Evaluation of Atmospheric and Aqueous Corrosion of Passenger Car Body in Mosul City through the Year 2009-2010

R. J. Al - Ghadanfary — Lecturer
G. M. Hannoush — Ass. Lecturer
H. A. Al-kareem — Engineer
Technical Institute / Mosul

Abstract

Corrosion of five steel bodies of passenger cars of models 1985, 1990, 1995, 2000, & 2005 that are used in Mosul city were studied under atmospheric and aqueous during 2009-2010. Atmospheric corrosion rates were below 1.7 mpy, which is classified as low corrosion, this is due to dry weather conditions during the study period , and the quality of steels of the car bodies. Aqueous corrosion rates were also low, below 4.57mpy, and this is due to good water quality of Mosul , low Langelier saturation index, ideal corrosion index, and the quality of steel body cars.

Key Words: Mosul city, Atmospheric Corrosion, Car Body Steels, 2010.

حساب التآكل الجوي والتآكل الرطب لأبدان سيارات الركاب في مدينة الموصل خلال 2010 – 2009

رائق جمال الغضنفري — مدرس
جورج متي حنوش — مدرس مساعد
حسين عبدالكريم إبراهيم — مهندس
المعهد التقني / الموصل

الخلاصة

تم دراسة التآكل الجوي والتآكل الرطب لخمسة أنواع من صلب ابدأن السيارات المستخدمة في مدينة الموصل والتي موديلاتها: 1985،1990، 1995، 2000، 2005. كانت قيم معدلات التآكل الجوي اقل من 1.7 mpy ، وبهذا يصنف التآكل من فئة التآكل القليل. ويعود سبب ذلك إلى الظروف الجوية الجافة خلال فترة البحث، والى نوعية الصلب المصنعة منه الأبدان. كذلك كانت معدلات التآكل الرطب قليلة ، اقل من 4.57mpy ويعود سبب ذلك إلى نوعية المياه الجيدة لمدينة الموصل، قيمة معامل لانكلير للإشباع القليلة ، ومعامل التآكل المثالي خلال فترة البحث و نوعية الصلب المستخدم لصنع ابدأن السيارات.

الكلمات الدالة: مدينة الموصل ، التآكل الجوي ، صلب ابدأن السيارات ، 2010 .

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Introduction

Automotive industry has become one of the key sectors of the economy throughout the world. More than 16% of working population are employed in activities related to the automotive sector in industrial countries [1].After 1973 and 1979 oil crisis, strategies to improve manufacturing costs, and improve profit margin, has brought about considerable change in automotive industry. New designs, improved processing, and new and/or improved materials and components have been developed to meet the challenge of optimum energy/strength/weight ratios. This is well understood by constant struggle to develop cars with high passive safety without increasing fuel consumption. High passive safety requires a very stiff behavior of the crash components. Accomplishing this often leads to an increase in the weight of the components. An increase in weight results in higher fuel consumption which is injurious for the environment as well as or car owner economy [2]. Also, continuous improvements in corrosion resistance field, had led to extended warranties which are currently 6-10 years for perforation, and 1-5 year for cosmic corrosion [3].

The severity of extended corrosion varies considerably throughout the world due to differences in the chemistry of the environment. Maximum corrosion always occurs in snow belt areas due to de-icing salts, and along coastal areas where warm humid salts atmosphere exists. During 21st century the chemistry of the environment changed dramatically. As a result of the changes, atmospheric corrosion of the cars increased; so, the current car users are facing a major problem which is corrosion that affects almost all parts of the car body [4].

Corrosion, is usually defined as deteriorative caused by chemical or electrical reaction with its environment [5]. So, car body corrosion is a result of electricity flow from not-well oxygenated areas that will act as a negative electrode, to another well supplied oxygen area, which will act as a positive electrode, in the presence of an electrolyte. Disobliging car design consideration is probably the main cause for body corrosion, due to sale potential, designing attractive shapes, and accountants monitor costs to meet price competitions [6]. Car bodies normally suffer from general and crevice corrosion. Corrosion rates depend upon both: metal alloy properties, and the environment variables which are; pH acidity, oxidizing power, temperature and heat transfer, fluid movement, and concentration of solvent components. Alloy steels are among the commonly used materials in sheet metal forming technology for car bodies. They are grouped, from European point of view into: temper rolled steels, micro-alloyed steels, re-phosphorised steels, dual-phased steels, bake-hardening steels, high strength steels, and isotropic steels [7].

Langan et al [8], studied three high strength low alloy steels in long-term exposure under constant immersion in an aqueous 3.5% sodium chloride solution to evaluate corrosion rates. It was concluded that variation in weight loss between the three coupons tested for each alloy was greater than differences between the alloys. The corrosion due to exposure to saline environment does not appear to be critical factor in alloy selection. Hamzah [4], studied the corrosion behavior and performance between coated and uncoated steel sheets, which are used in car body manufacturing. It was concluded that micro-scratches are responsible for crevice corrosion by allowing moisture diffusion through it, forming blisters that will enlarge by excessive moisture continuing to build under paint coating. Diaz et al [9], studied the mechanism of rust layer formation on unpainted weathering steels of car bodies under atmospheric corrosion conditions. Their study revealed that the most important factors are: time of wetness(TOW) , wet/dry cycling, and the presence of species, such as SO2 and Cl^{-}. Garcia et al [10], studied mill annealed AISI 4130 steel at 400C^{o} for 1, 1.5, 2 hour periods. It was concluded that mill-annealing conditions are favorable to improve toughness of steel. Katundi et al [11], concluded from their studies on corrosion behavior of welded steel sheets that were used in car industry, that pitting corrosion damage and crack initiation, always began and initiate at the heat affected zone HAZ, in the welded steel sheets.

The present study will focus on atmospheric as well as aqueous corrosion in car body of five European passenger cars of models 1985-2005, during the year 2009-2010, due to that major of Mosul city cars are of model lower than 2005. The general corrosion of car body is due to warm humid atmosphere and time of wetness, as well as car scrapping because of accidents obsolenscence, and corrosion correlation between injury in car accidents and car age.

Practical Part :

Five samples, from roofs of European passenger cars that were used in Mosul City, of models 1985 – 2005, were been cut, by electrical hand grinder. From these samples, atmospheric coupons were been cut to the size 100*150mm, according to ASTM G-50, while aqueous coupons were been cut into the size 25*50mm, according to ASTM G-31 The tensile samples were of 10mm wide and of gauge length 50mm, according to DIN 50 145. The following procedure was applied at samples to remove paint from their surfaces, and preparing them for tests: immersing in 10% HCl, then immersing in 5%NaOH, then cleaned with distilled water, rinsed and dried with warm air. The samples were wet ground to 600 emery paper by Metasrev electric grinder, then cleaned by distilled water, dried by hot air, and finally stored in dessecator.

Atmospheric corrosion coupons were set outdoors, inclined 45 degrees to the horizon, and directed to the West. They were removed each month for weight loss test [1]. Aqueous corrosion coupons were drilled to 1mm hole at the upper side, suspended in 1 liter tap water. Their weight loss was measured weekly [1].

The procedure applied for removing corrosion constituents from the coupon surface was: placing the coupons in turbulent solution of diluted HCl, heated to 40 degrees centigrade, for 10 minutes, then immersing in (50 gm NaOH + 200 gm granulated Zinc) , then cleaning with distilled water, then drying by warm air, and weighing with digital balance with 0.01gm accuracy.

Tensile tests were carried out on Tokyo Kikoyo universal tensile testing machine, while sheet thicknesses were measured by 0.01mm accuracy digital vernier, and the results were transferred to American Sheet Gage Number. Vickers hardness tests were carried on Wolpert Micro-Hardness tester. Samples from car sheets were mounted using automatic Metaserv specimen mounting. The specimens were then ground, polished, etched by 2% Nital then 4% Picral, and microscopically examined, while macro-structures were examined Zeiss stereo-microscope.

Results and Discussion :

Table1, shows the mechanical properties of sheet car steels, as resulted from tensile and micro-hardness tests, while table 2 shows their chemical composition obtained by analyzing the samples by SDI Brucker Alloy Analyzer. Table 3, shows Mosul city weather activities during 2009-2010, Table 4, give the results of atmospheric corrosion rates in mils per year monthly , at for aqueous corrosion weekly. while table 5, reveals physical and chemical composition of fresh water during the period of aqueous corrosion test . Table 6, shows Langlier Saturation Index (LSI) and corrosion power equation calculated for each car tested.

Atmospheric Corrosion:

Weather characteristics have direct influence on atmospheric corrosion effects, including aggressiveness impact of the pollution agents throughout period of this study [14, 16]. Table 3, gives weather activities of Mosul City during Oct. 2009 – May 2010. From this table, it can be concluded that time of wetness occurred during Dec., Jan., & Feb.[1], while maximum rain fall occurred during Dec. 2009. Solid particle concentration above average 125mg/m^3 [14],occurred during Oct., Nov., Dec., Apr., &May. From plate1 (a-e) which represents micro-structures of the studied car body steel.. Micro-structures are pearlite and ferrite, they differ in grain size and cold work ratio (Tables 1&2).

Table 1 : Mechanical Properties and Sheet Thicknesses of the Selected Cars

Car Sample N	Car Sample Mode	Sheet Gage N	HV	σ_{u}, Nlmm	Elong%
1	Car Model 1985	22	124	372	27.6
2	Car Model 1990	19	108	349	32.1
3	Car Model 1995	20	137	438	25.5
4	Car Model 2000	22	122	383	30.4
5	Car Model 2005	19	148	473	22.8

Table 2: Chemical Composition of Selected Body Sheet Cars Material (Analyzed by SDI Brucker Alloy Analyzer)

Car Sample & Model	C%	Si%	Mn%	P%	S%	Others%
Sample1 Model1985	0.13	0.19	1.0	0.04	0.9	Fe balance
Sample 2 Model 1990	0.09	0.49	0.09	0.06	0.03	Al 0.05, Nb 0.03, Cu 0.35, Cr 0.22 -Fe balance
Sample 3 Model 1995	0.04	0.09	0.2	0.004	0.01	Al0.04, Ni0.03,Cu0.13, Fe balance
Sample 4 Model 2000	0.09	0.3	1.6	-	-	Nb0.04, V0.03, Mo0.3, Fe balance
Sample5 M0del 2005	0.07	-	2.0	0.08	0.03	Al0.02,Ti0.05, Fe balance

Table 3: Atmospheric Activities of Mosul City Weather during 2009-2010 [12]

Weather Activity	Oct 2009	Nov 2009	Dec 2009	Jan 2010	Feb 2010	March 2010	Apr 2010	May 2010
Av. Max Temp, °C	32.5	20.4	16	14.3	17.5	19.7	25.8	34.2
Av. Min Temp,° C	15	9.3	7.0	-0.1	5.6	8.5	11.7	18.2
Av. Relative Humidity%	46	66	80	80	74	68	62	44
Rain Fall, mm	13.3	28.3	92	0.01	24.9	28.1	35.7	1.5
Atmos. Pressure Nlmm^2	101.4	101.8	101.88	100.25	101.3	101.47	101.21	100.94
Solid Particle Concentration, mg	338	235	143	Nil	Nil	Nil	599	307
Av. Dust Fall, g/m2	19	9	13	-	27	29	85	0

Fig.1, shows corrosion rate of car body steels during 2009-2010, in Mosul City. It can be seen that the relationships are fitted to a power model that is described [15, 17, 20] by the expression:

$$C = A\, t^{n}$$

Where C is the corrosion after time, t, while, n and A are constants. The value of n gives a measure for the resistance to transport processes within the corrosion product oxide once it is formed. When n=0.5, an ideal diffusion controlled mechanism case is formed, i.e. all corrosion products remain on the metal surface.

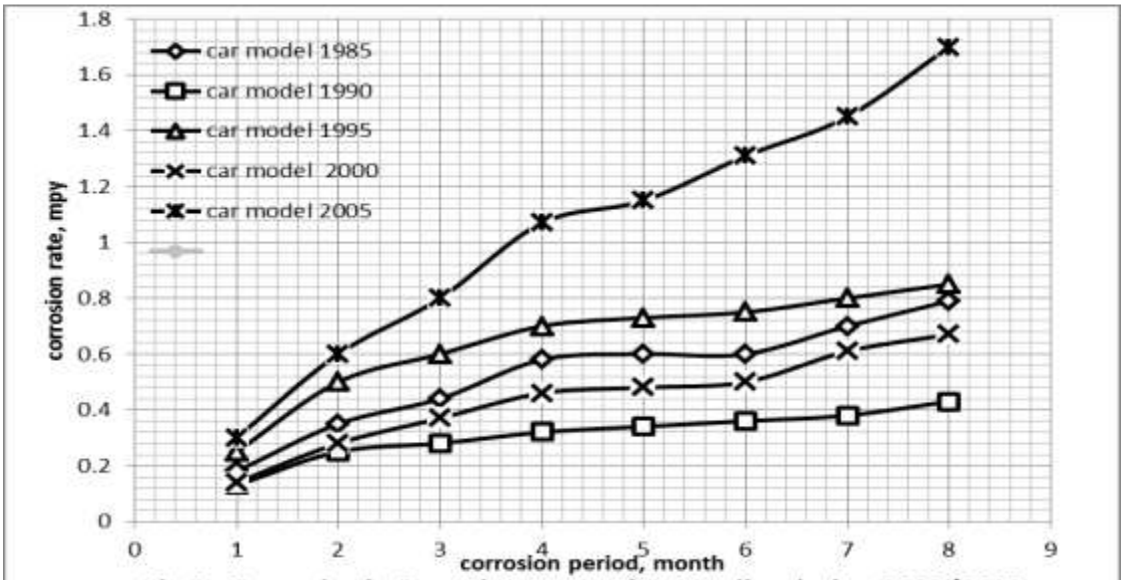


Fig.1: Atmospheric Corrosion Rates of Car Bodies during 2009/2010

When n is increased, diffusion process is accelerated as a result of rust detachment either by erosion flaking or cracking. Hence, from fig. 1 and table 4,

Table 4: Results of Atmospheric and Aqueous Corrosion Tests on Car Body Steels in Mosul City during 2009/2010

Car Model	Corrosion Index, n	Atmospheric Corrosion Rates, mpy* / month								Aqueous Corrosion Rates, mpy* per week			
		1	2	3	4	5	6	7	8	2	4	6	8
1985	0.66	o.18	0.35	0.44	0.58	0.6	0.6	0.7	0.79	0.85	1.23	1.63	1.7
1990	0.53	0.13	0.25	0.28	0.32	0.34	0.36	0.38	0.43	0.61	0.92	1.2	1.45
1995	0.74	0.25	0.5	0.6	0.7	0.73	0.75	0.8	0.85	1.86	2.0	2.21	2.8
2000	0.63	0.14	0.28	o.37	0.46	0.48	0.5	0.61	0.67	0.92	1.2	1.38	1.55
2005	0.79	0.3	0.6	0.8	1.07	1.15	1.31	1.45	1.7	2.45	3.08	3.89	4.22

***mils per year**

car body steels can be arranged according to their corrosion resistance ascendentaly, car model 1990, car model 2000, car model 1985, car model 1995, and car model 2005. Also, atmospheric corrosion rate can be classified as very low for all car models studied except for car model 2005 which can be classified as low corrosion rate [15,17]. Low corrosion rates can be well understood by atmospheric corrosion mechanism. Corrosion is initiated by forming an oxide film on the steel surface in low humidity periods (October and November – 2009, Table 3). This oxide film may dissolve due to high humidity, or break due to rainfall (November, December – 2009, January, February, March, and April – 2010, Table 3). This dissolution of the oxide film may cause local breakage and enhance corrosion, plate1&2 [18, 19].

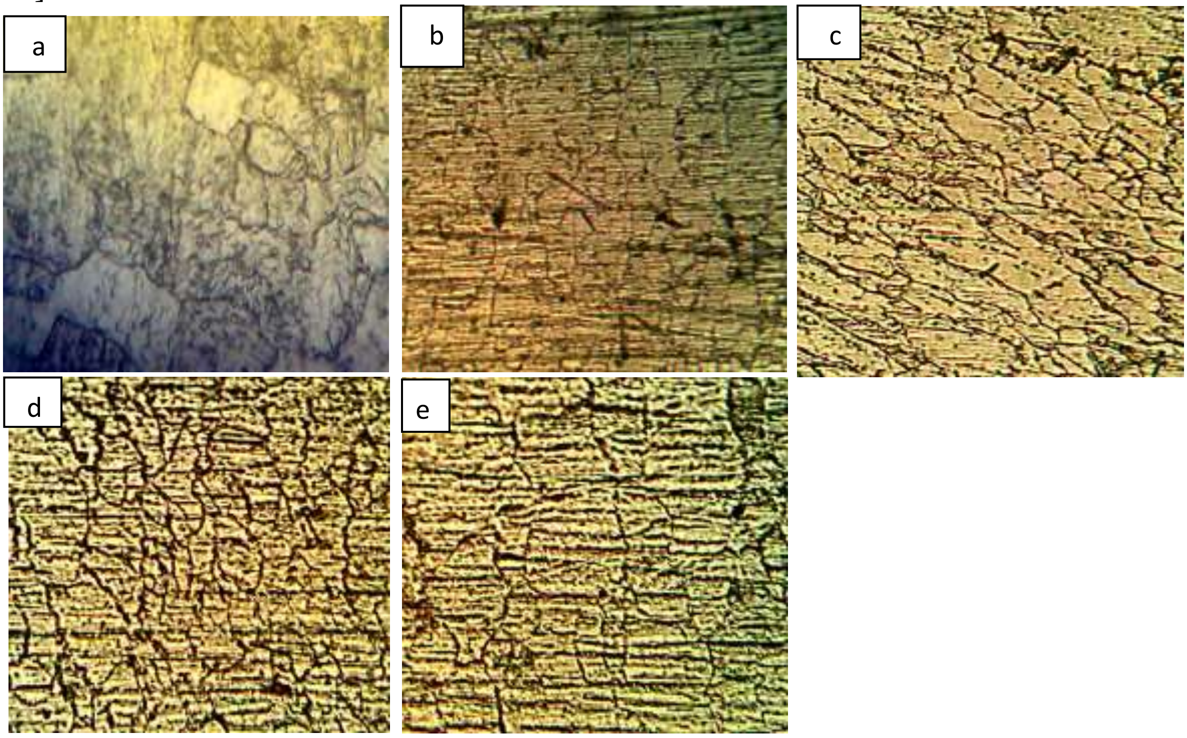


Plate 1: Micro-Structures of Body Cars, a- car model 1985, b- car model 1990, c- car model 1995, d- car model 2000, e- car model 2005.Structure: Ferrite (light area) +Pearlite (dark area) Etchant: 2% Nita Magnification: X600

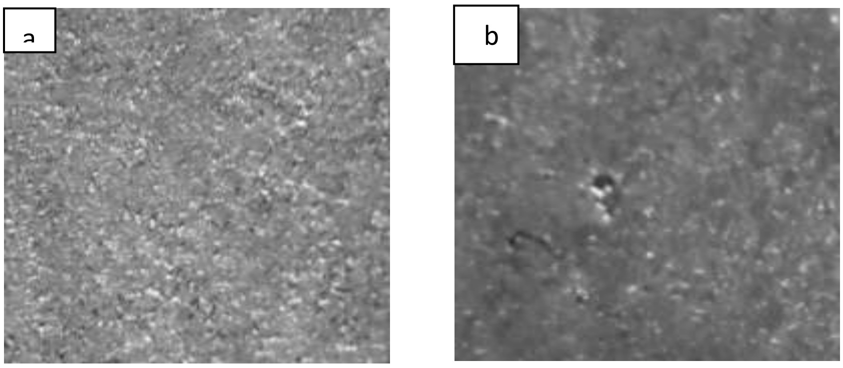


Plate 2: Atmospheric Corrosion of car model 2005 surface specimen
a- after 4 months b- after 8 months Magnification : X40

For comparison, and according to ISO 9223 corrosivity categories classification , the table blow shows corrosivity categories in five Eurapean cities during the year 2000-2001[20] , as well as that of Mosul city during the year 2009-2010.

City	Paris	London	Moskow	Rome	Madrid	Mosul
corrosivity categories* C1≤1.3 (very low) C2 1.3 – 25 (low)	**C2(9.93)**	**C2(11.8)**	**C2(9.4)**	**C2(5.5)**	**C2(5.3)**	**C1** (refer to table 5)**

* C2 – low corrosion rate

**all cars tested are of C1 corrosivity category except car model 2005 which is of C2.

Low corrosion rates of car body steels in Mosul , compared with that of European cities, may be well explained, by lower duration of time of wetness(TOW), and moderate presence of SO_2 which assists the formation of the protective layer on car body steels.

Aqeuous Corrosion:

Water aggressiveness is usually affected by: amount of dissolved Oxygen, type and amount of salts ingredients, pH of water, temperature and water flow rate, organic and microorganisms, and content of solid particles. The previous factors are controlled by Langelier Saturation Index (LSI) [21] :

Corrosion Rate (CR in mdd) = -12.5 (LSI) + 8.99 (mdd = milli-decimeter per day)

For Mosul City fresh water, Langelier saturation index is less than (-3) as seen from table 6, i.e. low corrosion rates are expected for all sheet steel studied [21]. Also, water quality index WQI, for Mosul city fresh water during the period of the research is computed to be 2.985 – 36.99, which is classified as good water [24]. From table 5, water hardness is over 150 mg/ L, i.e. corrosion rates are decreased by water hardness increase [23].

Table 5: Physical and Chemical Composition of Freshwater 2010 [12]

Freshwater Property	April 2010	May 2010	June 2010
Water Quality Index [23]	36.99	33.58	29.85
Av. Water Temperature ,^{o} C	18	27	30.8
Turbidity, mg/L	2.64	3.76	3.32
Total Hardness, mg/L	227	201	190
Alkalinity, mg/L	148	142	137
pH	7.71	7.73	7.7
Electrical Conductivity, µs/cm	448	398	387
Total Dissolved Particles, mg/L	291	272	243
Calcium, mg/L	49	42	41
Chlorides, mg/L	27	26	24
Magnesium, mg/L	18	15	17
Nitrogen Dioxide , mg/L	0.002	0.002	0.001

The power model equation , $C = A\ t^n$, calculated for car models aqueous corrosion rates, yielded that the index **n**, varied between 0.4 – 0.66 (table 6),

Table 6: Results of Aqueous Corrosion Tests on Car Body Steels in Mosul City During 2010

Car Mode	Aqueous Corrosion Rates, mpy per week					Langlier Saturation Index LSI	Corrosion Power Eq. $C=At^n$
	2	4	6	8	10		
1985	0.85	1.23	1.63	1.7	1.84	- 0.102	$C=0.62t^{0.49}$
1990	0.61	0.92	1.2	1.45	1.6	- 0.028	$C=2.6t^{0.66}$
1995	1.86	2.0	2.21	2.8	3.68	- 0.0872	$C=1.28t^{0.38}$
2000	0.92	1.2	1.38	1.55	1.9	- 0.076	$C=2.45t^{0.64}$
2005	2.45	3.08	3.89	4.22	4.57	- 0.1256	$C=1.8t^{0.4}$

which emphasizes ideal corrosion conditions, which means that the rust layer on steel is formed due to interaction with fresh water ingredients and physiochemical behavior of the corroded layer[23]. The value of the parameter A (table 6), provides a criterion for gauging short-time susceptibility. It provides a measure for the internal reactivity of steel surface as reflected in its tendency for that surface for producing a corrosion product layer in short time exposure [22]. Car model 1990 has lower corrosion rate , while car model 2005 has the largest corrosion rate, fig.2.

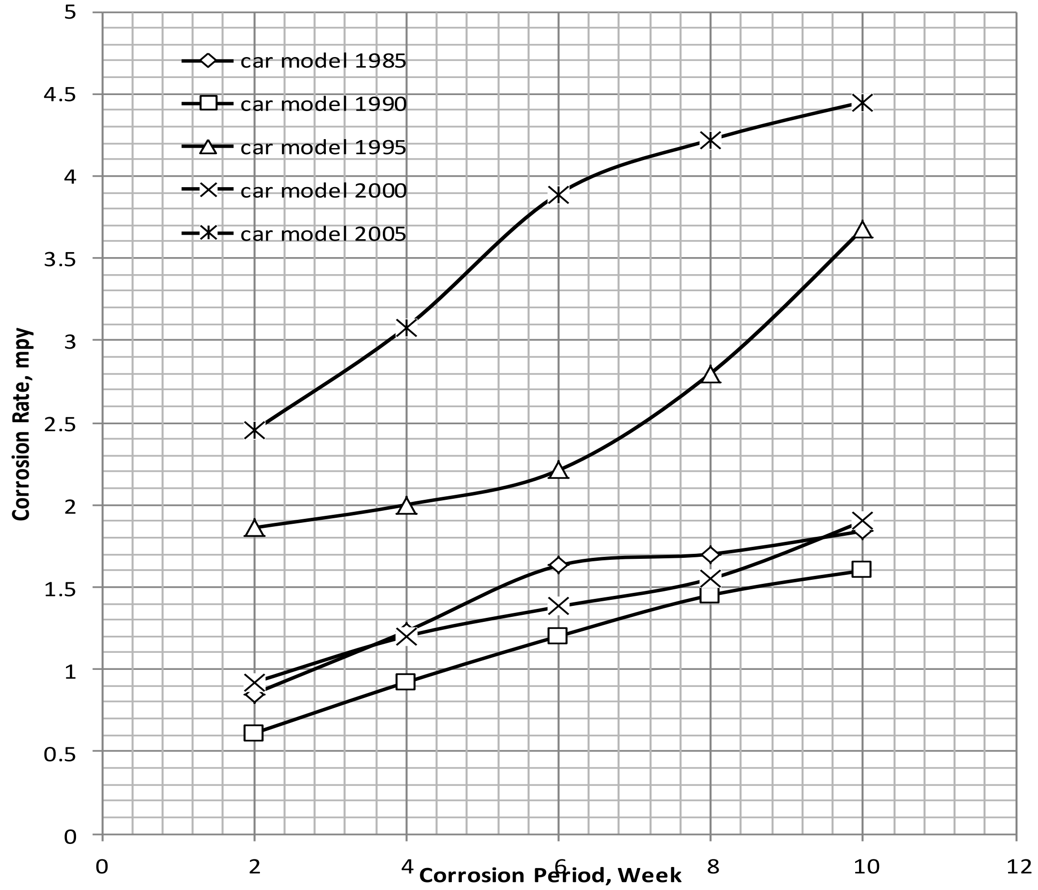
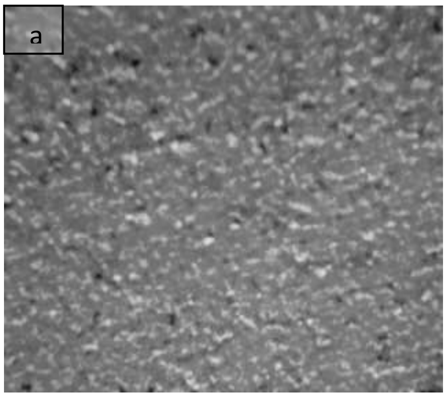


Fig. 2:Aqueous Corrosion of Car Bodies in Mosul City during 2010

This can be explained by higher percentages of micro-alloying elements (Si, Cu, & Cr) which raise corrosion resistance of steels, or the thermo-mechanical processing of the steel, and the final mechanical properties of the steels, Table1&2, Plate 1&3.



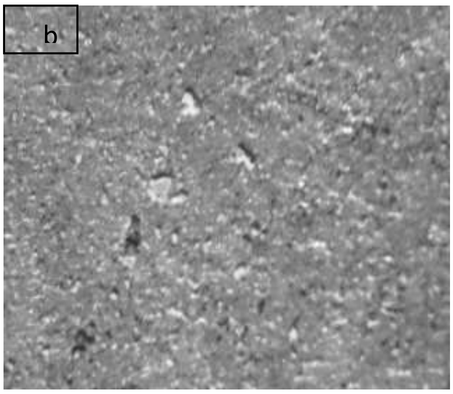


Plate 3: Aqueous Corrosion of Car Model 2005 surface specimen
a- after 4 weeks b- after 10 weeks
Magnification: X40

Conclusions:

1- In Mosul City, and during the period of study 2009-2010, atmospheric corrosion of car body steels studied are classified as low rate corrosion, due to dry weather conditions, low humidity%, and small rain fall and wet duration.
2- Corrosion rate values of the body car models studied are affected by micro-alloying elements, previous thermo-mechanical steel processing, and mechanical properties of sheet steel.
3- Corrosion rate under aqueous condition are classified as low rates due to good water quality index of Mosul fresh water, low langelier saturation index, and ideal corrosion index.

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