

Morphology and Optical Properties of Electropolished Steel in Presence of Vitamin C

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Received: 15 June 2015;

Accepted: 22 September 2015;

Published online: 30 December 2015;

AJC-17685

The studies of steel electrochemical polishing 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. The concentration of vitamin C influences 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.

Keywords: Steel, Electropolishing, Vitamin C, Scanning electron microscope, Atomic force microscope, 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 [1]. The proposal of electropolishing as an industrial surface finishing process is usually attributed to the work of Jacquet and Figoux in 1930 [2]. However, the first recorded publication dealing with electropolishing goes back even further in 1964 [3].

The surface phenomena of electropolishing are generally classified into two processes *i.e.*, 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 [4-11]. It is usually associated with a decrease of roughness in the micrometer or larger range [12] and can be achieved under the ohmic (primary current distribution), activation (secondary) and mass-transport (tertiary)-controlled metal dissolution reactions [13,14]. 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 [13-16]. 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 electropolishing process produce smooth and bright surfaces that are free of defects, stress and contamination.

Magaino *et al.* [17] and Gabe [18] measured the anodic polarization curves of mild steel in phosphoric acid and phosphoric-sulfuric acid mixtures. 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.* [19] who studied the anodic behaviour of steel in mixtures of phosphoric acid and sulfuric acid. Well-polished surfaces can be obtained at or above a limiting current density, which means that electropolishing takes place in the *trans* passive region under mass-transport control.

The impedance study [17] and the temperature effect on the appearance of metals/alloys through electropolishing in the phosphoric acid-sulfuric acid system [11,20] have also been done. Furthermore, addition of glycerol into this system was adopted [21,22]. In this glycerol containing system, the limiting

polishing current was found to depend slightly on the flow rate [21] and a concept for minimizing agitation of the electrolyte was proposed to eliminate the cost of pumping concentrated acids [22]

Based on these studies, several mechanisms have been proposed successively for the process of anodic dissolution *e.g.*, (i) salt film (dissolution products) mechanism [12]; (ii) acceptor mechanism [12]; (iii) preferential adsorption of shielding molecules [23,24]; and (iv) formation of a solid oxide film of aluminum [25]. 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 [26].

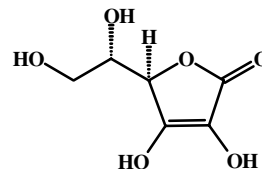
The examination of steel dissolution in acid solutions by different type of organic compounds has been extensively studied [27]. Among them, very few are environmentally acceptable, such as natural products *i.e.* extracts of various parts of plants, pharmaceutically active compounds, *i.e.* antibiotics, antibacterial, antioxidant *etc.* [28-37]. 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 electropolishing of steel.

Ascorbic acid (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.

EXPERIMENTAL

Electropolishing was performed on a rectangular steel sheet by an area of 10 cm × 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 electropolishing solution, which was surrounded by an isothermally circulated water system ($\pm 0.5^\circ\text{C}$) at different temperatures (20, 30, 40 and 50 °C). The cathode, which was a rectangular steel sheet with an area of 5 cm × 10 cm, was also immersed in the solution and faced the test sheet. The electropolishing solution was composed of 8 M H₃PO₄ phosphoric acid (85 %). The electropolishing experiment was conducted by a direct current (dc) power supply. Ten concentrations of vitamin C with 8 M H₃PO₄ are used, ranging from 1×10^{-5} to 10×10^{-5} M. Vitamin C was Fluka product of pure quality (> 97 %). The polishing potentials generally reach a steady-state value after the current is applied for 200 s. After the electropolishing 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 cm × 1 cm). The average surface roughness factor (Ra) was measured at two points near the centers of the test sheet

with an area of $75 \times 75 \mu\text{m}^2$ by an atomic force microscope (AP-0100 AUTOPROBE CP-Research, THERMOMICRO-SCOBES). 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 300-1500 nm.



Structure of vitamin C (ascorbic acid)

RESULTS AND DISCUSSION

Different regions of electropolishing polarization curve: A typical polarization curve for an electropolishing system are shown in Fig. 1. Three major regions can be identified on the curve *i.e.*, etching region, polishing region and gas evolution region. The etching region is characterized by an exponential increase in current until a certain voltage [38].

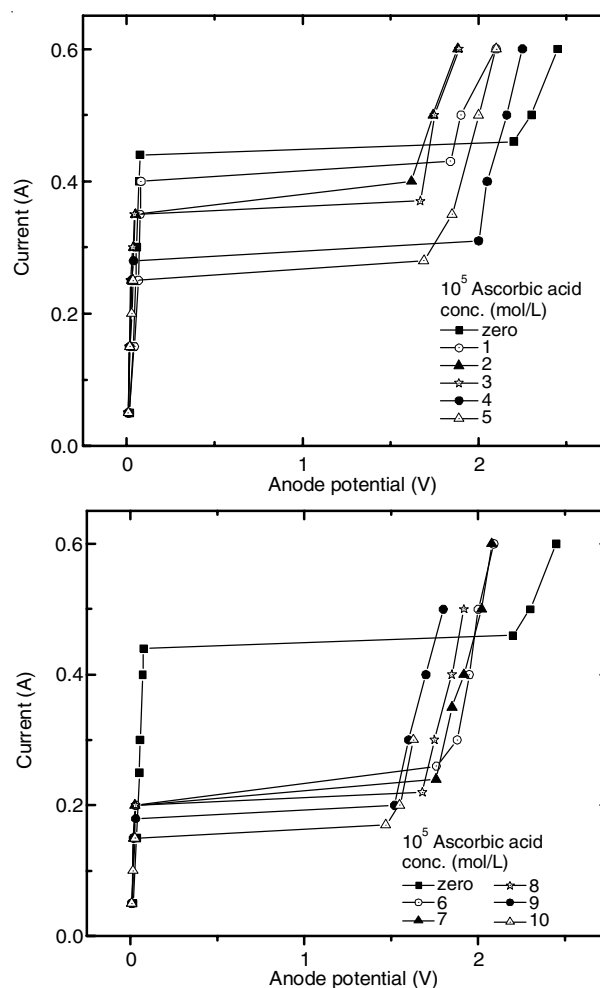


Fig 1. Typical polarization curves for the electropolishing of vertical steel in 8 M H₃PO₄ in presence of different concentration of vitamin C at 20 °C

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 over-potential (η), at a given overall applied potential, resulting in a different dissolution current [39]. 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 [40]. 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 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 [38]. 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 [41]. 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.* [40] 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.

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 shown in Fig. 1. Clearly, a limiting current plateau could be found in each anodic polarization curve. An obvious decrease in the limiting current was detected when the vitamin C was added (Table-1). This suggests that the anodic polarization behaviour of steel is very insightful to small concentrations of vitamin C.

If $(I_L)_{\text{blank}}$ is the limiting current in absence of vitamin C and $(I_L)_{\text{Vitamin C}}$ in the presence of vitamin C, then IE % can be calculated from the following equation:

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

The vitamin C molecules may then combine with Fe^{2+} 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 [42]. From the results obtained in this present investigation, it follows that the 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 [43,44]. The adsorption on the surface of the metal creates a barrier for mass and charge transfer leading to a decrease in the interaction between the metal and the acid environment. As a result, the dissolution rate of the metal is decreased. Vitamin C is heterocyclic compound in nature and contains O atoms in their structures. From the results of the dissolution process, it could be seen that the ascorbic acid has some inhibiting ability which is probable due to the adsorption of the heterocyclics on the surface of the metal [45,46].

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 Fig. 2. Fig. 2 reveals that at lower concentration of vitamin C

TABLE-1
VALUES OF LIMITING CURRENT, % INHIBITION FOR DISSOLUTION OF STEEL IN 8 M H_3PO_4 IN PRESENCE OF DIFFERENT CONCENTRATION OF VITAMIN C AT DIFFERENT TEMPERATURES AND ACTIVATED PARAMETERS FOR THE PROCESS

Vitamin C conc. (mol/L)	20 °C		30 °C		40 °C		50 °C		Activated parameters	
	I_L (A)	IE (%)	I_L (A)	IE (%)	I_L (A)	IE (%)	I_L (A)	IE (%)	E_a (kJ mol ⁻¹)	$A \times 10^3$
0	0.461	-	0.505	-	0.562	-	0.992	-	18.71	888.91
1.0×10^{-5}	0.432	6.29	0.461	8.71	0.502	10.68	0.931	6.15	18.52	765.09
2.0×10^{-5}	0.395	14.31	0.429	15.04	0.461	17.97	0.832	16.13	17.90	550.04
3.0×10^{-5}	0.365	20.82	0.392	22.38	0.431	23.31	0.777	21.67	18.32	595.85
4.0×10^{-5}	0.306	33.62	0.373	26.14	0.401	28.65	0.642	35.28	17.93	454.86
5.0×10^{-5}	0.282	38.83	0.342	32.28	0.381	32.21	0.562	43.35	17.03	292.95
6.0×10^{-5}	0.261	43.38	0.311	38.42	0.361	35.77	0.523	47.28	17.48	323.76
7.0×10^{-5}	0.240	47.94	0.291	42.38	0.342	39.15	0.475	52.12	17.32	284.29
8.0×10^{-5}	0.220	52.28	0.271	46.34	0.323	42.53	0.444	55.24	17.91	330.30
9.0×10^{-5}	0.201	56.40	0.253	49.90	0.290	48.40	0.412	58.47	17.96	311.06
10.0×10^{-5}	0.172	62.69	0.222	56.04	0.261	53.56	0.353	64.42	18.22	298.86

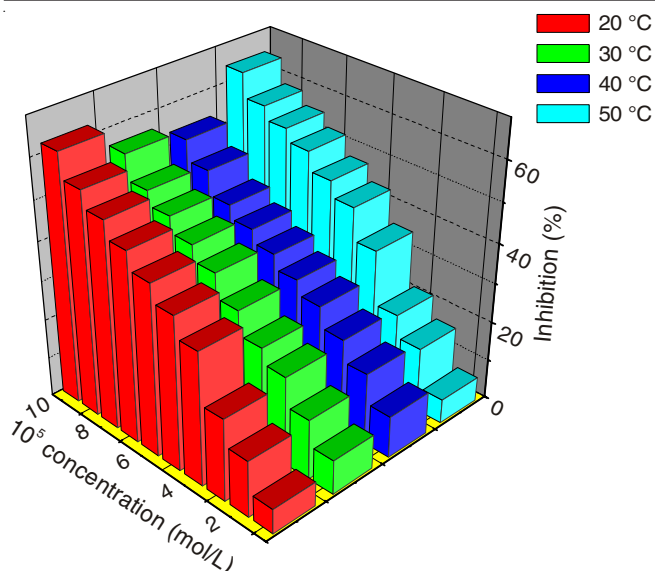


Fig. 2. Variation of inhibition efficiency with vitamin C concentration at different temperatures

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, *i.e.*, 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 [47].

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

$$\ln I_L = - (E_a/RT) + \ln A$$

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.

Fig. 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 [48-51] 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 Khorafi [49] 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 and the value of

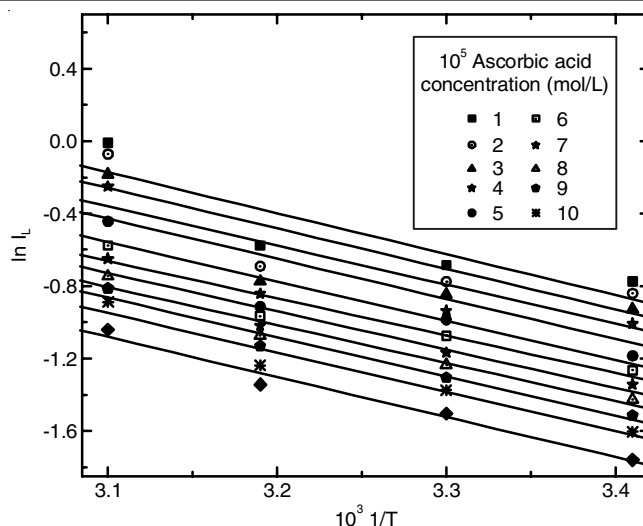


Fig. 3. Arrhenius plot of the dissolution process recorded for steel plate in 8 M H_3PO_4 containing different concentrations of vitamins C

dissolution process in the presence of additive molecules (rather than the absence of additive molecules) were also attributed to its chemisorption, while it was found to be opposite in the case with physical adsorption [50,51]. In present 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 [52]. 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, *i.e.*, 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 ($E_{a, additives} > E_{a, free acid}$) 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 ($E_{a, additives} < E_{a, free acid}$), which observed in vitamin C, the values of A in the presence of vitamin C lower than in 8 M H_3PO_4 , *i.e.* a smaller number of the more active sites remain uncovered which take part in the dissolution process [53].

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 [53].

Surface analysis

SEM analysis: As shown in Fig. 4a-f, the surface morphology before and after electropolishing in the absence of additives and in the presence of different concentrations of vitamin C. Raw sample (Fig. 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 electropolishing in 8 M 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 (Fig. 4b).

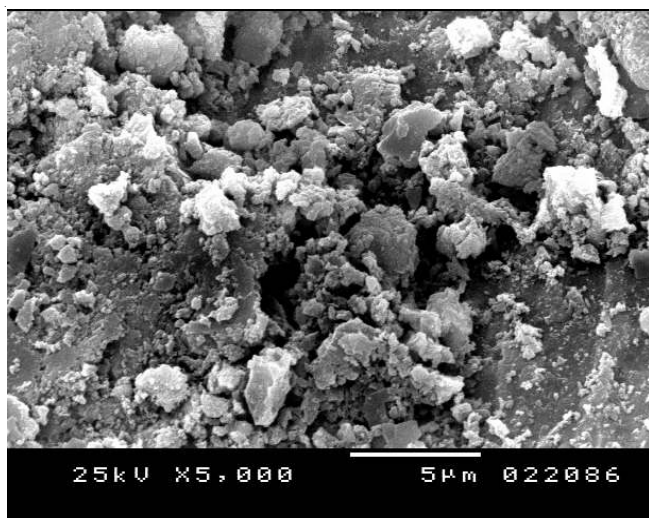


Fig. 4a. Raw sample before polishing

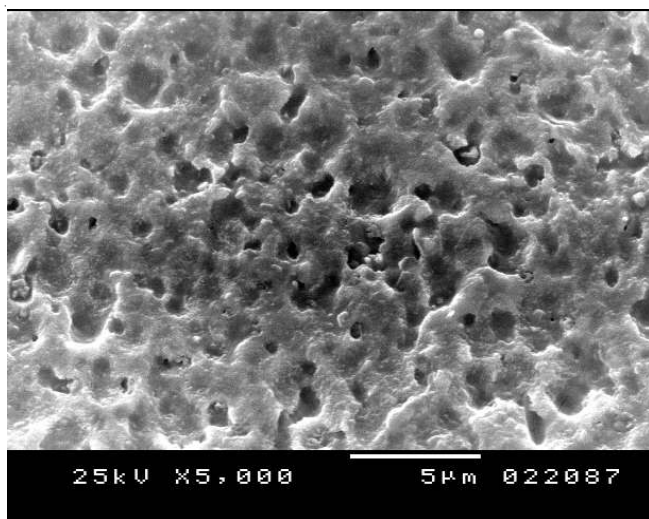


Fig. 4b. After electropolishing (blank) at 20 °C

Fig. 4c and 4d represent the SEM image of steel in 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 concentration of vitamin C to 7×10^{-5} M (Fig. 4e) and 10×10^{-5} M (Fig. 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 behaviour of vitamin C molecules on the surface of steel. At lower concentration (2×10^{-5} M, Fig. 4c) and moderate concentration (5×10^{-5} M, Fig. 4d) of vitamin C, there is a compact surface coverage by vitamin C particles including peaks and valleys which lead to uniform surface levelling. However, at higher concentration, the adsorbed layer became

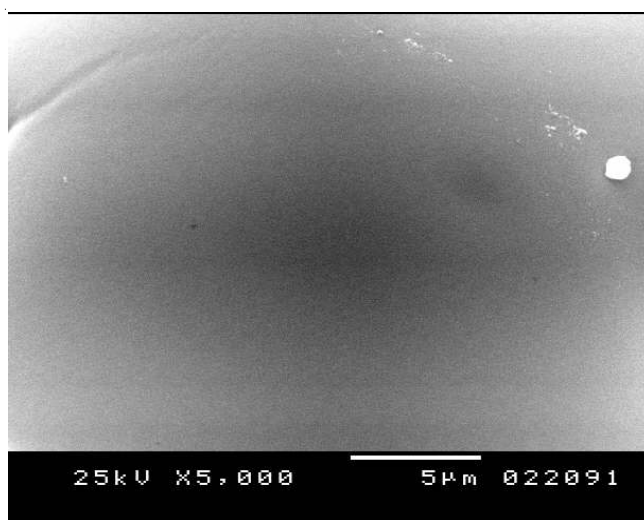


Fig. 4c. After electropolishing + 2×10^{-5} M vitamin C

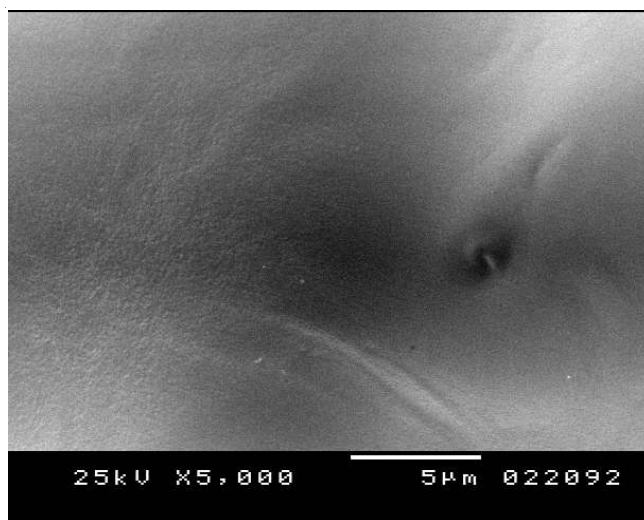


Fig. 4d. After electropolishing + 5×10^{-5} M vitamin C

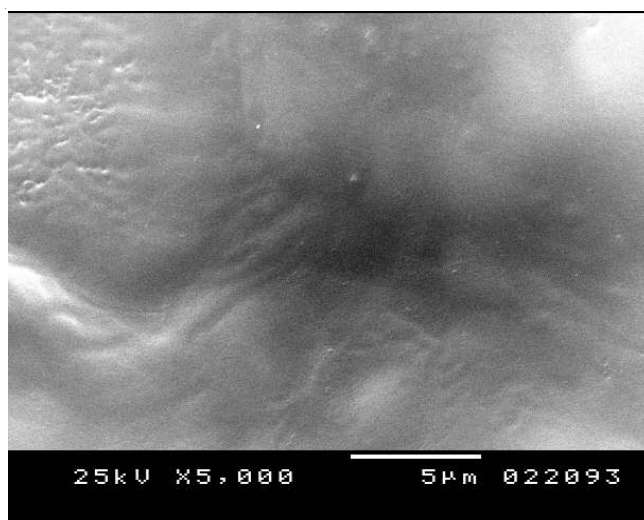
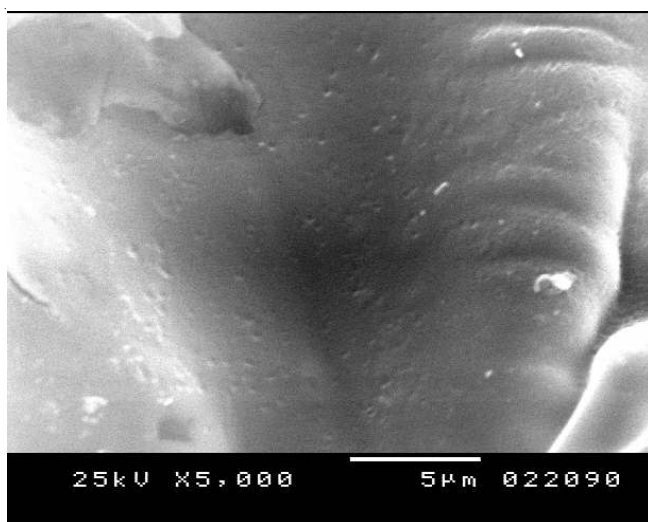


Fig. 4e. After electropolishing + 7×10^{-5} M vitamin C

loose, where vitamin C tends to repel each other, so it is concluded 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.

Fig. 4f. After electropolishing + 10×10^{-5} M vitamin C

According to the results, 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:

- Hydroxyl groups reduce the hydrogen embrittlement at the cathode surface.
- High viscosity reduces the electric conductivity and the aggressive attack of ions towards steel electrode.
- High densities of OH^- groups reduce the random anodic dissolution of steel
- Hydroxyl groups with negative charges reduce the evolution of oxygen adjacent to the surface of steel during electropolishing treatment which may cause some defects and pitting over the surface.
- 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 the high dissolution of the working electrode [46].

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 electropolishing without and with vitamin C are shown (Fig. 5a-e). As can be seen from Fig. 5(a), that the raw steel sample looked uneven and appeared to have potholes with a random hill like structure ($R_a = 236.7$ nm). The non-uniformity and non homogeneity are the general appearance of the specimen while after electropolishing in 8 M 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 Fig. 5c and 5d that the micrograph of steel surface after electropolished in 8 M 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 the average surface roughness factor (R_a) was decreased from 236.7 to 155 and 140 nm after addition 2×10^{-5} M and 5×10^{-5} M vitamin C, respectively. This result suggests that the vitamin C molecules may adsorb on

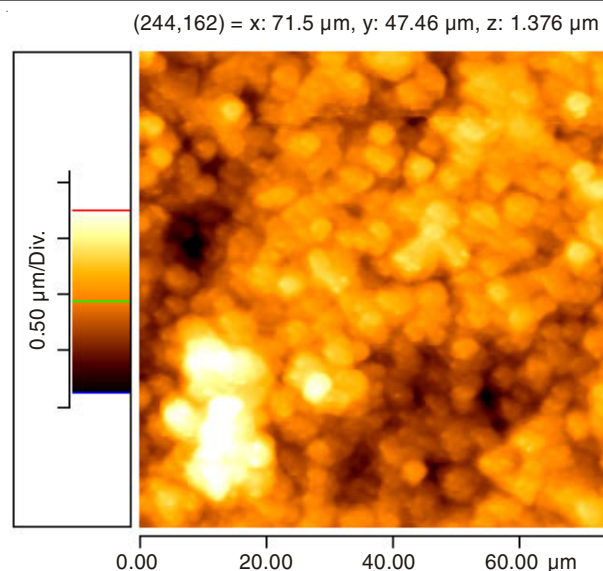


Fig. 5a. Raw sample before polishing

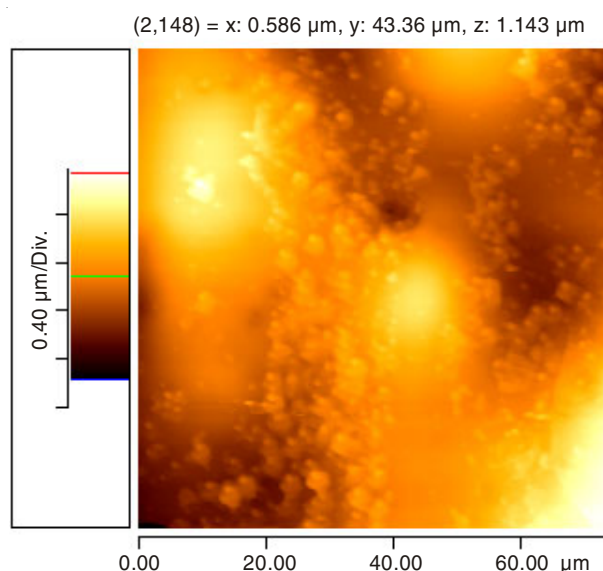
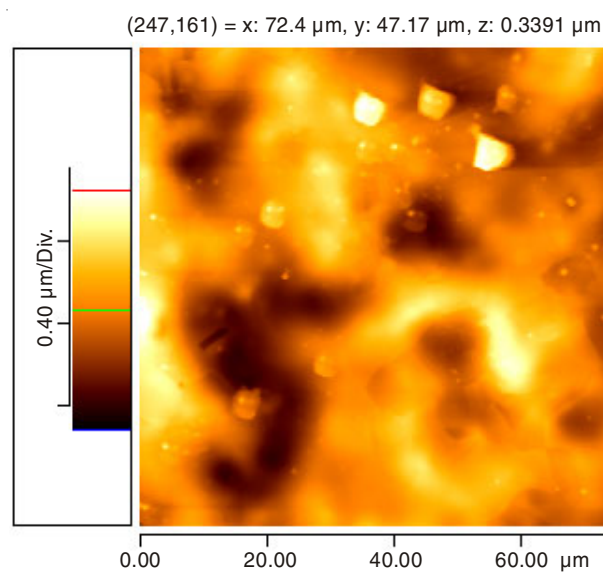
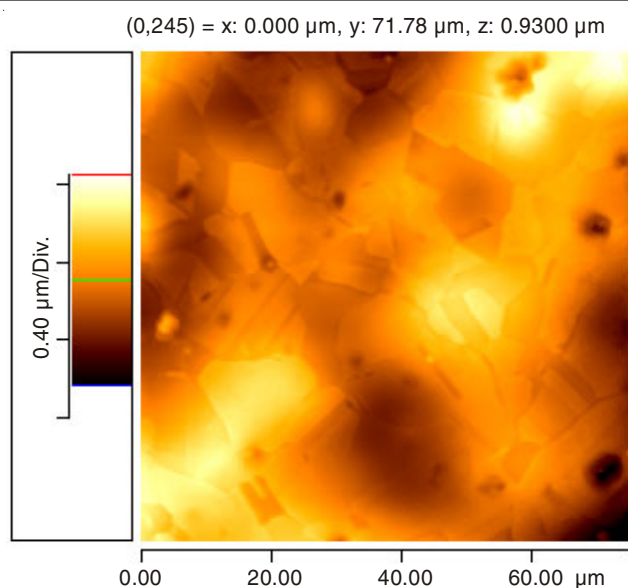
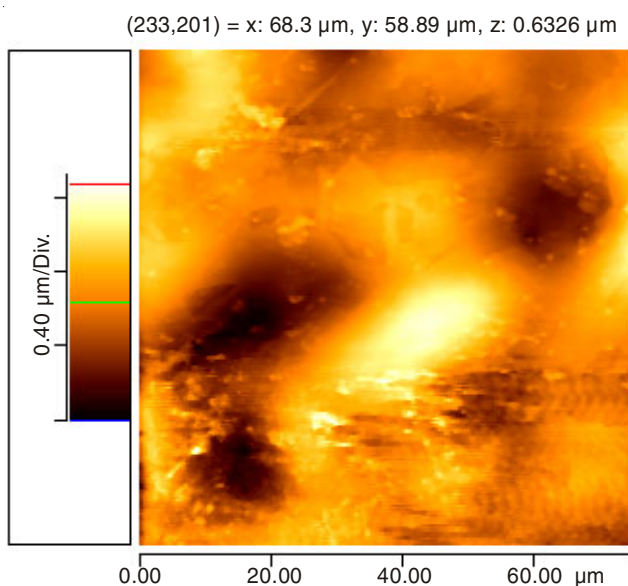


Fig. 5b. After electropolishing (blank) at 20 °C

Fig. 5c. After electropolishing + 2×10^{-5} M vitamin C

Fig. 5d. After electropolishing + 5×10^{-5} M vitamin CFig. 5e. After electropolishing + 10×10^{-5} M vitamin C

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 behaviour 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 the R_a , roughness values which have the same trend

Reflectance: The UV-VIS-NIR spectra of untreated specimen, the specimen that electropolished in 8 M H_3PO_4 and the specimen that electropolished in 8 M H_3PO_4 containing 2×10^{-5} , 5×10^{-5} , 10×10^{-5} M vitamin C (Fig. 6). It is seen that the reflectance of electropolished specimens is affected by concentration of vitamin C. It is observed that, by increasing the vitamin C concentration, the reflectance of the specimen will be enhanced and approached its maximum value in the presence of, 5×10^{-5} M vitamin C. When the vitamin C concentration exceed to 10×10^{-5} M, the reflectance value decreases, which confirmed the result obtained from SEM images and roughness value. It is clear that the vitamin C is an important additive for their effect on the formation of the insulating layer on the anode. In 8 M 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.

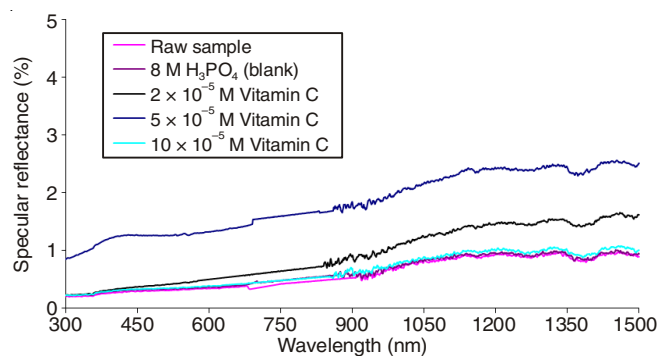


Fig. 6. Visible-IR spectra of electropolished specimens

From the results of the surface morphology study (SEM, UV-VIS-NIR spectra and AFM), the optimized parameters for electropolishing of steel in 8 M H_3PO_4 in presence of vitamin C. It is concluded that the optimum condition at 20 $^{\circ}\text{C}$ is addition of low and moderate concentration of vitamin C.

TABLE-2
MEASURED ROUGHNESS (R_a), R_q (RMS), PEAK-VALLEY RATIO OF STEEL SAMPLES

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

Conclusion

• The enhancement of the surface morphology and topography was achieved by the addition of vitamin C to the electrolytic solution.

• Improvement produced in electropolishing by the studied vitamin C was due to the adsorption of such molecules on the anode surface.

• 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.

• Vitamin C acts as a good inhibitor for the dissolution of steel in 8.0 M H_3PO_4 . The inhibition efficiency values increase with the increase of vitamin C concentration.

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