the two carbon steel reinforcing bar is noticed due to the small differences in the chemical composition of the steel used to fabricate the reinforcing bar, especially the factor named carbon equivalent (Ceq), which depends on other metal continents in addition to the carbon element. At ambient temperature the corrosion rate of Iraqi CSRB (i_{corr};12.68μA, weight loss; 3.17 $g.m^{-2}d^{-1}$, penetration loss;0.147mm/y) is somehow lower than that of the Ukraine CSRB (i_{corr}; 24.20μA, weight loss; 6.05$g.m^{-2}d^{-1}$, penetration loss; 0.281mm /y), while at higher temperature the corrosion rates seems to be the same.

References

1. Costa A, J Appleton (2002) Case studies of concrete deterioration in a marine environment in Portugal. Cement and Concrete Composites, 24(1): 169-179.
2. Goni S, C Andrade (1990) Synthetic concrete pore solution chemistry and rebar corrosion rate in the presence of chlorides. Cement and Concrete Research, 20(4): 525-539.
3. Femenias Y, et al (2018) Development of a novel methodology to assess the corrosion threshold in concrete based on simultaneous monitoring of pH and free chloride concentration. Sensors, **18**(9): 3101.
4. Maslehuddin M, et al (2007) Effect of chloride concentration in soil on reinforcement corrosion. Construction and building materials, 21(8):1825-1832.
5. Huet B, et al (2005) Electrochemical behavior of mild steel in concrete: Influence of pH and carbonate content of concrete pore solution. Electrochimica Acta, **51**(1):172-180.
6. Frankel GS, et al (2018) A comparative review of the aqueous corrosion of glasses, crystalline ceramics, and metals. npj Materials Degradation, 2(1): 15.
7. Biezma M, J San (2005) Cristobal, Methodology to study cost of corrosion. Corrosion engineering, science and technology, 40(4): 344-352.
8. Kurdowski W (2014) Cement and concrete chemistry. Springer Science & Business.
9. Shanmugapriya S, P Prabhakar, S Rajendran (2018) Corrosion Resistance Property of Mild Steel in Simulated Concrete Pore Solution Prepared in Well Water by Using an Aqueous Extract of Turmeric. Materials Today: Proceedings, 5(2): 8789-8795.
10. Biezma M, J San (2005) Cristobal, Methodology to study cost of corrosion. Corrosion engineering, science and technology, 40(4): 344-352.
11. Bentur A, Diamond S, Berke NS (1997) Steel Corrosion in Concrete, London: E & FN Spoon.
12. Goyal A, et al (2018) A Review of Corrosion and Protection of Steel in Concrete. Arabian Journal for Science and Engineering, 1-21.
13. Wu G, et al (2010) Mechanical properties of steel-FRP composite bar under uniaxial and cyclic tensile loads. Journal of materials in civil engineering, 22(10): 1056-1066.
14. S Feliu, JA Gonzalez, C Andrade, V Feliu (1988) On-Site Determination of the Polarization Resistance in a Reinforced Concrete Beam, Corrosion, 44(10):761-765.
15. Carbon equivalents and transformation temperature (2011) The Japan Welding Engineering Society. Retrieved 14.
16. Abdulkareem Mohammed Ali Al-Sammarraie, Mazin Hasan (2016) Reduced Graphene Oxide Coating for Corrosion Protection Enhancement of Carbon Steel in Sea water, Iraqi Journal of Science, Part B: 243-250.
17. Abdulkareem M Ali Al-Sammarraie, Khulood Abid Al-Saade, Mohammed H A Al-Amery (2015) Materials Sciences and Applications, 6: 681-693.
18. RaheemaAditi Chauhan, Umesh Kumar Sharma (2019) Influence of temperature and relative humidity variations on non-uniform corrosion of reinforced concrete, Structures, 19(6):296-308
19. Rong Liu, Linhua Jiang, Jinxia Xu, Chuansheng Xiong, Zijian Song (2014) Influence of carbonation on chloride-induced reinforcement corrosion in simulated concrete pore solutions, Construction and Building Materials, 56 (15): 16-20.
20. Magdalena Osiala, Daniel Wilińskib (2016) Organic substances as corrosion inhibitors for steel in concrete-an overview, J. Build. Chem., 1: 42-53.