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Improvement of the Corrosion Performance of 316L Stainless Steel Using Anodization Process

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Abstract. Corrosion prevention in biomaterials has become crucial particularly to overcome inflammation and allergic reactions caused by the biomaterials' implants towards the human body. When these metal implants contacted with fluidic environments such as bloodstream and tissue of the body, most of them became mutually highly antagonistic and subsequently promotes corrosion. An electrochemical anodizing approach was used to modify the surface of 316L stainless steel in this investigation. Stainless steel was subjected to voltages of 6 and 8 V for 5 and 10 minutes in these trials., and the distance between anode and cathode are 2 and 4 cm to form an oxide film. Analytical results demonstrated that after various anodization modifications, a dichromium trioxide (Cr_2O_3) oxide layer formed on the modified 316L BSS specimens. The effects of anodizing conditions (voltage, time and distance) on the roughness, thickness, and microhardness were studied. Finally, potentiodynamic polarization (PDP) tests were used to examine the corrosion behavior of a specimen. In a Ringer's solution, the amended 316L alloy demonstrated enhanced corrosion resistance.

Key words: 316L biomedical stainless steel; anodization; hardness; coating thickness; roughness and corrosion ate.

INTRODUCTION

Surgical tools, orthopedic implants, fixtures, orthodontics, and pharmaceutical equipment are all made of austenitic stainless steel, which is one of the most extensively used alloys in biomedical applications. Stainless steel's widespread use is due to its low cost, simplicity of manufacture, biocompatibility, appropriate mechanical strength, and corrosion resistance qualities.[1].

Stainless steel also has a proclivity for localized corrosion, which limits its structural uses, notably in the biomedical field, were corrosion accounts for 24 percent of implant failures. [2]. Stainless steel's long-term stability and enhanced biocompatibility remain a concern, and solutions to these issues are continuously being researched. To solve these challenges with stainless steel, many procedures have been used, including the application of coatings, surface modification, laser surface treatment, and grain refining. [3،4].

Electrochemical techniques of anodization include advantages such as cost effectiveness and environmental friendliness. [5]. Electrochemical anodic oxidation has been reported to generate nano-structural oxide layers on the surfaces of metals and various alloys, including titanium, aluminum, tantalum, and their alloys. [6]. The creation of a

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persistent oxide layer on metallic surface materials may also serve as a barrier to prevent metal ions from being released. [7].

Following the preparation of the anodization process and the supply of electricity, oxygen is created, and an oxide coating is formed on the metal substrate as a result of the oxygen generation [8]. By modifying the electrolyte, voltage, time, stirring speed, and temperature, the size and form of the nanostructures on the oxide layer created during the anodization process may be adjusted. [9].

In fact, anodization has been used to improve corrosion resistance in several research. Cere SM. [10] Anodizing treatment and bio ceramic particles were used to study dual-surface modification onto titanium alloy for upgrading prosthetic devices. Even after 30 days of immersion, the bare metal is protected from harsh fluids, allowing for the dissolution of bioactive particles without and with Sr, as well as the deposition of phosphate-related compounds. Peng PW. [11] An electrochemical anodizing process was used to modify the surface of 316L biomedical stainless steel. However, following several anodization modifications, the oxide layer of dichromium trioxide (Cr_2O_3) was discovered on the modified 316L specimens. On the surface of the modified 316L BSS specimens, a dual porous (micro/nano porous) morphology can also be found. The anodized oxide layer's microstructure was made up of amorphous austenite and nano-Cr_2O_3. K. Turalıo˘glua. [12] investigated the corrosion resistance of the anodic oxidized specimens were higher compared to untreated 316L and layered Ti6Al4V/316L substrates, and the best results were obtained from the anodized specimen treated for 60 min.

Therefore, the main purpose of this study is to reduce the corrosion rate of surgical equipment made of 316Lss stainless steel by anodizing process, which works to form a dense, thick and highly adhesive layer of chromium oxide Cr_2O_3

EXPERIMENTAL WORK

To investigate the effects of anodic factors such as voltage, duration, and distance on anodic oxide film, a series of experiments on 316L SS alloy were conducted in a modified anodic polarization medium with 3 ml sulfuric acid and 3 ml nitric acid solution dilute in 250 ml distilled water.

Anode material

In this study, the workpiece was made of 316L stainless steel. Table 1 shows the chemical composition of this alloy. For the anodizing test, 15mm diameter and 3mm height specimens were manufactured. The workpiece was placed as a positive polarity during the anodizing process.

Table 1: Chemical Composition of the Alloy used in this Research

Material	Cr	Ni	Mo	Mn	Cu	Si	C	Fe
% Weight	17	10.36	2.37	1.36	0.185	0.813	0.03	Bal.

Cathode material

The anodizing procedure was used to form an oxide layer on the workpiece's exterior face. As an electrode, a piece of 20mm in length and 10mm in breadth was employed. The cathode was constructed of silver and had a purity of 99.9%. It was negative polarity.

Mensuration of oxide film properties

Discussions relay to evaluating the assets of an anodizing process, for example: coating thickness, surface roughness and corrosion rate stay obtainable in the following sub-sections.

coating thickness.

The thickness measuring device (TT260) was used to measure the thickness of Cr_2O_3 thin film.

Surface roughness estimation

The new anodized paradigm's surface roughness was assessed under a variety of anodizing settings. This test was completed using a demanding surface roughness tester (TR210). To determine the Ra, the sensor scans the surface and compares peaks and valise. The surface roughness value was obtained after each evaluation, and the sample was gently repositioned for subsequent reading. In this experiment, the average of three readings was obtained.

Corrosion Tests

Corrosion experiments on anodized 316l alloy were performed. The solution of Ringer was employed. The solution was deaerated and kept at 37^0degree. The -Auto Lab computer controlled potentiate was used to collect cyclic polarization information in form of potential vs. logarithmic current density graphs in the region of -250 to 250 mV. The potentials of the electrodes were compared to a saturated calomel reference electrode.

The levels of anodizing parameters

The anodic parameters chosen (voltage, duration, and distance) were changed up to two levels. Table 2 lists the anodic variables and their levels.

Table 2: The levels of anodizing parameters

Factors	Unit	Stages
voltage	volt	8
time	min	10
distance	cm	4

RESULTS AND DISCUSSIONS

Film Composition and Coating Morphology

Figure 1 shows optical microscope of surface microstructure of anodized 316l at different distance, voltage and time. The surface is made up of porous that appear at higher magnification of 400X. There are numerous pores visible in the optical microscope of the samples anodized at 2cm. Because of the microstructures of these samples, there are relatively large pores, and the grain size distribution is not uniform. The porosity quantity is larger and the pores are spherical in optical micrographs of the samples anodized at 4cm, resulting in a significant improvement in mechanical characteristics such as micro hardness. The anodizing process of this group of samples is acceptable in terms of the geometry of the pores and high porosity, according to the optical micrograph of this group of samples. Figure 2 presents XRD spectra of anodized sample at 6 V for 5 minutes at modified voltage The usual reflection peaks of the austenite (γ) phase were clearly seen in the anodized sample. On the anodized sample, however, the reflection peaks corresponding to chromium oxide Cr_2O_3 were discovered.

Thickness result

Figure 3 shows the graph that depicts the thickness as a function of anodization parameters: voltage, distance and time. The oxide film thickness increased with increase in anodization voltage. As the anodization voltage increased from 6 to 8 volt, the thickness increased from 66.1 to 69.1 µm. Similar increase in the thickness was observed in case of samples anodized in 2 and 4cm with respect to anodization voltage and time (8V,5min), where the thickness increased from 68.5 to 69.1 µm. It was also observed that decrease in the thickness from 69.1 to 64.6 µm when the time increase from 5 to 10min.

Surface roughness result

In this study, the sample's Ra value decreased from 0.146 to 0.102 µm at the different voltage. Fig. 3 shows the samples surface roughness after the anodizing with various time and distance. The Ra value decreased from 0.461 to 0.102 µm by the change of distance from 2 to 4 cm, but it slightly increases into 0.812 µm in the using of 5 and 10 min. Figure (4) shows plot of the main effect of the three controllable parameters on Ra. It is understandable that two of the variables (voltage and time) have more influence impacts on Ra. Ra intensifications with time increasing, in further words, the increase in time causes the increase in Ra, and the oxidation of the surface of the sample more intensely. Among the anodic oxidation groups, the surface roughness (Ra) of the voltage group treated at 6 and 8 V was the lowest.

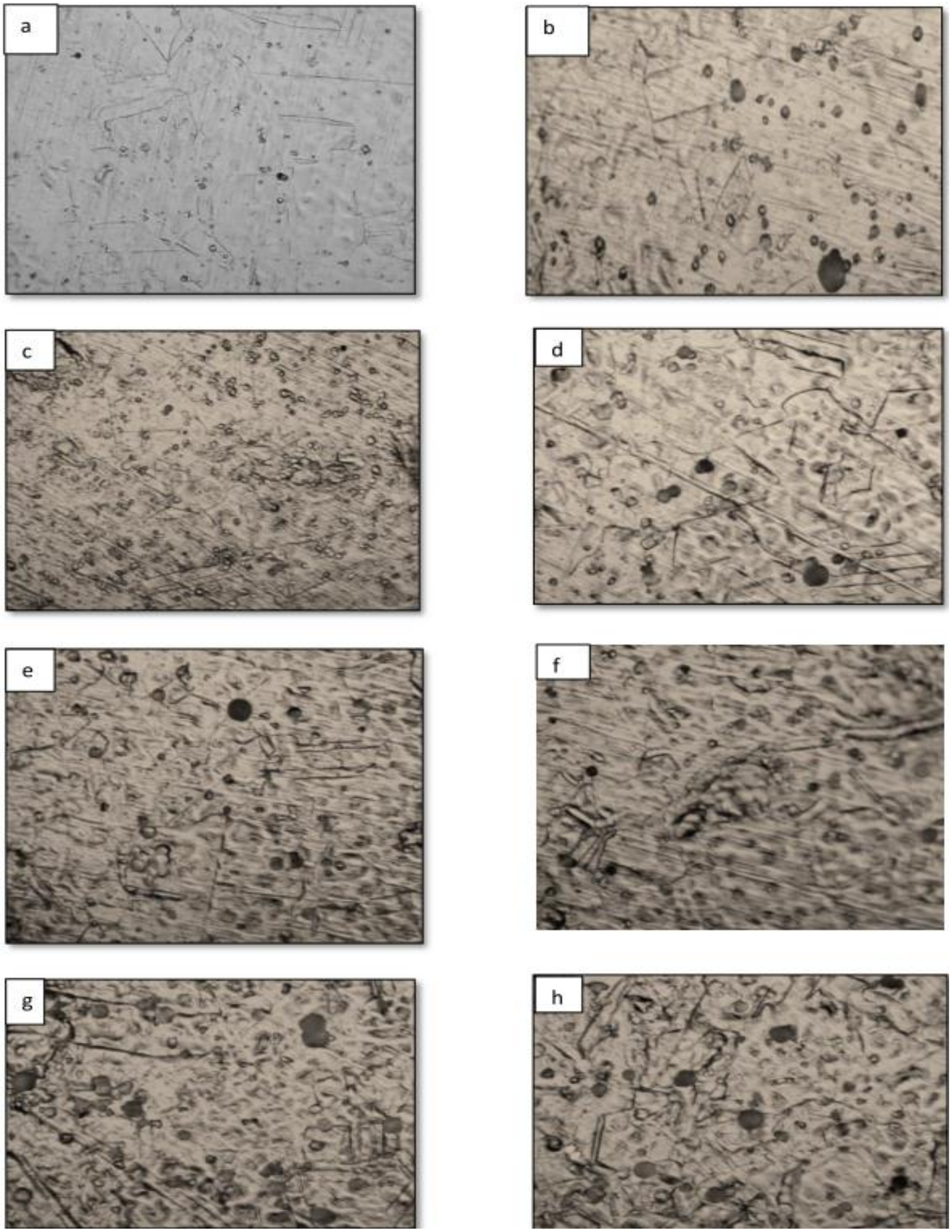

FIGURE 1: OM morphology of an anodize 316l alloy surface (at 2 cm a: 6 V,5min, b: 6 V,10 min, c: 8 V,5min, d: 8 V,10min), (at 4 cm a: 6 V,5min, b: 6 V,10 min, c: 8 V,5min, d: 8 V,10min)

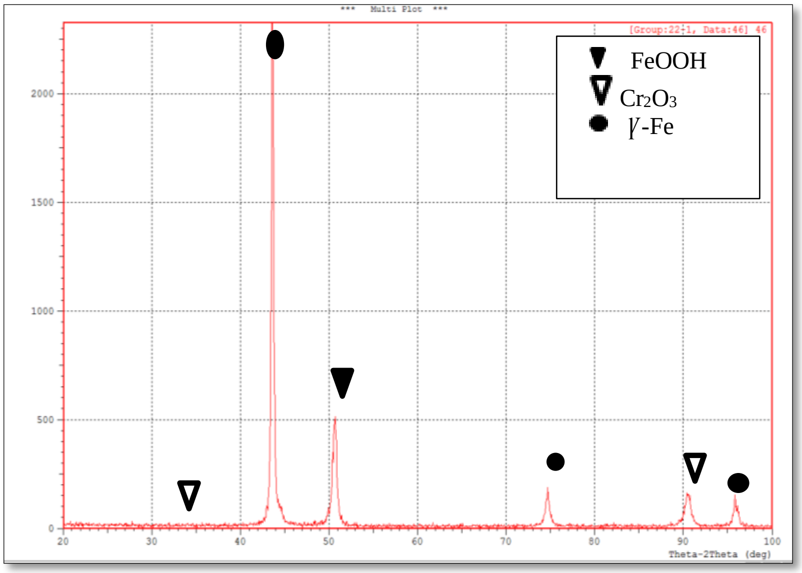

FIGURE 2: X-ray diffraction pattern of anodized sample at 6v, 5min

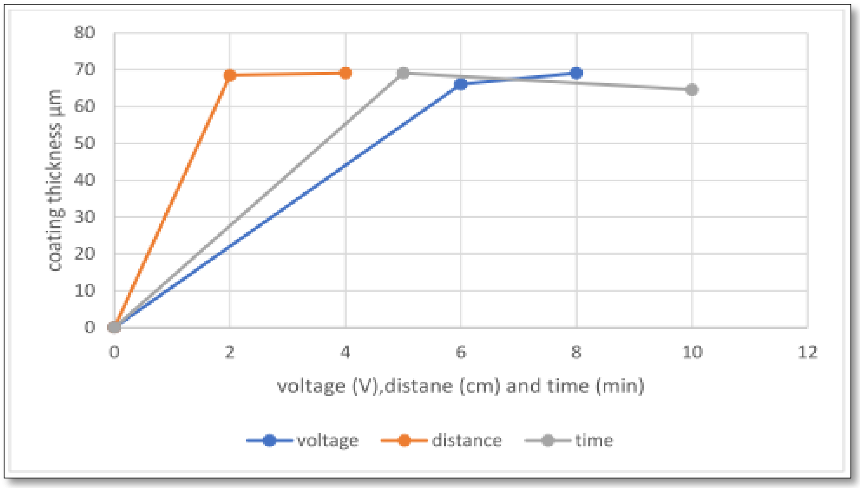

FIGURE 3: coating thickness vs. voltage, distance and time.

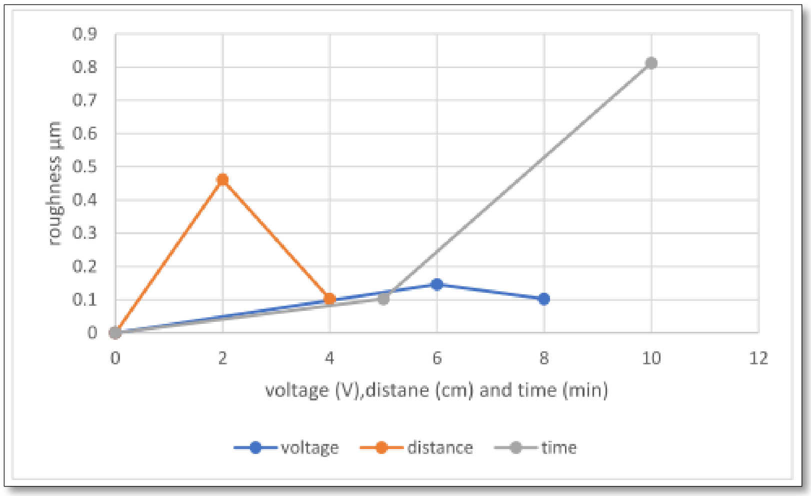

FIGURE (4): surface roughness vs. voltage, distance and time

Corrosion Behavior

Polarization Tests

In bodily fluid, any metal selected if used as a biomaterial should be resistant to pitting and crevice corrosion. linear polarization studies in Ringer's solution at 37 °C can be used to determine this Fig. (5) At 2 cm, shows the anodized 316L had the highest corrosion rate. (6 volt,5min) followed by the 316l alloy. The lowest rate of corrosion was obtained for the anodized sample at (8-volt, 5 min). In similar surface treatments, protective coatings generated on the surface of the 316L greatly enhanced i_{corr} and E_{corr}. The pace at which samples corrode at 4 cm as shown in Fig. (6) shows that the maximum corrosion rate was detected for the anodized 316L (8-volt,10 min) followed by the anodized 316l (6-volt,10 min) alloy. For the anodized sample, the lowest corrosion rate was reported at (8-volt, 5 min). E_{corr} was improved by anodizing, which had a comparable effect.

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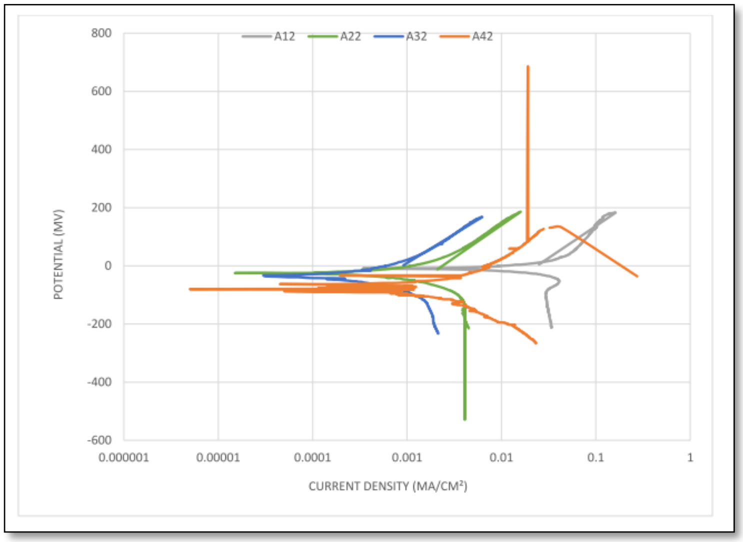

FIGURE (5): Potentiodynamic Polarization for 316l Alloy in Ringer's Solution at 2 cm

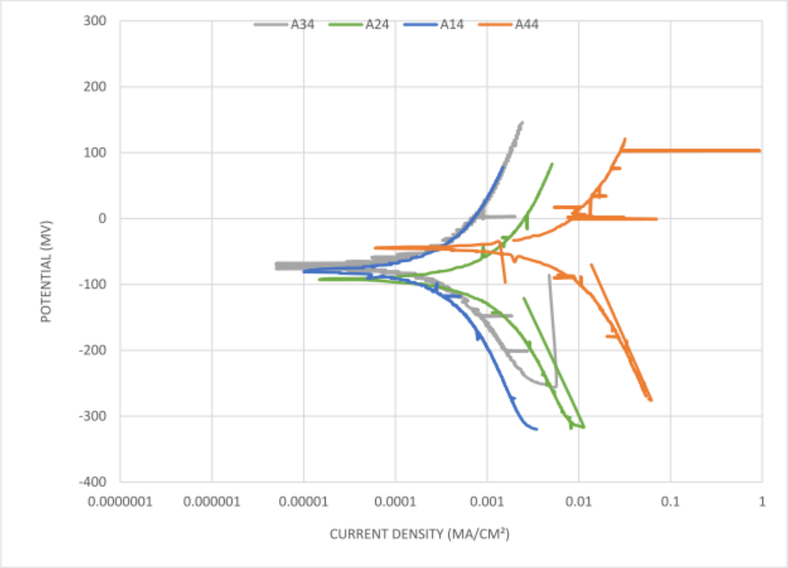

FIGURE (6): Potentiodynamic Polarization for 316l Alloy in Ringer's Solution at 4 cm

CONCLUSIONS

The stainless steel is one of the most important alloys which can be used many applications. The stainless steel has outstanding characteristics such as low cost, simplicity of manufacture, biocompatibility, appropriate mechanical strength, and corrosion resistance qualities. However, the localized corrosion is main challenge. The anodization process has been used to improve corrosion resistance. This work is efficiently undertaken anodization method to enhance the corrosion resistance by production of an anodic oxide layer on 316L SS. The sulfuric acid and nitric acid used as acidic electrolyte. The obtained results indicated the effect of anodic factors such as voltages, times, and distances on anodic oxide film. The surface roughness increases with time increased. When increase time of anodic process the thickness coating decreased. It can be said this study open the gate for promising study and further investigate to find out new data by applying different factors in term of additives materials.

REFERENCES

1. Walczak, J., Shahgaldi, F., & Heatley, F. (1998). In vivo corrosion of 316L stainless-steel hip implants: morphology and elemental compositions of corrosion products. *Biomaterials*, *19*(1-3), 229-237.
2. Sailer, I., Philipp, A., Zembic, A., Pjetursson, B. E., Hämmerle, C. H., & Zwahlen, M. (2009). A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. *Clinical oral implants research*, *20*, 4-31.
3. Eric Jones, J., Chen, M., & Yu, Q. (2014). Corrosion resistance improvement for 316L stainless steel coronary artery stents by trimethylsilane plasma nanocoatings. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, *102*(7), 1363-1374.
4. Zhang, K., Zou, J., Grosdidier, T., Dong, C., & Yang, D. (2006). Improved pitting corrosion resistance of AISI 316L stainless steel treated by high current pulsed electron beam. *Surface and Coatings Technology*, *201*(3-4), 1393-1400.
5. Xu, Q. F., Wang, J. N., & Sanderson, K. D. (2010). A general approach for superhydrophobic coating with strong adhesion strength. *Journal of Materials Chemistry*, *20*(28), 5961-5966.

6. Chung, S. H., Son, S. J., & Min, J. (2010). The nanostructure effect on the adhesion and growth rates of epithelial cells with well-defined nanoporous alumina substrates. *Nanotechnology*, *21*(12), 125104.
7. Díaz, M., Sevilla, P., Galán, A. M., Escolar, G., Engel, E., & Gil, F. J. (2008). Evaluation of ion release, cytotoxicity, and platelet adhesion of electrochemical anodized 316 L stainless steel cardiovascular stents. *Journal of Biomedical Materials Research Part B: Applied Biomaterials: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials*, *87*(2), 555-561.
8. Nosonovsky, M., & Bhushan, B. (2007). Biomimetic superhydrophobic surfaces: multiscale approach. *Nano letters*, *7*(9), 2633-2637.
9. Chen, Y., Zhang, Y., Shi, L., Li, J., Xin, Y., Yang, T., & Guo, Z. (2012). Transparent superhydrophobic/superhydrophilic coatings for self-cleaning and anti-fogging. *Applied Physics Letters*, *101*(3), 033701.
10. Galdos, G., Pastore, J. I., Ballarre, J., & Cere, S. M. (2017). Dual-surface modification of titanium alloy with anodizing treatment and bioceramic particles for enhancing prosthetic devices. *Journal of Materials Science*, *52*(15), 9151-9165.
11. Hsu, H. J., Wu, C. Y., Huang, B. H., Tsai, C. H., Saito, T., Ou, K. L., ... & Peng, P. W. (2020). Surface characteristics and cell adhesion behaviors of the anodized biomedical stainless steel. *Applied Sciences*, *10*(18), 6275.
12. Turalıoğlu, K., Taftalı, M., Tekdir, H., Çomaklı, O., Yazıcı, M., Yetim, T., & Yetim, A. F. (2021). The tribological and corrosion properties of anodized Ti6Al4V/316L bimetallic structures manufactured by additive manufacturing. *Surface and Coatings Technology*, *405*, 126635.