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Electropolishing of 410 stainless steel in perchloric acid solution

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Abstract

Stainless steel type 410 is widely used due to its good corrosion resistance. For further improvement, an electropolishing process was applied to it in 15% by volume Perchloric acid. The electropolishing process conditions were 18V for 10 minutes at two different temperature of room and 70 c^0 temperature. Potentiodynamic polarization test were applied for 410 stainless steel specimens before and after electropolishing at both temperature . Corrosion resistance improve for electropolishing specimen at room temperature because improve passive chromium surface oxide layers observe at xrd analyses. AFM and surface roughness measurement were also obtained and the surface roughness decrease for 101 to 0.45 for electropolishing specimen of room temperature.

Keywords: Electropolishing;stainless steel type 410;Surfaceroughness;corrosion resistance

1. INTRODUCTION

Martensitic stainless steel is characterized by limited chromium concentration, generally ranging from 11.5% to 18%, and by a very high carbon content (between 0.1% and 1%).The martensitic steels are magnetic at all temperatures and are selected for resistance to wear and abrasion. These types are generally not as corrosion resistant as the ferritic and austenitic types. They have fair cold forming characteristics and can be welded, but usually require annealing after forming or welding to prevent cracking **[1,2].**

Electropolishing is the controlled corrosion of a metal surface to bring about a reduction in surface roughness and an increase in corrosion resistance of the components. Electropolished pieces also decrease wear and increase lubricity in engines, thus reducing a major cause of failure, and offer several other functional benefits. **[3].**

During electropolishing, the metals component becomes an anode, and a counter electrode isutilized as a cathode. The anode and cathode are submergedin an acidic electrolyte, and a current is applied.Electropolishing improves surface finish by removing metalfrom the surface of a piece, ion by ion[4].

Parameters that influence the electropolishing process include: anodic current density, applied potential, bath temperature, reaction time, composition and concentration of electrolytes, and the anode-to-cathode surface area ratio [5].

Temperature is a significant factor ensuring the mass diffusion and flow rate of ions during electropolishing. As temperature increases, the dissolution rate and current density vary. The effect of temperature is also related to the composition and viscosity of electrolytes. It has been observed that the polarization curve for a given electrolyte increases with an increase in temperature, due to the higher current density, where 316 L stainless steel is electropolished in a sulfur free acid solution[6].

Sami AbualnounAjeel[2012],[7] studying an electropolishing effect on 304 stainless steels with variable electropolishing conditions of current densities (1,3 and A/dm), temperatures (70.80 and 90 °C)and times (5.10 and 15 minutes). The best electropolishing conditions are: applied current density of 5A/dm, temperature of 90%c and time of 10 minutes due to the best brightness and smoothness as observed in AFM measurements and low hardness. This also is due to the formation of nickel chromium oxide layer on the surface.

This work aims to investigate the effect of the electropolishing process on the corrosion resistance and surface roughness of 410 stainless steel metal. Perchloric acid solution was used as an electrolyte and the temperature of the electrolyte was changed in order to study its effect on the efficiency of the electropolishing process.

2. EXPERIMENTAL WORK

2-1 materials used

The specimens used for this study were stainless steel type 410 , Chemical composition analysis for the materials was carried out .Table (1) shows the results of nominal and analytical stainless steel type 410.

Table 1. The nominal [8] and analytical results of stainless steel type 410.

Stainless steel analysis type	Chemical composition				
	Fe%	Cr%	Si	Mn%	Ni%
Analytical wt%	85.15	13.09	0.14	0.47	0.27
Nominal wt%	balance	11.50-13.50	1.00	1.00	0.750

2-2 Specimens preparation

The specimens were cut into the dimensions of (2×2×0.5 cm). They were ground using different degree of grinding papers of SiC.These papersgrids are 180, 400 ,800, 1000 and1200 grit size. Water was used in the grinding step as a coolant to avoid the rising in temperature which resulted from the friction between grinding papers and the surface of specimens. The specimens are polished using diamond paste to get mirror surface. Then, the specimens were degreased with acetone for 10 min. at room temperature.

Heat treatment process for all prepared specimens was done using an electrical furnace. The specimens were applied to heat treatment to relieve stresses that remain locked in a structure as a consequence of a manufacturing sequence, it includes heating the specimens to (787 °C) and soaking for (2 hour), then cooling in air.

The electropolishing baths for 410 stainless steel contain concentration of 15% by vol. Perchloric acid and distilled water . The metal work piece (stainless steel type 410) was immersed in a electrolyte and connected to the positive terminal (anode) of a DC power supply; the negative terminal being attached to (stainless steel type 316) used as the cathode. The electropolishing process is carried out in 250ml capacity beaker containing 150 ml of solution in low and high temperatures and their parameters of electropolishing process are shown in Table 2.

Table2. Theelectropolishingprocessparameters

Electropolishingsolution	Voltage(V)	Time (min.)	Temperature (C^0)

15wt.%$HClO_4$solution	18	10	Room temperature
15 wt.% $HClO_4$ solution	18	10	70

Potentiodynamic polarization tests were utilized for 410 stainless steel specimens before and after electropolishing .Three electrodes for electrochemical cell immersed in 3.5%Nacl solution connected to computerized .Potentiostat device open circuit potential was measured for this cell without any applied potential. The measured open circuit potential is used to determine cathodic and anodic regions for potatiodynamic polarization curves of 410 stainless steel specimens .Tafel plot can be generated for these curves .tafel plots legin with scan rate of 0.1 mv/sec at $E_{corr.}$ and scaning to either -250 mv vs. E_{corr} (for a cathodictafel plot)or +250 mv vs. (for an anodic tafel plot).These both tafel plots are obtained in a single scan by beginning the scan at -250 mv vs. E_{corr} and scanning continuously to +250 mv vs.E_{corr}. The resulting curve is a plot of applied potential vs. the logarithm of the measured current density .

A surface roughness tester was (TR200ohand-held roughness tester, model TA620Stann).In each case, the specimens were mounted on a flat base then the distance to be tested was appointed and the probe of the measuring instruments was attached by special lever to the surface of the specimens, after that the instrument was switched on. X-Ray Diffraction , Atomic Force Microscopy and Scanning Electron Microscopy/Energy Dispersive Spectroscopy were applied measuring before and after electropolishing process.

2-3 RESULTSANDDISCUSSION

The corrosion parameters can be determine from figures 1,2 and 3 using tafel plot .the main polarization curve parameters are E_{corr},I_{corr} and corrosion rate , an equation can be used to calculate the corrosion rate (in millimeters per year)can be calculated from the following equation [9]:

Corrosion rate (mpy)=0.13 icorr *((E.W.)/A.p

Where

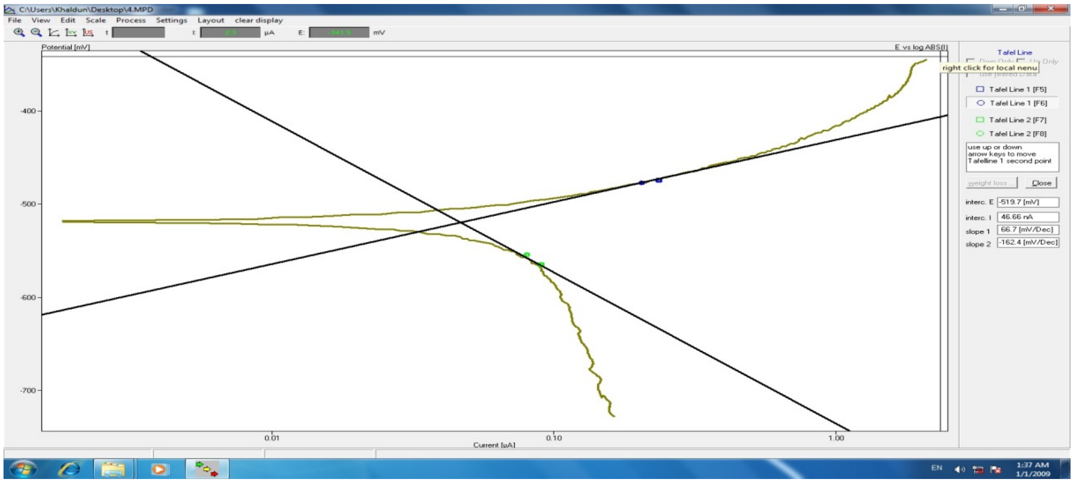
E. W. = equivalent weights (g/ eq)
A = areas (cm^3)
p= density's (g/ cm^3)
0.13 = metric and time conversion factor.

$i_{corr.}$ = density of current (μA / cm_2).

The measured parameters ,corrosion rate for each case are shown in table 3.It can be assumed that the electropolishing at hight temperature was not performed sufficiently (if the temperature is higher than necessary, the surface is damaged due to excessive ionization.). Conversely, in the electropolishing at low temperature, electropolishing was sufficient . In electropolishing at hight temperature , the metal surface was overall rough and irregularly damaged. In general, corrosion of stainless steel grows with pitting and intergranular corrosion. Pits grow in parts where a potential difference is generated by impurities on the metal surface.

Table(3) shows main corrosion for electropolishing of 410 stainless steel in two different temperatures.

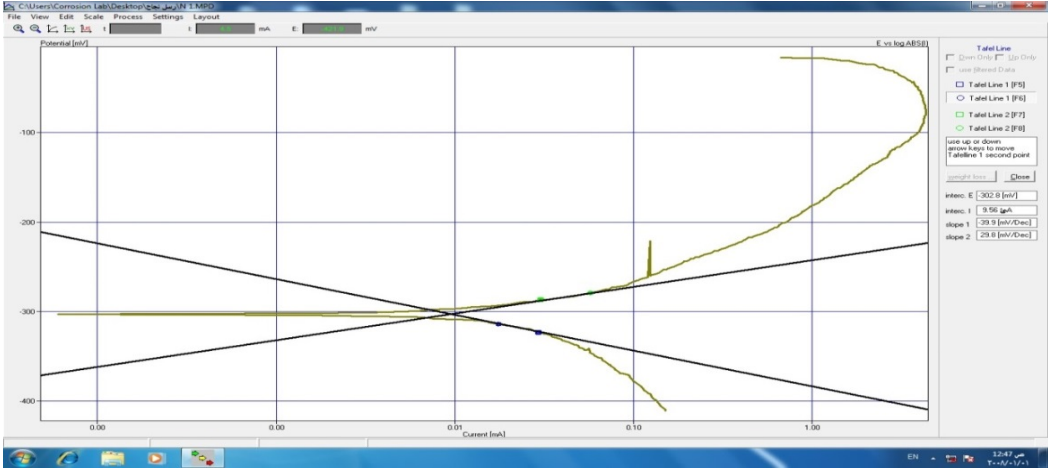
corrosion test conditions	Corrosion current density icorr (uA/cm^2)	Corrosion potential Ecorr (mV)	Corrosion rate mpy
Before electropolish	46.66	-527	5.45
Electropolishing at Room temperature (25^{0}C)	20.35	-293.5	2.37
Electropolishing at High temperature (70 ^{0}C)	117.37	-527.6	13.73



use up or down arrow keys to move Tafelline 1 second point

interc. E -519.7 [mV]
interc. I 46.66 nA
slope 1 66.7 [mV/Dec]
slope 2 -162.4 [mV/Dec]

Figure (1):: Potentiostatic polarization behavior of 410 stainless steel.



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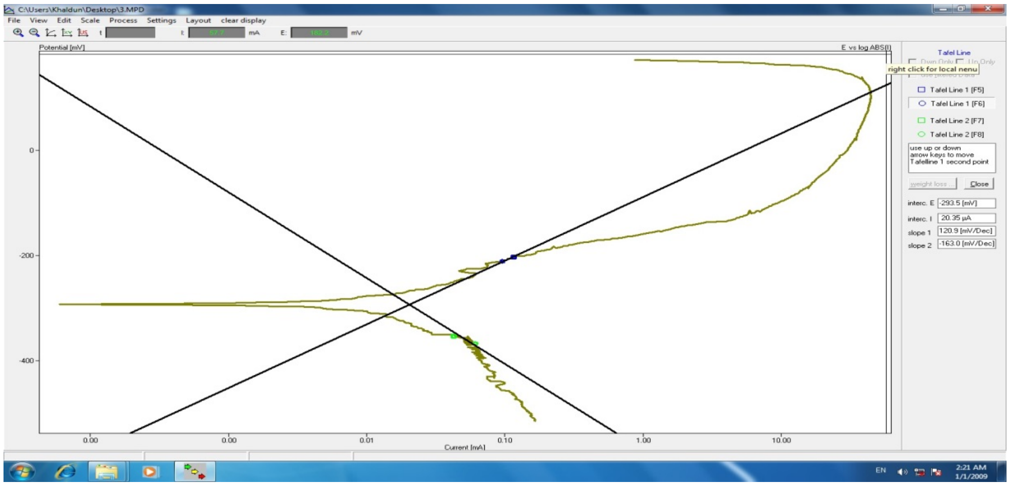
interc. E -302.8 [mV]
interc. I 9.56 µA
slope 1 -39.9 [mV/Dec]
slope 2 29.8 [mV/Dec]

Figure (2):: Potentiostatic polarization behavior of electropolishing at room temperature



interc. E -293.5 [mV]
interc. I 20.35 µA
slope 1 120.9 [mV/Dec]
slope 2 -163.0 [mV/Dec]

Figure (3):: Potentiostatic polarization behavior of electropolishing at (70 ⁰C) temperature

Surface roughness measuremant of specimens are shown in table 4, the results indicate that the best electropolishing performance was achieved with the room temperature, which ensured optimum electrolytic conductivity, reduced energy costs, avoided producing toxic vapours, and degrading the electrolyte.Increased temperature significantly influences the conductivity of the solution and decreases in the clamp voltage of electrolysis.

Table(4):. The result of surface roughness.

Electropolishingtemperature	Surfaces roughness(µm)
Before electropolish	1.01
Electropolishing at Room temperature	0.45
Electropolishing at High temperature (70 ^{0}C)	2.47

The chromium to iron ratio is a measure of the corrosion resistance of the passive layer on all stainless steels. During the passivation process, which can occur in air , the chromium combines with oxygen and forms an impervious barrier to further reaction of the material below that film . As the chromium content increases the film becomes a thicker barrier. During electropolishing, the iron and other elements are preferentially dissolved, allowing the chromium to increase in its atomic percentage on the surface. The XRD diagram of the 410 stainless steel before and after electropolishingare shown in Figures (4) and (5).The XRD patterns for electropolishing specimen were similar to the initial specimen. However, the intensity of element signals was relatively larger than the initial one[10,11]

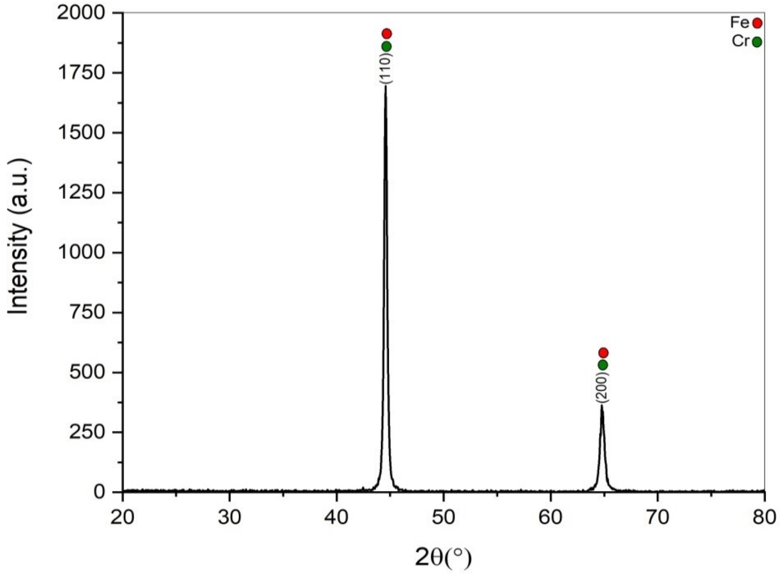


Figure (4) The XRD diagram of the 410 stainless steel before electropolish.

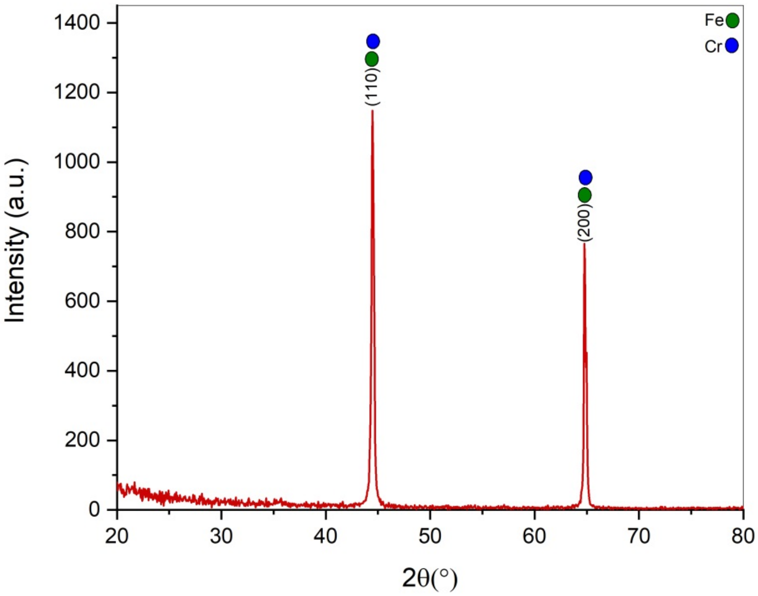


Figure (5) The XRD diagram of the 410 stainless steel after electropolish at room temperature.

in order to understand the interactive effects of electropolishing variables on the surface morphology of 410 stainless steel, AFM is used to capture the information about the specimen surface before and after the electopolishing in this work. Before electropolishing, the specimen surface is shown to be rough with sharp edges and contained several hills and valleys shown in figure(6) . Figure (7) shows smooth surface after electropolishing without any surface defects or irregularities. This shows effective improvement of the surface characteristics by electropolishing of the specimen.

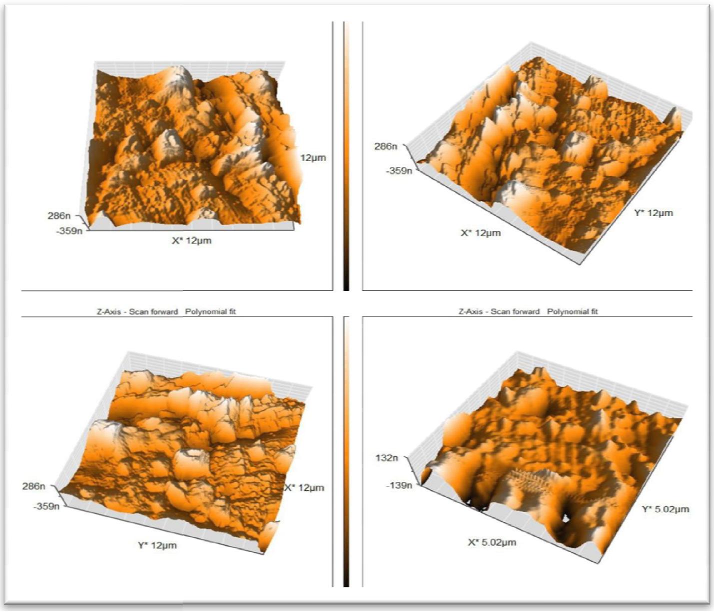


Figure (6) AFM of the 410 stainless steel before electropolishing.

SEM done for 410 stainless steel specimens before and after electropolishing as shown in Figures8and 9; before electropolishing , the surface is covered with spherical particles, so the surface is very rough but after electropolishing the surface morphology of the spherical particles becomes less and smaller.

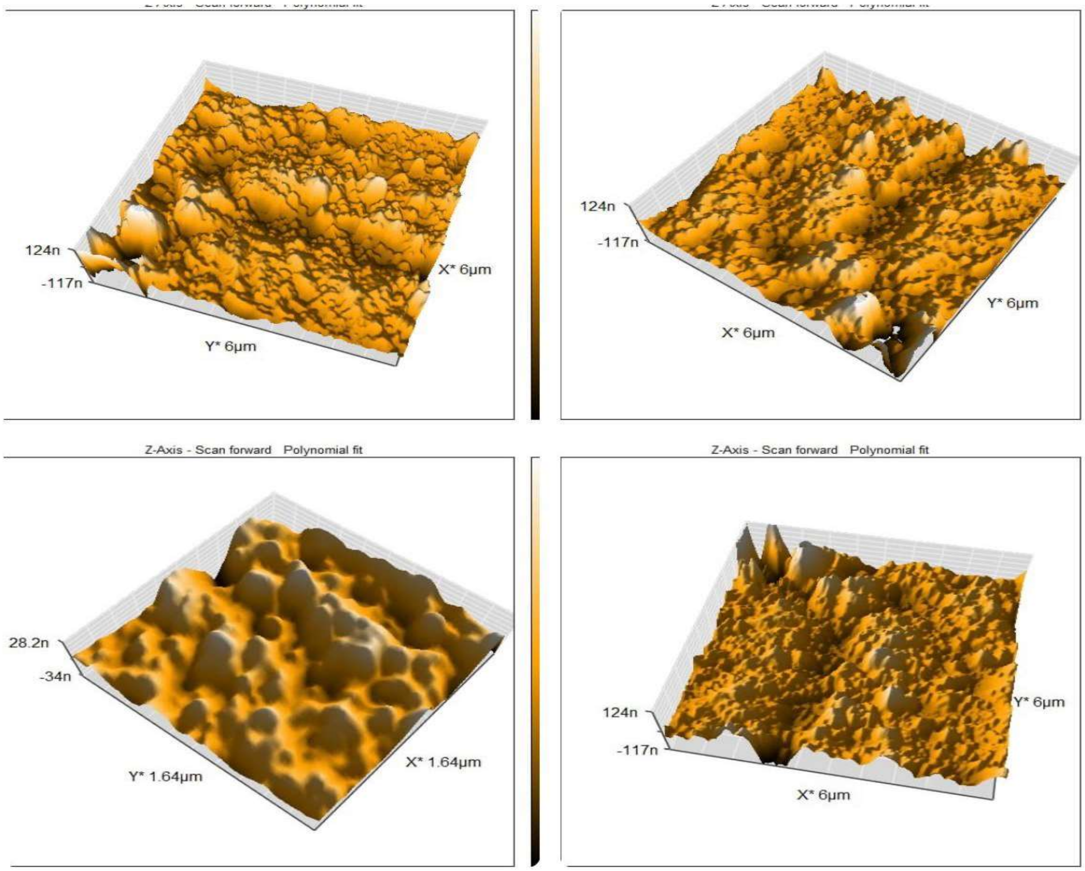


Figure (7) AFM of the 410 stainless steel after electropolishing.

Figure (8) SEM of the 410 stainless steel :A) before electropolishing.

Figure (9)SEM of the 410 stainless steel after electropolishing,

4-Conclusion

1-The best temperature for electropolishing 410 stainless steel alloy is at room temperature
2-Surface roughness improves after electropolishing 410 stainless steel alloy at room temperature from 1.01µm to 0.45 µm.
3-AFM examination for 410 stainless steel specimen before electropolishing reads surface contained several hills and valleys, whilespecimen afterelectropolishingappeared much different with less spherical particles and smaller
4-Electropolishing for 410 stainless steel specimen improve corrosion resistance due to rich chromium layer observed on the surface especially at room temperature

5-Reference

1. Tranchida, G. (2020). Corrosion resistance of different stainless steel grades in food and beverage industry,Dottorato in IngegneriaCivile, Am bientale e deiMaterialipp 14.

2. Harvey, P. D. (1982). Engineering properties of steel. ASM international, pp (1-2).
3. Welton, T. (2008). Electrodeposition from Ionic Liquids. Edited by Frank Endres, Andrew P. Abbott, and Douglas R. MacFarlane ,pp.293.
4. Tyagi, P., Brent, D., Saunders, T., Goulet, T., Riso, C., Klein, K., & Moreno, F. G. (2020). Roughness reduction of additively manufactured steel by electropolishing. The International Journal of Advanced Manufacturing Technology, 106, 1337-1344.
5. Nazneen, F., Galvin, P., Arrigan, D. W., Thompson, M., Benvenuto, P., & Herzog, G. (2012). Electropolishing of medical-grade stainless steel in preparation for surface nano-texturing. Journal of Solid State Electrochemistry, 16, 1389-1397.
6. Kumar, K., Zindani, D., &Davim, J. P. (2018). Advanced machining and manufacturing processes. Springer ,pp.100.
7. Ajeel, S. A (2012)corrosion behavior of ellectropolishing 304 stainless steel in marine environment,Research and development in mechanical andproductionand metallurgical engineering ,joint publication of TU bergakademiefreiberg and iraqipartner universities – DAAD.
8. ASTM, 2016, "Standard Specification for Chromium and Chromium-NickelStainless Steel Plate, Sheet, and Strip for Pressure Vessels and for GeneralApplications," ASTM International, West Conshohocken, PA, Standard No.ASTM A240/A240M-16a.
9. Ajeel, S. A., Hanoon, M. M., & Mohamed, A. (2023). Effect of temperature on the corrosion rate of low carbon steel with nano dill plant as an inhibitor in industrial water. World Journal of Engineering, 20(5), 931-937.
10. PE, J. C. T., Tube, T., &Kerber, S. J. color tinted electropolishing surface ::what do they mean.
11. Chang, J. K., Lee, C. Y., Tzeng, Y. C., Lin, M. H., Ger, M. D., Kao, C. H., ... &Jian, S. Y. (2021). Electropolishing of Additive Manufactured 17-4 PH Stainless Steel Using Sulfuric Acid. International Journal of Electrochemical Science, 16(3), 21032.