R. Yamanoglu¹, E. Fazakas², F. Ahnia³, D. Alontseva⁴, F. Khoshnaw^{5*}

¹ *Metallurgical and Materials Engineering, Kocaeli University, Kocaeli, Turkey*

² *Semilab Semiconductor Physics Laboratory Co. Ltd., Budapest, Hungary*

³ *Department of Mechanical Engineering, Faculty of Technology, University A/Mira Bejaia, Algeria*

⁴ *School of Information Technologies and Intelligent Systems, D. Serikbayev East Kazakhstan Technical University, Kazakhstan*

⁵ *School of Engineering and Sustainable Development, De Montfort University, LE1 9BH, Leicester, United Kingdom*

* *fuad.hassankhoshnaw@dmu.ac.uk*

PITTING CORROSION BEHAVIOUR OF AUSTENITIC STAINLESS-STEEL COATED ON Ti6Al4V ALLOY IN CHLORIDE SOLUTIONS

ABSTRACT

This study aims to investigate the influence of adding a coating layer of austenitic stainless steel type 316L on Ti6Al4V alloy on corrosion behaviour. Samples of 316L, Ti6Al4V, and 316L on Ti6Al4V were prepared by hot-press sintering of their powders. The potentiodynamic polarization technique was used to characterize the corrosion behaviour of the samples in 0.9 and 3.5 wt. % NaCl concentrations. The corrosion potential (E_{corr}), current density (i_{corr}) and corrosion rate (CR) of the sintered samples were compared in this study. The results showed that 316L samples had the best corrosion resistance, although micropits were observed on the surface, while Ti6Al4V samples had the lowest. This corrosion behaviour of sintered 316L samples can be interrelated to the existence of a passive layer on stainless steel alloys that can be attacked by chloride ions and causing localized corrosion. In general, the CR values of Ti6Al4V samples coated by 316L were between the 316L and Ti6Al4V samples. The CR values of the samples, in 0.9 wt. % NaCl, did not show significant changes with increasing time, as the CR for 316L values were around 0.003 mm/year, while for Ti6Al4V the CR values changed noticeably from 0.018 mm/year of 0 hr, to 0.015 mm/year for 24 hours. However, the changes were less than that of Ti6Al4V. For 3.5 wt. % NaCl solution, although the same order of CR remained, i.e., the CR values of coated Ti6Al4V samples were between 316L (lowest) and Ti6Al4V (highest), the overall CR values for the samples were higher than 0.9 wt. % NaCl.

Keywords: *Corrosion rate, powder technology, coating, 316L, Ti6Al4V*

INTRODUCTION

Titanium alloys are widely used in different applications such as automotive, defence, aerospace, and oil and gas industries. This wide usage is attributed to their high fatigue strength, low density, and high corrosion resistance [1-4]. In the last two decades, among titanium alloys, type Ti6Al4V (grade 5) in particular, has widely been used in the biomedical field. The main two reasons which have attracted the researchers and manufacturers to use

this type of Ti alloy are their biocompatibility with human tissue and having a modulus of elasticity that is close to that of bones. Thus, the alloy has been used for orthopedics, bone implant, hip prosthesis, dental implants, surgical screws [5-8].

Although Ti6Al4V has become popular, however, the low wear resistance makes its use limited [9, 10]. Many researchers have attempted to solve this problem by applying various surface treatments and coating processes to increase surface wear resistance [11-14]. Gao *et al.* [11] showed that a biofunctional magnesium coating, deposited on porous Ti6Al4V scaffold, can improve adhesion, extracellular matrix (ECM) mineralization compared with bare Ti6Al4V. Jemat *et al.* [12] investigated the effect of the adequate roughness role of Ti alloys in providing a surface for bone-implant contact and cell proliferation. The results showed a significant role of surface roughness despite the mechanical properties of the alloys. Hou *et al.* [13] deposited nano-TiC particles on Ti6Al4V by vacuum hot-press sintering (HPS) and hot extrusion. To improve the mechanical properties of Ti6Al4V, they found that the TiC coating improves tensile strength. Luan J.H., *et al.* [14] investigated the effects of boron (B) and yttrium (Y) on the mechanical properties and oxidation behaviour of cast Ti-6Al-4V alloys. The results indicated that boron is beneficial for improving the ductility by not only grain-size refinement but also grain-boundary enhancement. At the same time, yttrium is effective in increasing the oxidation resistance. Together with their high strength, these improved properties have made a microalloyed cast Ti-6Al-4V alloys competitive for practical engineering applications.

On the other hand, austenitic stainless steel type 316L alloy provides better wear resistance than Ti6Al4V[15-17]. Brończyk *et al.* [15] worked on the tribo-corrosion behaviour of Ti6Al4V, and AISI 316L simulated in normal and inflammatory conditions. The results showed that 316L has a lower tribo-corrosion wear rate than the Ti6Al4V alloy. Therefore they recommended using 316L stainless steel alloy as an implant. In the context of joint and bone replacement which mainly depends on the stability of the mechanical fixation, Mahesh M. Sonekaret *et al.* [16] made a comparative study on the tribological behaviour between 316L and Ti6Al4V using a wear test under different loads. The results showed better friction behaviour of AISI 316L steel. The author, Yamanoğlu *et al.* [17], studied the wear behaviour of coated 316L on Ti6Al4V powder, using a uniaxial hot press. The results showed that coating of 316L on Ti alloy reduced the wear rate of the powder alloy. In terms of the biocompatibility tests of coating austenitic stainless-steel alloy on Ti alloys, recent investigations [18,19] show that there is a relationship between pitting corrosion resistance and microbiologically induced corrosion (MIC), based on the similarities of the localized corrosion of MIC in nature, which is the phenomena of pitting and crevice corrosion. The previous paper of the author [17] indicates that the coated Ti6Al4V with 316L powder alloy, were tested in a bacterial environment of *E. coli* and *S. aureus* bacteria, and the results showed good antibacterial properties, no bacteria observed on the surface of 316L.

Ibragim *et al.* [20] used a potentiodynamic polarization technique complemented with XRD and SEM measurements to study the corrosion behaviour of some austenitic stainless steels in 2.5 M NaCl. The electrochemical parameters E_{corr} , j_{corr} and E_{pit} were used to compare the corrosion resistance of the tested samples. The results showed that an increase in either NaCl concentration or solution temperature decreases the corrosion resistance. While the increase in Mo or Cr content in the alloys of the stainless steels improves their corrosion resistance [21]. Fossati *et al.* [22] showed that the nitriding process on austenitic stainless-steel alloys does not support pitting corrosion resistance due to the microcavities produce during nitriding coating. Yang and Luo [23] investigated the effect of hydrogen - which was introduced cathodically to the samples through applying a constant current density - and the applied stress on austenitic stainless steel in chloride solution. The results showed that

hydrogen significantly decreases the critical chloride concentration for the breakdown of passive films, which indicates that hydrogen promotes the breakdown of passive films. Also, with an increase in the tensile stress, the critical chloride concentration decreased.

Although the above researches showed different attempts to treat the surface of Ti alloys with different coating techniques as biomaterial applications, at the same time some approaches indicate the existence of relationships between biocompatibility and corrosion behaviour. For example, there are as yet unconfirmed approaches indicating an interconnection between microbiologically induced corrosion (MIC) and pitting corrosion behaviour. Therefore, to fill such gaps, this research aims to study the electrochemical polarization behaviour of coated Ti6Al4V alloy by 316L using powder metallurgy.

MATERIALS AND EXPERIMENTAL WORKS

The preliminary materials used in this study were powders of hydride-dehydride HDH Ti6Al4V powders (Table 1) and water atomized stainless steel powders type AISI 316L (Table 2). The chemical composition of AISI 316L stainless steel (UNS S31603) is outlined in Table 3

Table 1. Chemical composition of Ti6Al4V powders (wt. %)

Al	V	Si	Fe	Ti
6.2	4.14	0.02	0.14	balance

Table 2. Chemical composition of stainless steel powders type AISI 316L (wt. % of element)

Cr	Ni	Mo	Mn	Si	C	Fe
17.6	13.6	2.9	2.0	1.	0.03	balance

Table 3. Chemical composition of AISI 316L stainless steel (wt. % of element, UNS S31603)

Cr	Ni	Mo	Mn	Si	C	N	P	S	Fe
16.0 – 18.0	10.0-14.0	2.0 – 3.0	≤ 2.0	≤ 1.0	≤ 0.03	0. 11	0.045	0.03	balance

Scanning electron microscopy (SEM) by JSM6060 (JEOL, Japan) and energy dispersive spectroscopy analysis by INCA Energy (Oxford Instruments, United Kingdom) were used to investigate the microstructural morphology and elemental composition of the electrochemical tested surfaces. SEM images of the powders are given in Figure 1.

Fig. 1. SEM images of the powders, a. Ti6Al4V, b. 316L

A hot-press sintering technique was used in this study to prepare the samples. Stainless steel powders type AISI 316L was placed (coated), with 250 μm thickness, on titanium alloy powders, type Ti6Al4V in a graphite die and, in-situ, sintered by uniaxial hot pressing, besides, each alloy, Ti and 316L, was prepared individually. A schematic illustration of the hot press process is shown in Figure 2. The sintering process was carried out at two different temperatures, 950 and 1050°C, vacuumed at 10^{-4} mbar, for 30 minutes, under 50 MPa pressure.

Fig. 2. Schematic of in-situ coating process by hot press

The samples' electrochemical characterization and corrosion behaviour were studied using the potentiodynamic polarization as a function of time, in a chloride solution with two concentrations of 0.9 and 3.5 wt. % of NaCl at 25 °C, which is similar to the human body environment [18-21]. The electrochemical tests were performed using a model Bio-Logic SP-150 potentiostat measuring instrument. The experimental set-up was included an electrochemical cell with three electrodes: a platinum counter electrode, a saturated calomel electrode SCE/Hg/Hg₂Cl₂ as a reference electrode and preparation working electrodes, which were used in the prepared samples. The working electrodes were prepared for the electric contact made by AP wire glue. Where the copper wire was glued to the sample, the surface was masked with lacquer, and only the working part of the sample remained uncoated. The exposed surface area varied from 2 cm² to 6 cm².

Before starting the electrochemical tests, to remove dust and dirt, the samples were placed in an ultrasound device, cleaned using acetone and distilled water, and dried. Then, the samples were introduced in two different aerated electrolytic solutions, freshly prepared from analytical grade chemicals of NaCl and distilled water, immersed at different times 0, 0.5, 1, 3, 5 and 24 h.

The evaluation of the corrosion potential as a function of the immersion time was measured at a scan rate of 1.5 mV/s. The potentiodynamic polarization curves were recorded by a potential sweep from -250 to + 250 mV.

RESULTS

Figure 3 shows the potentiodynamic polarization curves as a function of time, at different concentrations of aerated two NaCl concentrations and pH values, at 25°C.

Fig.3. Potentiodynamic polarization curves in NaCl solutions, a) 316L in 0.9 %, b) 316L in 3.5 %, c) Ti6Al4V in 0.9 %, d) Ti6Al4V in 3.5 %, e) Ti6Al4V coated by 316L in 0.9 %, f) Ti6Al4V coated by 316L in 3.5 %

Figures 3a and b show the potentiodynamic polarization of 316L as a function of time immersed in two aerated NaCl solutions of 0.9 and 3.5 wt. %, respectively. The figures show that the corrosion potentials were shifted to the negative (anodic) side up to 5h for 0.9% and up to 1h for 3.5%, and then tended to more positive values for the remainder of the immersion time. This displacement was clearer in the 3.5% solution since one passes from -0.4V to -0.8V, while for 0.9% solution, the displacement did not exceed -0.6V.

Figures 3c and d show the potentiodynamic polarization curves of the titanium alloy Ti6Al4V as a function of the immersion time in both NaCl solutions 0.9 and 3.5%, respectively. The potential of corrosion in both solutions increases over time, i.e., becomes more cathodic, i.e. noble, of the equilibrium potential with immersion time.

Figures 3e and f show the curves of the potentiodynamic polarization of the coated 316L as a function of the immersion time of 0.9 and 3.5 % of NaCl solutions, respectively. The corrosion potentials of these curves indicate intermediate values between 316L and Ti6Al4V alloy.

Tables 4 and 5 show the electrochemical parameter values of corrosion current density (i_{corr}), corrosion potential (E_{corr}) and corrosion rate (CR).

Table 4. Electrochemical parameters were obtained by Tafel for 316L, Ti6Al4V and 316L /Ti6Al4V in a solution of 0.9 % NaCl, pH 6.3

Immersion Time (h)	i_{corr} ($\mu\text{A}/\text{cm}^2$)			E_{corr} (V)			CR (mm/y)		
	316L	Ti64	316L /Ti64	316L	Ti64	316L /Ti64	316L	Ti64	316L /Ti64
0	-0.265	-1.089	-0.811	-0.408	-0.256	-0.22	0.003	0.018	0.013
0.5	-0.286	-1.08	-0.668	-0.518	-0.229	-0.294	0.003	0.017	0.011
1	-0.295	-1.100	-0.613	-0.553	-0.205	-0.332	0.003	0.018	0.01
3	-0.300	-1.054	-0.634	-0.58	-0.172	-0.332	0.0032	0.017	0.01
5	-0.302	-1.024	-0.618	-0.59	-0.156	-0.346	0.0032	0.0166	0.01
24	-0.293	-0.932	-0.671	-0.539	-0.128	-0.347	0.003	0.015	0.011

Table 5. Electrochemical parameters were obtained by Tafel for 316L, Ti6Al4V and 316L/Ti6Al4V in a solution of 3.5 wt. % NaCl, pH 6.3

Immersion Time (h)	i_{corr} ($\mu\text{A}/\text{cm}^2$)			E_{corr} (V)			CR (mm/y)		
	316L	Ti64	316L /Ti64	316L	Ti64	316L /Ti64	316L	Ti64	316L /Ti64
0	-0.238	-1.915	-1.171	-0.427	-0.136	-0.317	0.005	0.031	0.019
0.5	-0.226	-1.713	-1.109	-0.741	-0.116	-0.405	0.005	0.028	0.018
1	-0.224	-1.594	-1.062	-0.762	-0.087	-0.412	0.005	0.026	0.017
3	-0.380	-1.487	-1.029	-0.589	-0.07	-0.406	0.008	0.024	0.017
5	-0.370	-1.401	-1.034	-0.600	-0.06	-0.415	0.008	0.023	0.017
24	-0.200	-1.375	-0.951	-0.714	-0.05	-0.450	0.004	0.022	0.015

DISCUSSION

316L Alloy

Table 4 shows that the current density, i_{corr} , of 316L in 0.9% was decreased from 0 to 5h then increased at 24h. This result can be explained by the high degree of surface corrosion at the beginning of contact with the solution. Table 5 shows that the i_{corr} values of 3.5% solution decreased from 0 to 1h, increased at 3h, and then continued to decrease until 24h. Meanwhile, a significant passivation rate is observed in the 3.5 wt. % NaCl solution during the periods of 30 min, 1h and 24 h. This can be attributed to the formation of the oxide protective layer [20,21], then reduced the times, 3 and 5h due to breakage of the passive film, as a result of the deterioration and dissolution [22-25] due to localized attack by adsorption of ion Cl^- [26-28].

Table 5 shows that the electrochemical behaviour of the 316L samples was stable with increasing the time of immersion. However, an increase was observed for the CR in the 3.5% solution at times 30 and 5 hours, $CR = 0.008$ mm/year, which was also remained insignificant until 24 hours, when reached $CR = 0.004$ mm/year. These results are similar to what other researchers have found [20,21]. Table 4 shows the CR value of 316L in 0.9 % solution was lower than that of 3.5 % solution, as the resistance to corrosion decreases with the increase of concentration of NaCl [20].

Ti6Al4V Titanium alloy

The anodic parts of both curves showed the presence of a pseudo-passivation stage with the presence of fluctuations due to the propagation of the Cl^- ion, which corresponds to the breakdown of passivation at the potential of 0 V for immersed samples in a 3.5% solution and -0.3 V for immersed samples in 0.9 %. Figures 3c and d show extrapolation of certain Ti6Al4V electrochemical parameters. Tables 4 and 5 show that the corrosion potential ($E_{corr.}$) of Ti6Al4V in both solutions increased with increasing immersion time. This can be attributed to the passivation layer formation [29, 30]. Moreover, the values of i_{corr} in all samples were increased with increasing immersion time in both NaCl solutions. This reflects the occurrence of dissolution and release of metal ions in the long term in the clinical failure of orthopedic or dental implants [29, 30]. Tables 4 and 5 show that the CR values of Ti6Al4V slightly decreased with increasing the immersion time in both NaCl solutions. The CR of Ti6Al4V in 0.9 % solution was lower than those of 3.5% solution.

Coating 316L on Ti6Al4V

Based on the data in Table 4 and Figure 3, the $i_{corr.}$ of the coated 316L samples in 0.9% of NaCl solution were increased from 0 to 1h, then decreased from 3 to 24h, while the $E_{corr.}$ was decreased with time while become more anodic due to the continuous dissolution. Table 5 shows that for coated 316L samples, the $E_{corr.}$ values in 3.5% NaCl solution decreased from 0 to 1 h, increased at 3 h and continued to decrease to 24 h, while the i_{corr} values increased with increasing immersion time due to dissolution of the passive film. Overall, Tables 4 and 5 show that the 316L samples had the lowest value of the CR followed by 316L coated with Ti6Al4V, then Ti6Al4V alloy. The very low values of the CR of 316L can be attributed to the passive layer, which acts as a barrier to protect the surface.

Characterization by SEM and EDS

Figures 4a and b show the surface morphology of 316L and Ti6Al4V samples respectively, which were immersed in 3.5 % solution for 24 h. Figure 4a shows the existence of micropores on 316L sample, also - due to the process of elaboration by HPS –micropits are shown. This is an indication of the localized corrosion attack by Cl^- ions, cause micropits on the surface. The qualitative analysis over a specific area of the surface, see Figure 4, indicates a significant amount of oxygen of 18 (at. %t) which confirms the oxidation of the surface of 316L in contact with the aggressive solution of 3.5 wt. %. In terms of Ti6Al4V, the existence of micropores was observed. However, there was no clear indication of corrosion types, e.g., micropits, on the surface after an immersion time of 24 hours. section of the coated sample,

Fig. 4. SEM Micrographs of surface samples after 24 h immersion time, a: 316L, b:Ti6Al4V

Figure 5 shows the bonded coating thickness of stainless steel on Ti6Al4V alloy, as in average equals 250 µm, which shows relatively high homogeneity of the stainless steel layer. This homogeneousness is an important property for the coated material because the interlayer between bonded materials is strongly affects the final properties of the materials. Thick coating materials and techniques are necessary for tribological and load bearing applications.

Fig. 5. Optical image of bonding of stainless steel as a coating layer on Ti6Al4V alloy

It should be noted that corrosive behaviour is one of the most important factors affecting the biocompatibility of metal implants because metal ions released during corrosion can cause various adverse effects, both in the tissues surrounding the implant, and allergic reactions. The corrosion rate influences the reaction of tissues, that is, the number of metal ions released [30]. Therefore, although the generally relatively corrosion resistance of the titanium alloy Ti6Al4V observed in our study, which is in good agreement with the results of Vora H.D. *et al.* [29], implantation may lead to an increase in the amount of titanium released in the tissue due to the influence of proteins, for example, albumin [31]. It should also be noted that, unlike 316L stainless steel, titanium alloy Ti6Al4V can easily osseointegrate during implantation, that is, promote bone formation in direct contact with a metal surface [32]. An essential role in the success of osseointegration is played by the oxide layer on the alloy surface, while thicker layers promote rapid osseointegration for titanium alloy Ti6Al4V [32, 33]. The oxide

layer also has the effect of passivating the metal, so that corrosion is inhibited and the release of titanium ions is minimized [12, 30, 33]. Therefore, for both materials of this study, stainless steel and titanium alloy, the formation of coatings on their surfaces may increase their biocompatibility. The study of their corrosion resistance plays an important role in determining the requirements for the materials and microstructure of such coatings.

CONCLUSIONS

Corrosion behaviour, through applying potentiodynamic tests, were investigated on stainless steel powders, were in situ coated on Ti6Al4V alloy, in two NaCl concentrations. The main conclusions are:

- The 316L samples showed higher corrosion resistance than coated and uncoated Ti6Al4V. However, micropits were observed on the surface.
- The 316L samples did not show a significant change with increased time in 0.9% NaCl, but the change was noticeable in 3.5% NaCl.
- The corrosion resistance of the coated Ti6Al4V by 316L has a lower corrosion resistance than 316L alloy.
- The Ti6Al4V samples showed the lowest corrosion resistance; however, a passivation region was observed.
- Increasing the concentration of NaCl caused an increase in the corrosion rate for all the samples.

ACKNOWLEDGMENTS

This is part of the Further Funded VC2020 project funded by De Montfort University - DMU, in the United Kingdom, to establish a research collaboration with Kocaeli University in Turkey. The research was supported by the Scientific Research Unit at Kocaeli University, also by Semilab Semiconductor Physics Laboratory Co. Ltd., in Hungary, University A/Mira Bejaia in Algeria and D. Serikbayev East Kazakhstan Technical University in Kazakhstan. The authors are grateful to DMU to support this research to build this research cooperation.

REFERENCES

1. Yamanoglu R., Khoshnaw F., Daoud I., Efendi E.: Effect of Silver Content on Wear and Mechanical Properties of Powder Metallurgical Ti-5Al-2.5Fe-xAg Alloys. *J. Min. Metall. Sect. B-Metall* 56 (1) (2020) 119-125.
2. Hou J., Chi F., Cui G., Chen W., Zhang W.: Strengthening effects of in-situ synthetic nano-TiC particles on Ti64 based nanocomposites through adding graphene nanoplatelets. *Vacuum* 177 (2020) 109-431.
3. Duraiselvam M., Valarmathi A., Shariff S.M., Padmanabham G.: Laser surface nitrided Ti-6Al-4V for lightweight automobile disk brake rotor application. *Wear* 309 (1-2) (2014) 269-274.

4. Huang G., Lu W., Li H., Sun X., Zhang D.: Reinforcements stimulated dynamic recrystallization behavior and tensile properties of extruded (TiB p TiC p La₂O₃)/Ti6Al4V composites. *J. Alloys Compd.* 699 (2017) 874-881.
5. Ataee A., Li Y., Wen C.: A comparative study on the nanoindentation behavior, wear resistance and in vitro biocompatibility of SLM manufactured CP-Ti and EBM manufactured Ti64 gyroids scaffolds. *Acta Biomater.* 97 (2019) 587-596.
6. Gepreel M. A-H., Niinomi M.: Biocompatibility of Ti alloys for long term implantation. *J. Mech. Behav. Biomed. Mater.* 20 (2013) 407-415.
7. Liu W, Liu S, Wang L. Surface Modification of Biomedical Titanium Alloy: Micromorphology, Microstructure Evolution and Biomedical Applications. *Coatings* 9 (4) (2019) 249-272.
8. Alontseva D. L., Abilev M. B., Zhilkashinova A. M., Voinarovych S. G., Kyslytsia O. N., Ghassemieh E., Russakova A., Łatka L.: Optimization of hydroxyapatite synthesis and microplasma spraying of porous coatings onto titanium implants. *Adv. Mater. Sci.* 18(3) (57) (2018) 79-94.
9. Tortuero S., Garrido M.A., Poza P., Rodríguez J.: Evaluating the erosion resistance of Ti6Al4V coatings deposited by cold spray. *Wear* 454-455 (2020) 203-337.
10. Yuana S., Lina N., Zoua J., Liud Z., Yue Y., Maa Y., Wanga Z., Zhaog B., Zengh Q., Tiana L., Qina L., Zhangb H., Wangc Z., Liua X., Tanga B., Wua Y.: Manipulation tribological behavior of Ti6Al4V alloy via a duplex treatment of double glow plasma surface molybdenizing-laser surface texturing (LST). *J Mater. Res. Technol.* 9 (3) (2020) 6360-6375.
11. Gao P., Fan B., Yu X., Liu W., Wu J., Shi L., Yang D., Tan L., Wan P., Hao Y., Li S., Hou W., Yang K., Lia X., Guo Z.: Biofunctional magnesium coated Ti6Al4V scaffold enhances osteogenesis and angiogenesis in vitro and in vivo for orthopaedic application. *Bioact. Mater.* 5 (2020) 680-693.
12. Jemat A., Ghazali M.J., Razali M., Otsuka Y.: Surface modifications and their effects on titanium dental implants. *BioMed. Res. Int.* 2015 (2015) 791-725.
13. Hou J., Chi F., Cui G., Chen W., Zhang W.: Strengthening effects of in-situ synthetic nano-TiC particles on Ti64 based nanocomposites through adding graphene nanoplatelets. *Vacuum* 177 (2020) 109-431.
14. Luan J.H., Jiao Z.B., Chen G., Liu C.T.: Improved ductility and oxidation resistance of cast Ti-6Al-4V alloys by microalloying. *J. Alloys Compd.* 602 (2014) 235-240.
15. Brończyk A., Kowalewski P., Samoraj M.: Tribocorrosion behaviour of Ti6Al4V and AISI 316L in simulated normal and inflammatory conditions. *Wear* 434-435 (2019) 202-966.
16. Sonekar M. M., Rathod W. S.: An experimental investigation on tribological behavior of bio-implant material (SS-316 l & Ti6Al4V) for orthopaedic applications. *Mater. Today-Proc.* 19 (2) (2019) 444-447.
17. Yamanoglu R., Khoshnaw F., Kolayli F., Uzuner H.: Antibacterial Properties of Stainless Steel Coated on Ti6Al4V Alloy. *Int. J. Mech.Prod. Eng.* 7 (9) (2019) 2321-2071.
18. Eliaz N.: Corrosion of Metallic Biomaterials: A Review. *Materials*, 12 (3) (2019) 407.
19. Obota I. B., Onyeachu I. B., Zeino A., and Umoren S. A.: Electrochemical noise (EN) technique: review of recent practical applications to corrosion electrochemistry research, *J. Adhes. Sci. Technol.*, 33, (13) (2019) 1453-1496.
20. Ibrahim M.A.M., Abd El Rehim S.S., Hamza M.M.: Corrosion behavior of some austenitic stainless steels in chloride environments. *Mater. Chem. Phys.* 115 (2009) 80-85.
21. Sedriks J.: Corrosion of Stainless Steels. J. Wiley & Sons 2nd [ed.], Inc, New York, 1996.

22. Fossati A., Borgioli F., Galvanetto E., Bacci T.: Corrosion resistance properties of glow-discharge nitrided AISI 316L austenitic stainless steel in NaCl solutions. *Corros. Sci* 48 (6) (2006) 1513-1527.
23. Yang Q., Luo J.L.: Effects of hydrogen and tensile stress on the breakdown of passive films on type 304 stainless steel. *Electrochim. Acta* 46 (6) (2001) 851-859.
24. Phanis S.V., Satpati A.K., Muthe K.P., Vyas J.C., Sundaresan R.I.: Comparison of rolled and heat treated SS304 in chloride solution using electrochemical and XPS techniques. *Corros. Sci.* 43 (11) (2003) 2467- 2483.
25. Ameer M.A., Fekry A.M., Heakal F.E.T.: Electrochemical behaviour of passive films on molybdenum-containing austenitic stainless steels in aqueous solutions. *Electrochim. Acta* 50 (1) (2004) 43-49.
26. El-egamy S.S., Badway W.A.: Passivity and passivity breakdown of 304 stainless steel in alkaline sodium sulphate solutions. *J. Appl. Electrochem.* 34 (11) (2004) 1153-1158.
27. Tsuchiya H., Fujimoto S., Chihara O., Shibata T.: Semi conductive behavior of passive films formed on pure Cr and Fe–Cr alloys in sulfuric acid solution. *Electrochimica Acta* 47 (2002) 4357-4366.
28. Hastuty S., Nishikata A., Tsuru T.: Pitting corrosion of type 430 stainless steel under chloride solution droplet. *Corros. Sci.* 52 (2010) 2035-2043.
29. Vora, H.D.; Rajamure R.S., Dahotre S.N., Ho, Y.-H., Banerjee R.; Dahotre N.B.: Integrated experimental and theoretical approach for corrosion and wear evaluation of laser surface nitrided, Ti–6Al–4V biomaterial in physiological solution. *J. Mech. Behav. Biomed. Mater.* 37 (2014) 153–164.
30. Nicholson J.W.: Titanium Alloys for Dental Implants: A Review. *Prosthesis* 2 (2020) 100–116.
31. Yu F., Addison O., Davenport A.: A synergistic effect of albumin and H₂O₂ accelerates corrosion of Ti6Al4V. *Acta Biomater.* 26 (2015) 355–365.
32. Apostu D., Lucaciu O., Lucaciu G.D.O., Crisan, B., Crisan L., Baciut M., Onisor F., Baciut G., Câmpian R.S., Bran S.: Systemic drugs that influence titanium implant osseointegration. *Drug Metab. Rev.* 49 (2017) 92–104.
33. John, A.A., Jaganathan S.K., Supriyanto E., Manikandan A.: Surface modification of titanium and its alloys for the enhancement of osseointegration in orthopaedics. *Curr. Sci.* 111 (2016) 1003–1015.