

Full Length Research Paper

A study of the morphology and optical properties of electro polished steel in the presence of Vitamin-C

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The studies of steel electrochemical polishing Electropolishing (EP) in orthophosphoric acid were performed by potentiodynamic polarization. Electropolishing was conducted in solution containing Vitamin C. Addition of Vitamin C to electropolishing solution results in a lower limiting current. Vitamin C concentration influence on electropolishing process and surface texture (AFM, SEM) and UV-VIS-NIR Spectroscopy was established. The results show that by increasing Vitamin C concentration from 2×10^{-5} to 5×10^{-5} M, roughness and reflectance of steel specimens decrease/increase respectively. The opposite trend is seen when the concentration increases to 10×10^{-5} M. The roughness of steel specimen before electropolishing is 236.7 nm and it will decrease to 140 nm by electropolishing in the presence of 5×10^{-5} M Vitamin C. A similar trend is also seen in reflection. The SEM study confirms that low and moderate concentration of Vitamin C was effective to enhance levelling and brightness more than higher concentrations.

Key words: Steel, electropolishing, Vitamin C, scanning electron microscope (SEM), atomic force microscope (AFM), reflectance.

INTRODUCTION

Electropolishing (EP) is one of the anodic methods widely employed in the industry for the surface finishing of metals or alloys to obtain the fine surface brightness and stress-free surface (Rajurkr, 1992). The proposal of EP as an industrial surface finishing process is usually attributed to the work by Jacquet, who took a patent in 1930 (Figoux and Jacquet, 1930). However, the first recorded publication dealing with EP goes back even further (Hoar and Rothwell, 1964).

The surface phenomena of EP are generally classified into two processes: anodic levelling and anodic brightening. Anodic levelling results from a difference in

the dissolution rate between peaks and valleys on a rough metal/alloy surface depending on the current distribution or mass-transport conditions (Oniciu and Muresan, 1991; Wagner, 1954; Fitzgerald and McGeough, 1969; Fedkiw, 1980; Sautebin and Landolt, 1982; Clerc and Landolt, 1984; Clerc and Landolt, 1987; Matlosz and Landolt, 1989). It is usually associated with a decrease of roughness in the micrometer or larger range (Landolt, 1987) and can be achieved under the ohmic (primary current distribution), activation (secondary), and mass-transport (tertiary)-controlled metal dissolution reactions (Sautebin et al., 1980; Clerc et al., 1984).

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Anodic brightening, on the other hand, is associated with the suppression of the influence of the metal microstructure on the dissolution rate. It can be achieved only under the conditions in which the metal dissolution is mass-transport-controlled and the formation of a precipitated salt layer at the electrode surface is possible. The presence of a salt layer can suppress the influence of crystallographic orientation and surface defects in the dissolution process (Sautebin et al., 1980; Clerc et al., 1984; Datta and Landolt, 1975; Datta and Landolt, 1980). This phenomenon will lead to microfinishing in the sub-micrometer scale and specular reflectivity of metals/alloys can be obtained. Accordingly, a fine electropolished surface of metals/alloys, which appears bright to the naked eye, generally results from an effective combination of levelling and brightening.

The use of an appropriate electrolyte and operating conditions in an EP process will produce smooth and bright surfaces that are free of defects, stress, and contamination. Gabe measured the anodic polarization curves of mild steel in phosphoric acid and phosphoric-sulfuric acid mixtures (Magaino et al., 1993; Gabe, 1973). Passivation was observed in these solutions and the passive current density was found to depend on the electrolyte composition. In addition, a phosphoric acid solution containing sulfuric acid gave a better surface finish than a pure phosphoric acid. Similar results were also obtained by Ponto et al. (1987) who studied the anodic behavior of steel in mixtures of phosphoric and sulfuric acids. Well-polished surfaces can be obtained at or above a limiting current density, which means that EP takes place in the trans passive region under mass-transport control.

The impedance study (Magaino et al., 1993) and the temperature effect on the appearance of metals/alloys through EP in the phosphoric-sulfuric acid system (Matlosz and Landolt, 1989; Datta and Verduyck, 1990) have also been done. Furthermore, addition of glycerol into this system was adopted (Datta and Romankiw, 1998; Datta et al., 1991). In this glycerol containing system, the limiting polishing current was found to depend slightly on the flow rate (Datta and Romankiw, 1998) and a concept for minimizing agitation of the electrolyte was proposed to eliminate the cost of pumping concentrated acids (Datta et al., 1991).

Based on these studies, several mechanisms have been proposed successively for the process of anodic dissolution: (i) salt film (dissolution products) mechanism (Landolt, 1987); (ii) acceptor mechanism (Landolt, 1987); (iii) preferential adsorption of shielding molecules (Yuzhakov et al., 1997; Bandyopadhyay et al., 1996); and (iv) formation of a solid oxide film of aluminum (Parkhutiuk and Shershulsky, 1992). Steel is an important category of materials due to their wide range of industrial applications. It is used in many industries due to its excellent mechanical properties. These are used in industries as pipelines for petroleum industries, storage tanks, reaction vessels and chemical batteries (Zhang et al., 2010).

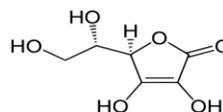
The examination of steel dissolution in acid solutions by different type of organic compounds has been extensively studied (Shukla et al., 2008). Among them, very few are environmentally acceptable, such as natural products, that is, extracts of various parts of plants, pharmaceutically active compounds, that is, antibiotics, antibacterial, antioxidant etc. (Raja and Sethuraman, 2008; Shukla and Quraishi, 2009a, b; Shukla and Quraishi 2010a, b; Singh et al. 2011; Arslan et al., 2009; Eddy et al., 2010; Morad, 2008; Abdallah, 2002). In this study, an attempt is extended to reduce the roughness of the surface by reducing the etched pits and defects formed over the steel surface, consequently, the surface smoothness and brightness could be increased. Accordingly, the present work is aimed to study the effect of addition of Vitamin C (ascorbic acid) to orthophosphoric acid solutions used as electrolytes for EP of steel.

Ascorbic acid or Vitamin C is a common enzymatic cofactor in mammals used in the synthesis of collagen. Ascorbat is a powerful reducing agent capable of rapidly scavenging a number of reactive oxygen species (ROs).

EXPERIMENTAL DETAILS

Electropolishing was performed on a rectangular steel sheet by an area of 10 × 5 cm covered with a Teflon coating with an exposed area of 5 cm × 1 cm. The test sheets were used directly without any pretreatment. The steel sheet [0.0257% S, 0.07% P, 0.4% Mn, 0.1% C and the rest iron] was immersed into the corner of a rectangular cell with the 100 mL EP solution, which was surrounded by an isothermally circulated water system (± 0.5°C) at different temperatures (20, 30, 40 and 50°C). The cathode, which was a rectangular steel sheet with an area of 5 × 10 cm, was also immersed in the solution and faced the test sheet. The EP solution was composed of 8M H₃PO₄ phosphoric acid (85%). The EP experiment was conducted by a direct current (dc) power supply. Ten concentrations of Vitamin C (ascorbic acid) with 8M H₃PO₄ are used, ranging from 1 × 10⁻⁵ to 10 × 10⁻⁵ M. Vitamin C (ascorbic acid) were Fluka products of pure quality (>97%). The polishing potentials generally reach a steady-state value after the current is applied for 200 s. After the EP treatment (under various conditions, the test sheet was rinsed in deionized water with a measured resistivity > 18 m.Ω. The scanning electron microscope images were taken using (JEOL, JSM-5300, scanning microscope, OXFORD instrument). For this purpose the steel sheet anode was (1 × 1 cm). The average surface roughness factor (Ra) was measured at two points near the centers of the test sheet with an area of 75 × 75 μm² by an atomic force microscope (AP-0100 AUTOPROBE CP-Research, THERMOMICROSCOBES). The resolution is 256 × 256 lines, scan rate is 1 Hz and the AFM images were analyzed using proscan 1.8 software while the software used for image processing is IP2.1.A Shimadzu UV-3101 PC Spectrophotometer (UV-VIS-NIR) Scanning spectrophotometer was used to obtain reflection spectra of specimens in the range of 300 to 1500 nm.

The structure of Vitamin C (ascorbic acid) is given below:



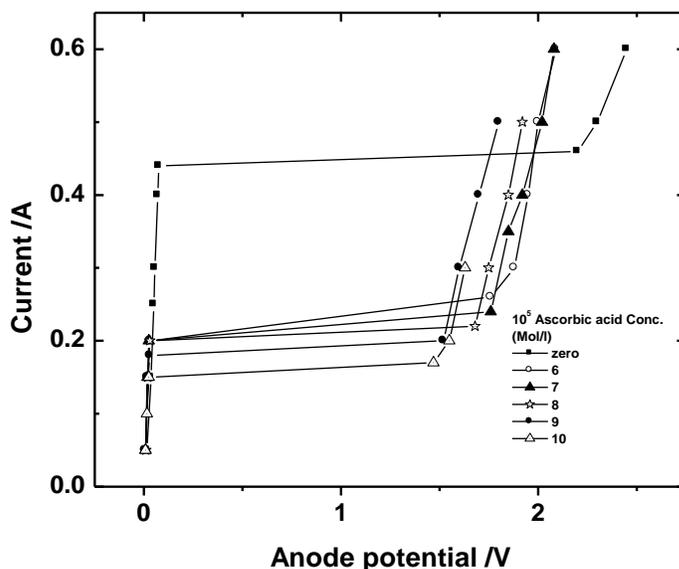
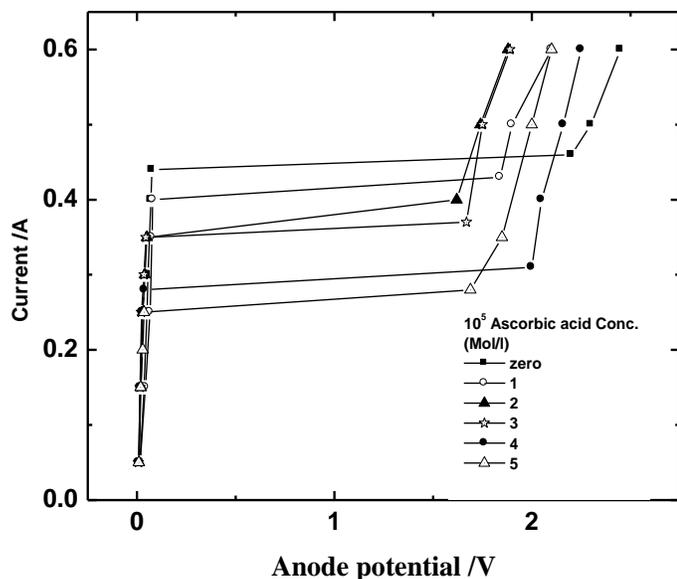


Figure 1. Typical polarization curves for the electropolishing of vertical steel in 8M H_3PO_4 in presence of different concentration of Vitamin C at 20°C.

RESULTS AND DISCUSSION

Different regions of electropolishing polarization curve

A typical polarization curve for an electropolishing system looks like Figure 1. Three major regions can be identified on the curve: etching, polishing and gas evolution regions. The etching region is characterized by an exponential increase in current until a certain voltage (Frankel, 2010).

It has been reported that sites such as grain boundaries and defects have different standard reversible potential than the metal surface and thus have a different value of overpotential, η , at a given overall applied potential, resulting in a different dissolution current (Bard and Faulkner, 2001). This results in crystallographic etching rather than polishing. The rate of transport of the anions to the surface also increases with voltage in the etching region. As further increase in voltage leads to a competition between the thickening viscous film and the increasing transport rate of anions to the surface. It becomes increasingly difficult for the anions to reach the surface because of the thickening viscous layer (Palmieri, 2003).

At plateau, the diffusion layer establishes a suitable thickness and further increase in voltage does not result in any increase in current. The current peak before the current density plateau is also explained on the basis of super-saturation of the contain electrolyte below the gas bubble resulting in etching. Depending on the system, the dissolution rate in the occluded area may be higher or lower than the remaining salt forming in the case of the

salt film mechanism of Electropolishing. The film then equilibrates to the saturation level, resulting in a drop of the current density in the limiting current density value (Frankel, 2010).

The plateau region and the best electropolishing conditions are found in this region. The plateau is formed because of mass transport control. Increase in potential above plateau region results in oxygen evolution on the metal surface along with the metal dissolution. Electropolishing in this voltage regime result in the surface being rougher because oxygen bubbles formed may attach to the surface and cause occlusion of the surface at certain locations resulting in differing dissolution rates (Jacquet, 1935). The occluded area may be higher or lower surface. Pitting results if the rate is higher and a bump is formed if the rate is lower. In either case, a rough surface results if electropolishing is attempted in this potential region. It has also been reported that polishing can take place at potentials way above the plateau region. Palmieri et al. (2003) States that polishing occurs in this region because the rate of oxygen generation is so fast that oxygen bubbles leave the surface as soon as they are formed and hence do not get a chance to occlude the surface and cause pitting (Palmieri, 2003).

Electropolishing of steel in H_3PO_4 electrolyte with Vitamin C added

The anodic polarization curves for the steel anode that were electropolished in 8M H_3PO_4 electrolytes with the addition of Vitamin C of different concentrations are

Table 1. Values of limiting current, % inhibition for dissolution of steel in 8M H₃PO₄ in presence of different concentration of Vitamin C at different temperatures and activated parameters for the process.

Temperature Vitamin C Conc. (mol/l)	20°C		30°C		40°C		50°C		Activated parameters	
	I _L (A)	IE %	Ea kJ.mol ⁻¹	A*10 ³						
0.00	0.461	-	0.505	-	0.562	-	0.992	-	18.71	888.91
1.0E-05	0.432	6.29	0.461	8.71	0.502	10.68	0.931	6.15	18.52	765.09
2. 0E-05	0.395	14.31	0.429	15.04	0.461	17.97	0.832	16.13	17.9	550.04
3. 0E-05	0.365	20.82	0.392	22.38	0.431	23.31	0.777	21.67	18.32	595.85
4. 0E-05	0.306	33.62	0.373	26.14	0.401	28.65	0.642	35.28	17.93	454.86
5. 0E-05	0.282	38.83	0.342	32.28	0.381	32.21	0.562	43.35	17.03	292.95
6. 0E-05	0.261	43.38	0.311	38.42	0.361	35.77	0.523	47.28	17.48	323.76
7. 0E-05	0.24	47.94	0.291	42.38	0.342	39.15	0.475	52.12	17.32	284.29
8. 0E-05	0.22	52.28	0.271	46.34	0.323	42.53	0.444	55.24	17.91	330.3
9. 0E-05	0.201	56.4	0.253	49.9	0.29	48.4	0.412	58.47	17.96	311.06
10. 0E-05	0.172	62.69	0.222	56.04	0.261	53.56	0.353	64.42	18.22	298.86

shown in Figure 1. Clearly, a limiting current plateau could be found in each anodic polarization curve. An obvious decrease in the limiting current was detected when Vitamin C was added (Table 1). This suggests that the anodic polarization behavior of steel is very insightful to small concentrations of Vitamin C. If $(I_L)_{blank}$ is the limiting current in absence of Vitamin C and $(I_L)_{Vitamin\ C}$ in the presence of Vitamin C, then IE % can be calculated from Equation 1:

$$IE\% = \frac{I_{L(blank)} - I_{L(vitamin\ C)}}{I_{L(blank)}} \times 100 \quad (1)$$

Vitamin C molecules may then combine with Fe²⁺ ions on the metal surface, forming metal- Vitamin C complex. The resulting complex could either inhibit or catalyzed further metal dissolution, depending on its solubility (Okafor et al., 2008). From the results obtained in this present investigation, it follows that Vitamin C forms soluble complexes with the metal ions which retard the dissolution reaction.

Vitamin C has polycentric adsorption sites (including various O atoms). These characteristics would afford the compounds the abilities to adsorb on the metal/solution interface via, the electrostatic attraction between the charged metal and the charged inhibitor molecules, dipole-type interaction between unshared electron pairs in the compounds with the metal, π electrons-interaction with the metal, and a combination of all of the above (Abdel-Gaber et al., 2006; Schweinsberg et al., 1988). The adsorption on the surface of the metal creates a barrier for mass and charge transfer leading to a decrease in the interaction between metal and acid environment. As a result, the dissolution rate of the metal is decreased. Vitamin C is heterocyclics in nature and contains O atoms in their structures. From the results of the dissolution process. It could be seen that the ascorbic

acids have some inhibiting ability which is probable due to the adsorption of the heterocyclics on the surface of the metal (Okafor et al., 2013).

Temperature effect

Potentiodynamic measurements were performed in the temperature range from 20 to 50°C in the absence and presence of different concentration of Vitamin C and the inhibition efficiencies was calculated and the relation between temperature and inhibition efficiencies was depicted in Figure 2. Inspection of Figure 2 reveals that, at lower concentration of Vitamin C as the temperature increase (20 to 40°C) an increase in the inhibition efficiencies (IE%) were clear, but at 50°C inhibition efficiencies (IE%) decreases due to desorption, at high concentration of Vitamin C as the temperature increase (20 to 40°C) a decrease in the inhibition efficiencies (IE%) were clear, but at 50°C inhibition efficiencies (IE%) increases.

Activated parameters for the dissolution process

It was generally accepted that organic molecules inhibit the dissolution process by adsorption at the metal-solution interface and that the adsorption depends on the molecule's chemical composition, the temperature and the electrochemical potential of the metal/solution interface. Activated parameters for dissolution process play an important role in understanding the inhibitory mechanism, that is, in defining the spontaneity of the dissolution of the metal to dissolution products that can be formed in the environment to which the metal was exposed (Osman et al., 2003).

The dependence of the dissolution rate on temperature was expressed by the Arrhenius equation.

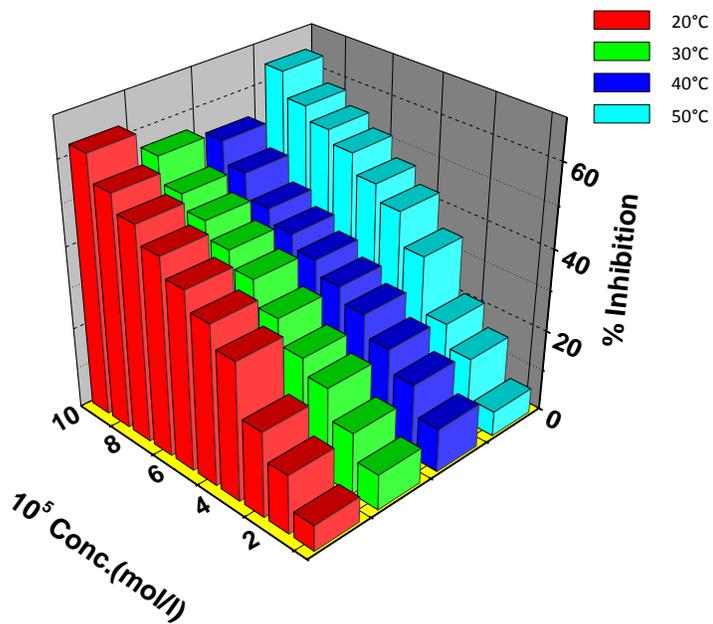


Figure 2. Variation of inhibition efficiency with Vitamin C concentration at different temperatures.

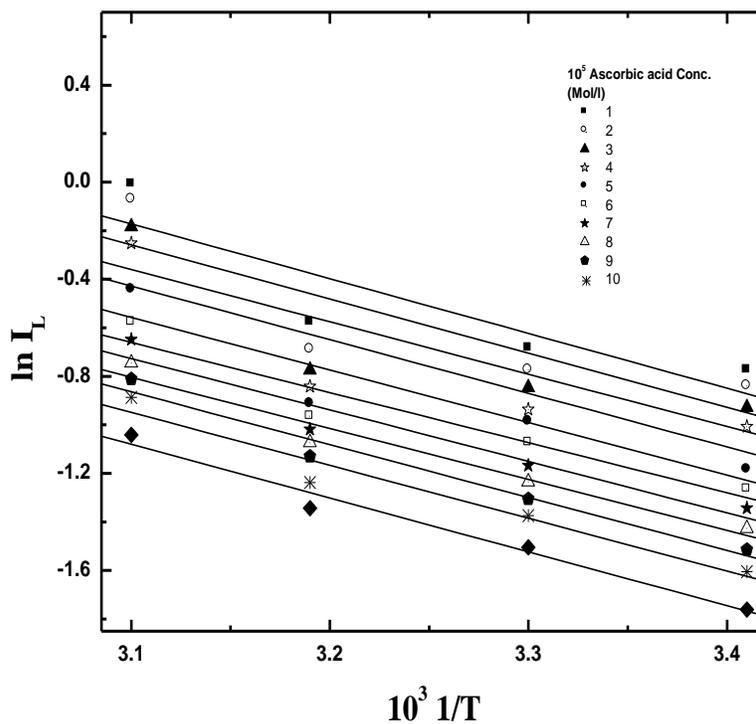


Figure 3. The Arrhenius plot of the dissolution process recorded for steel plate in 8M H₃PO₄ containing different concentrations of Vitamins C.

In $I_L = - (E_a/RT) + \ln A$, where A is the pre-exponential factor, which reflects the adsorption capacity of additives on the metal surface, E_a , is the activation energy of the

metal dissolution reaction, R is the gas constant and T is the temperature.

Figure 3 shows the Arrhenius plots for the dissolution of

steel with and without Vitamin C. The results give rise to satisfactory straight lines with slopes of $(-E_a/R)$. From the results, we can draw a conclusion that the E_a in the presence of Vitamin C is lower than that in the absence of Vitamin C. Many researchers (Gomma, 1998; Ammar and el-Khorafi, 1973; Omar and Mokhtar, 2011; Avci, 2008) also reported the activation energy in the presence of additive molecules was lower than in the absence of them, where it was attributed to the chemical nature of interaction between additive molecules and the steel surface. Ammar and el Khorafi (1973) proposed the lowering of activation energy by considering the kinetics of the dissolution process being diffusion controlled. Additionally, in the literature, the lower activation energy value of dissolution process in the presence of additive molecules (rather than the absence of additive molecules) also was attributed to its chemisorption, while it was found to be opposite in the case with physical adsorption (Omar and Mokhtar, 2011; Avci, 2008). In our case, the values of E_a were lower than that of free solution in the presence of Vitamin C, indicating that the chemisorption tendency is predominant in the presence of Vitamin C (Li et al., 2012). These results will be confirmed by the pre-exponential factor in the Arrhenius equation (A), for heterogeneous reaction is related to the number of active centers where the adsorbed additive molecules block an essential part of the active site, that is, those with the lowest E_a value, on the metal surface. On the other hand, these active centers have different energies, if energetic surface heterogeneity is assumed. There are two possibilities: in the first case ($E_{a, \text{additives}} > E_{a, \text{free acid}}$) where the values of A in case of additives are greater than that of blank. The additive molecules are adsorbed on the most active adsorption sites (having the lowest energy) and the dissolution process takes place predominantly in the active sites of higher energy. In the second case ($E_{a, \text{additives}} < E_{a, \text{free acid}}$, which observed in Vitamin C, the values of A in the presence of Vitamin C lower than in 8 M H_3PO_4 , that is, a smaller number of the more active sites remain uncovered which take part in the dissolution process (Amin et al., 2011).

This phenomenon is normally observed when the adsorbed molecules shield several sites on the electrode surface. The adsorbed additive molecules shield both the active and less active sites on the metal surface. Thus, some active sites (of lower E_a) are left, and they determine the value of the apparent activation energy of the dissolution process (Amin et al., 2011).

Surface analysis

Surface analysis includes three techniques:

- i. Scanning electron microscope (SEM),
- ii. Atomic force microscope (AFM),
- iii. Reflectance.

SEM analysis

The surface of morphology before and after EP in the absence of additives and in the presence of different concentrations of Vitamin C was shown in Figure 4a-f. Raw sample (Figure 4a) looked uneven and appeared to have potholes. A large number of pits with large size and high depth distributed over the surface are seen. However, after EP in 8M H_3PO_4 , only a slight difference was observed more than raw material, where grain boundaries and the number of bits are still observed. The specimen surface was smooth to some extent, where levelling and brightening occur and some deep cavities were filled up (Figure 4b).

Figure 4c and d represent the SEM image of steel in the presence of 2×10^{-5} and 5×10^{-5} M Vitamin C. It shows a completely uniform, smooth and bright surface. Grain boundaries are completely diminished. The well polished surface may be due to increase in the adsorption ability of Vitamin C molecules, leading to filling up of all deep cavities.

By increasing Vitamin C to 7×10^{-5} (Figure 4e) M and 10×10^{-5} M (Figure 4f), smoothness and brightness are observed by visual observation. However, the SEM micrograph shows uniformity decreases where the surface appears not flat to some extent.

This may be explained as a result of the change of adsorption behavior of Vitamin C molecules on the surface of steel. At lower concentration (2×10^{-5} M, Figure 4c) and moderate concentration (2×10^{-5} M, Figure 4d) of Vitamin C, there is a compact surface coverage by Vitamin C particles including peaks and valleys which led to uniform surface levelling. However, at higher concentration, the adsorbed layer became loose, where Vitamin C tends to repel each other, so we may conclude that the molecules of Vitamin C released from peaks which lead to localized difference in the dissolution rate of steel and lead to formation of small protrusions.

According to the results obtained, the addition of Vitamin C to the electrolytic solution improved the level of brightness and smoothness of the surface, the interpretation of that phenomenon may be attributed to:

- i. Hydroxyl groups reduce the hydrogen embrittlement at the cathode surface,
- ii. High viscosity reduces the electric conductivity and the aggressive attack of ions towards steel electrode,
- iii. High densities of OH^- groups reduce the random anodic dissolution of steel,
- iv. Hydroxyl groups with negative charges reduce the evolution of oxygen adjacent to the surface of steel during EP treatment which may cause some defects and pitting over the surface,
- v. Vitamin C containing high density of OH^- groups increases the viscosity of the electrolytic solution, giving the advantage to retard the aggressive attack of ions and

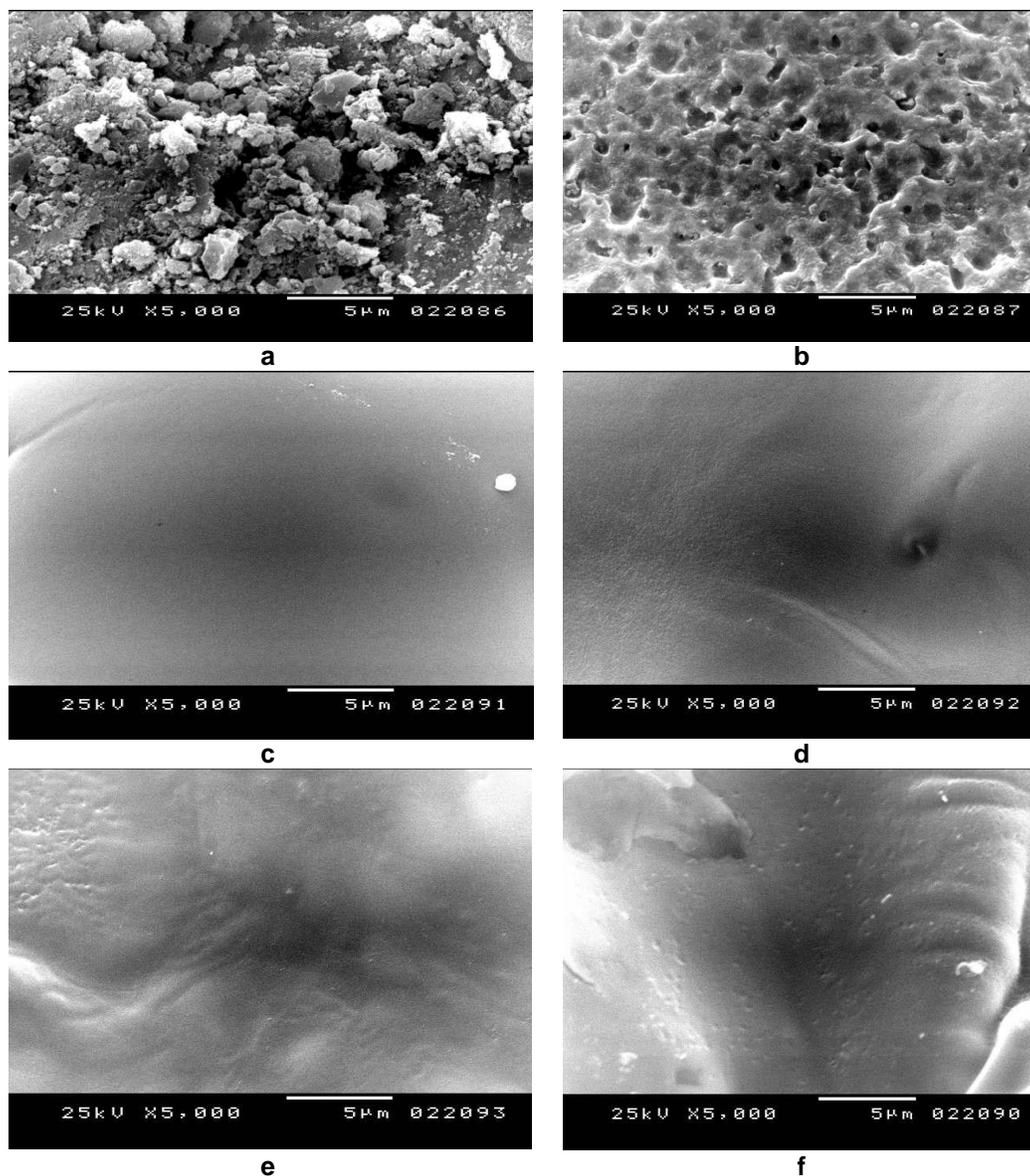


Figure 4. (a). Raw sample before polishing, (b). After electropolishing (blank) at 20°C, (c). After EP + 2×10^{-5} M vitamin C, (d). After EP + 5×10^{-5} M vitamin C, (e). After EP + 7×10^{-5} M Vitamin C and (f). After EP + 10×10^{-5} M Vitamin C.

the high dissolution of the working electrode (Awad et al., 2010).

Atomic force microscope (AFM)

Surface topography and roughness were characterized by AFM measurements. In order to highlight the effect of Vitamin C concentration on electropolishing, topography of a polished specimen is also compared. The two-dimensional AFM images of steel surface before and after EP without and with Vitamin C are shown Figure 5a-e. Figure 5(a) shows that the raw steel sample looked

uneven and appeared to have potholes with a random hill like structure ($R_a = 236.7$ nm). The nonuniformity and non homogeneity is the general appearance of the specimen while after EP in 8M H_3PO_4 , the surface becomes more flat and closely to some extent where the surface roughness decreases to 209.23 nm. It can be seen from Figure 5c and d that the micrograph of steel surface after electropolished in 8M H_3PO_4 containing 2×10^{-5} M and 5×10^{-5} M Vitamin C shows the main characteristic of uniform polishing. Steel surface appears flat, compact and homogenous. Random hills structure disappeared and replaced with uniform surface. On the other hand, R_a was decreased from 236.7 to 155 and

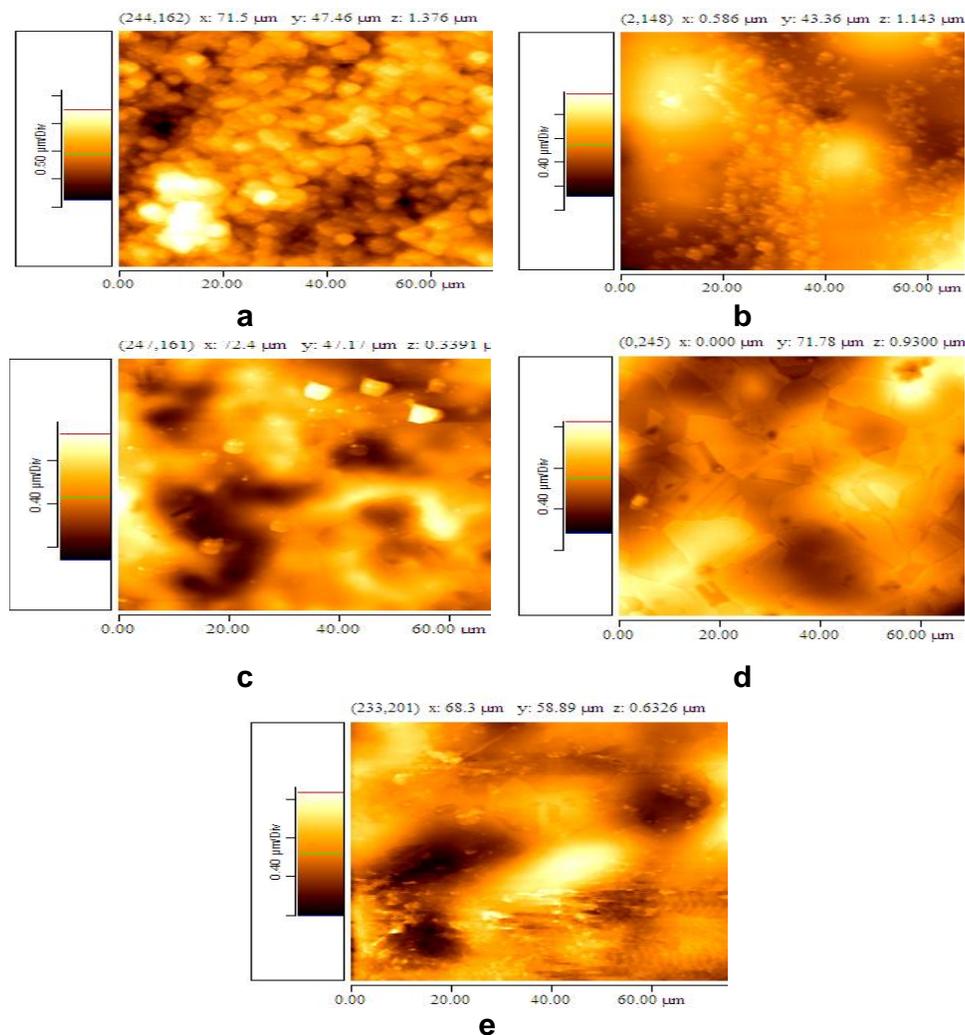


Figure 5. (a). Raw sample before polishing, (b). After electropolishing (blank) at 20°C, (c). After EP + 2×10^{-5} M Vitamin C, (d). After EP + 5×10^{-5} M Vitamin C and €. After EP + 10×10^{-5} M Vitamin C.

140 nm after addition of 2×10^{-5} M and 5×10^{-5} M Vitamin C, respectively. This result suggests that Vitamin C molecules may adsorb on the sharp peaks and decrease the dissolution rate at peaks, leading to uniform dissolution rates between peaks and valleys and a brighter, cleaner appearance too. The shielding film of Vitamin C molecules is compact enough to extend its coverage on the whole surface so that the species will dissolve uniformly from the anode surface and a very smooth surface on the micrometer scale is obtained.

While in the presence of 10×10^{-5} M Vitamin C, the AFM analysis revealed the non uniform, non homogenous surface, irregular random hill return to appear, potholes are represented in surface and additional roughening ($R_a = 169.5$ nm) as compared to the values obtained in the presence of lower concentration of Vitamin C. This behavior can be attributed to great molecular interaction between Vitamin

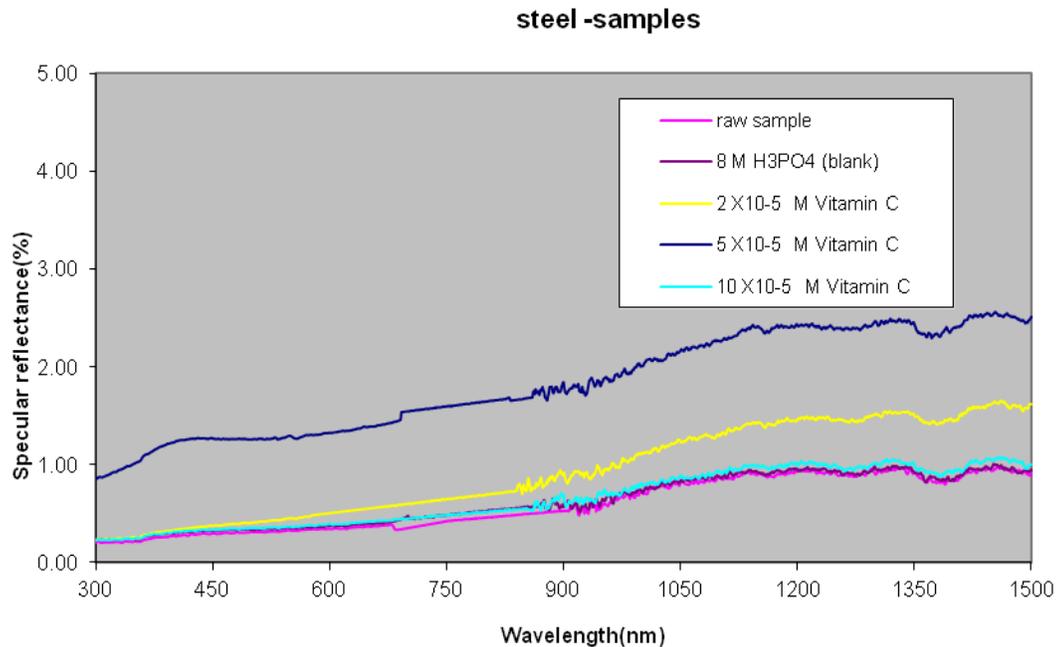
C and the microstructure of the shielding film became loose. Hence, the difference in dissolution rates between shielded and less-shielded portions becomes obvious, resulting in a rough surface. From Table 2, it is clear that, the peak-valley ratio (R_{P-V}) confirmed R_a , roughness values which have the same trend.

Reflectance

The UV-VIS-NIR Spectra of untreated specimen, the specimen that electropolished in 8M H_3PO_4 and the specimen that electropolished in 8M H_3PO_4 containing 2×10^{-5} , 5×10^{-5} , 10×10^{-5} M Vitamin C (Figure 6). It is seen that the reflectance of electropolished specimens is affected by concentration of Vitamin C. It is observed that, by increasing Vitamin C concentration, the reflectance of the specimen will be enhanced and

Table 2. Measured roughness (Ra), Rq (RMS), Peak - valley ratio of steel samples.

EP conditions	Peak - valley ratio (μm)	Ra (nm)	Rq (RMS) (nm)
Before electropolishing	2.115	236.7	271.9
After electropolishing without additives	1.99	209.0	269.8
After EP + 2×10^{-5} M Vitamin C	1.25	155.0	193.4
After EP + 5×10^{-5} M Vitamin C	1.15	140.0	172.8
After EP + 10×10^{-5} M Vitamin C	1.33	169.5	214.6

**Figure 6.** The Vis-IR spectra of electropolished specimens.

approached its maximum value in the presence of, 5×10^{-5} M Vitamin C. When Vitamin C concentration exceeded to 10×10^{-5} M, the reflectance value decreases, which confirmed the result obtained from SEM images and roughness value. It is clear that Vitamin C is important for their effect on the formation of insulating layer on the anode. In 8M H_3PO_4 (blank), the thickness of insulating layer is low; so, the smoothness and brightness of the surface is very low even in comparison with the raw unpolished specimen. But in the presence of Vitamin C, the formation rate of the insulating layer and thickness is high and appreciate enough for producing a high reflectance for metal while at high concentration of Vitamin C (10×10^{-5} M), the faster formation of the insulating layer lead to deformation of the insulating layer and non uniform dissolution, consequently producing a rough surface and decrease the reflectance.

From the result of the surface morphology study (SEM, UV-VIS-NIR Spectra and AFM), the optimized parameters for electropolishing of steel in 8M H_3PO_4 in

presence of Vitamin C. We can conclude that the optimum condition at 20°C is addition of low and moderate concentration of Vitamin C.

Conclusion

- i. The enhancement of the surface morphology and topography was achieved by the addition of Vitamin C to the electrolytic solution,
- ii. Improvement produced in EP by the studied Vitamin C was due to the adsorption of such molecules on the anode surface,
- iii. According to SEM, UV-VIS-NIR Spectra and AFM, addition of lower and moderate concentration of Vitamin C to the electrolytic solution was highly effective to enhance surface quality,
- iv. Vitamin C acts as a good inhibitor for the dissolution of steel in 8.0M H_3PO_4 . The inhibition efficiency values increase with the Vitamin C concentration increase.

Conflict of Interest

The authors have not declared any conflict of interest.

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