Salud, Ciencia y Tecnología - Serie de Conferencias. 2024; 3:914
doi: 10.56294/sctconf2024914

Category: STEM (Science, Technology, Engineering and Mathematics)

ORIGINAL

Investigation The Effect of Tellurium Addition on Corrosion Resistance of Ti6Al4V alloy

Investigación del efecto de la adición de telurio en la resistencia a la corrosión de la aleación Ti6Al4V

Haydar H.J. Jamal Al-Deen[1], Basmal H. Abdul Amir[1]

[1]Metallurgical Department, Material Engineering College, Babylon University. Babylon, Iraq.

Cite as: Jamal Al-Deen HH, Abdul Amir BH. Investigation The Effect of Tellurium Addition on Corrosion Resistance of Ti6Al4V alloy. Salud, Ciencia y Tecnología - Serie de Conferencias. 2024; 3:914. https://doi.org/10.56294/sctconf2024914

Submitted: 07-02-2024 **Revised:** 23-04-2024 **Accepted:** 11-06-2024 **Published:** 12-06-2024

Editor: Dr. William Castillo-González

Note: Paper presented at the 3rd Annual International Conference on Information & Sciences (AICIS'23).

ABSTRACT

The purpose of this study is to investigate the impact of Tellurium alloying element (0,5, 1, 1,5, 2, 2,5, 3, 3,5, 4, 4,5 and 5 wt%) on corrosion resistance of Ti6Al4V alloy in Hank and saliva solutions. All alloys have been prepared by powder metallurgy technique, the compact pressure was determined as 800MP and the green samples sintered at 350 C^0 for 1h then at 550 C^0 for 1h and at 1000 C^0 for 2 h in inert gas (of Argon), then the samples cooledin the furnace to room temperature. The microstructure was observed using a light optical microscope and has shownthat all specimens of alloys contain two regions: the α-Ti phase and the ß-Ti phase. Generally, compared with the base alloy, the addition of the Te element leads to an increase in the α-phase due to the effect of Te as the α stabilizer element. Electrochemical tests (potentiodynamic polarization and OCP - Time measurement) in Hank's and saliva solutions were used to evaluate corrosion resistance of Ti6Al4V alloy. When tellurium was added, the OCP shiftedto the positive direction. This makes the alloy more noble and increases its resistance to corrosion by decreasing corrosion current density. The percentage of improvement ranges from 2,50 % to 61,92 % in saliva solution and from 16,27 % to 88,32 % in Hank's solution. For both solutions, the best percentage of improvement is 5 % Te.

Keywords: Corrosion Resistance; Ti6Al4V; Tellurium; Hank and Saliva.

RESUMEN

El propósito de este estudio es investigar el impacto del elemento de aleación telurio (0,5, 1, 1,5 ,2 ,2,5 ,3, 3,5, 4, 4,5 y 5 % en peso) sobre la resistencia a la corrosión de la aleación Ti6Al4V en soluciones Hank y saliva. Todas las aleaciones se han preparado mediante la técnica pulvimetalúrgica, la presión de compactación se determinó en 800MP y las muestras verdes se sinterizaron a 350 C0 durante 1h, después a 550 C0 durante 1h y a 1000 C0 durante 2 h en gas inerte (de Argón), a continuación las muestras se enfriaron en el horno hasta temperatura ambiente. La microestructura se observó utilizando un microscopio óptico de luz y ha demostrado que todas las muestras de aleaciones contienen dos regiones: la fase α-Ti y la fase β-Ti. En general, en comparación con la aleación base, la adición del elemento Te conduce a un aumento de la fase α debido al efecto del Te como elemento estabilizador α. Para evaluar la resistencia a la corrosión de la aleación Ti6Al4V se utilizaron ensayos electroquímicos (polarización potenciodinámica y OCP - medición del tiempo) en soluciones Hank's y de saliva. Cuando se añadió telurio, la OCP se desplazó hacia la dirección positiva. Esto hace que la aleación sea más noble y aumenta su resistencia a la corrosión al disminuir la densidad de corriente de corrosión. El porcentaje de mejora oscila entre el 2,50 % y el 61,92 % en la solución de saliva y entre el 16,27 % y el 88,32 % en la solución de Hank. Para ambas soluciones, el mejor porcentaje de mejora es del 5 % Te.

Palabras clave: Resistencia a la Corrosión; Ti6Al4V; Telurio; Hank y Saliva.

INTRODUCTION

A major advancement was made in material science during the last century, and certain substances were successfully utilised for helping, repairing and replacing some bodily functions and locations.(1) Because it has the benefit of due to its non-toxicity, it is not rejected by the human body, and it may stay inside patient's body for more than 20 years. Titanium is a non-ferrous metal with low elastic moduli that match bone and the enable distribution of load. The loads imposed by the skeleton are distributed equally among the bone and implants.(2) Due to the protection from stress and the possibility of a bone fracture near a prosthetic device, this leads to a decrease in the rate of bone degeneration.(3) As a result, it excels in areas like biocompatibility, corrosion resistance, and specific strength. Also, a quick reaction to oxygen at room temperature leads to the development of a passively stable film. Titanium and its alloys, especially Ti6Al4v, are the best examples of a biomaterial.(4) The crystalline form of titanium undergoes an allotropic metamorphosis, changing from one crystallographic to the other. It has a hexagonal close-packed (HCP) structure at room temperature, which is known as the alpha (α) phase. At 883 °C, it changes to a body centered-cubic structure (BCC), which is known as the (β) phase. Transus temperatureβ is the temperature at which α or α+ β transforms to all β.(5) The presence of the two distinct crystal arrangements and the conforming allotropic transformation temperature are essential because they lay the groundwork for the large range of properties that Ti alloys might acquire.(6) Titanium alloying elements are categorized as neutral, α stabilizers, or β stabilizers based on their effect on the β-transus temperature.(7) The aim of this work is to investigate the effect of tellurium addition on corrosion resistance of Ti6Al4V alloy.

METHODS

The powder metallurgy technique used to manufacture the samples, the compact pressure was determined as 800MP followed by sintering at 350 C^0 for 1h then at 550 C^0 for 1h and at 1000 C^0 for 2 h in inert gas (of Argon), then the samples cooled in the furnace to room temperature. Table 1 detailing the metals used in this work is provided. The composition of the base Ti6Al4V alloy is (90 %Ti ,6 % Al and 4 % V), The following are the percentages of tellurium used (0,5, 1, 1,5, 2, 2,5, 3, 3,5, 4, 4,5 and 5 wt%). The diameter of specimens was 15 mm. The specimen code's and chemical compositions utilised in this study are listed in table 2.

Table 1. Purity % and Average Particle Size of Powder Materials

Material (powder)	Purity%	Average partials size (μm)
Titanium	99,99	23,53
Aluminum	99,99	20,32
Vanadium	99,99	46,59
Tellurium	99,99	1,849

Table 2. Prepared Samples in The Present Study

Alloy Wt%	The Weight Percentage of Element (%)				
	Ti	Al	V	Te	AlloyCode
Ti6Al4V	90	6	4	0	B
Ti6Al4V0,5Te	89,5	6	4	0,5	B 1
Ti6Al4V1Te	89	6	4	1	B 2
Ti6Al4V1,5Te	88,5	6	4	1,5	B 3
Ti6Al4V2Te	88	6	4	2	B 4
Ti6Al4V2,5Te	87,5	6	4	2,5	B 5
Ti6Al4V3Te	87	6	4	3	B 6
Ti6Al4V3,5Te	86,5	6	4	3,5	B 7
Ti6Al4V4Te	86	6	4	4	B 8
Ti6Al4V4,5Te	85,5	6	4	4,5	B 9
Ti6Al4V5Te	85	6	4	5	B 10

Microstructure Observation

Wet grinding with grades of (220, 400, 600, 800, 1000, 2000, and 3000) and Diamond paste is used to polish (1 μm particle size) were performed on the specimens, the samples then etched with a swab solution of 10 ml HF, 5 ml HNO3 and 85 ml H2O for 10 second.(8) The microstructure of Ti6Al4V-XTe alloys was seen and studied using a light optical microscope showed in figure 1.

Figure 1. Light optical microscope

Electrochemical Test

To evaluate the corrosion resistance of Ti6Al4V-XTe alloys, Open Circuit Potential (OCP) - time measurements and potentiodynamic polarisation are the two types of electrochemical tests were performed using two different solutions (Hank's and saliva solutions). The OCP was measured versus a SCE (saturated calomel electrode) with a five-minute interval. The test was completed when the potential attained a practically constant value. ASTM standard G 102 - 89 was followed to achieve potentiodynamic polarization,(9) platinum and SCE are employed as the auxiliary electrode and reference electrode, respectively. The polarization test range in relation to OCP is (+800 and -250 mV). For calculating corrosion rate, the following equation was employed.(10) The chemical composition of artificial saliva and hank's solutions is illustrated in table 3 and 4.

Table 3. Artificial saliva solution's chemical composition (11)

NO.	Constituent	(g/L)
1	NaCl	0,4
2	KCl	0,4
3	$NaH_2 PO_4.2H_2O$	0,906
4	$Na_2S.9H_2O$	0,005
5	urea	1

Table 4. Hank solution's Chemical composition (12)

NO.	Constituent	(g/L)
1	NaCl	8
2	CaCl2	0,14
3	KCl	0,4
4	NaHCO3	0,35
5	Glucose	1
6	MgCl2.6H2O	0,1
10	Na2HPO4.2H2O	0,06
11	KH2PO4	0,06
12	MgSO4.7H2O	0,06

$$\text{Corrosion Rate (mpy)} = \frac{0.13\ icorr(E.W.)}{A.\rho}$$

Where:

E.W. = equivalent weight (g/eq.).

A = area (cm^2).

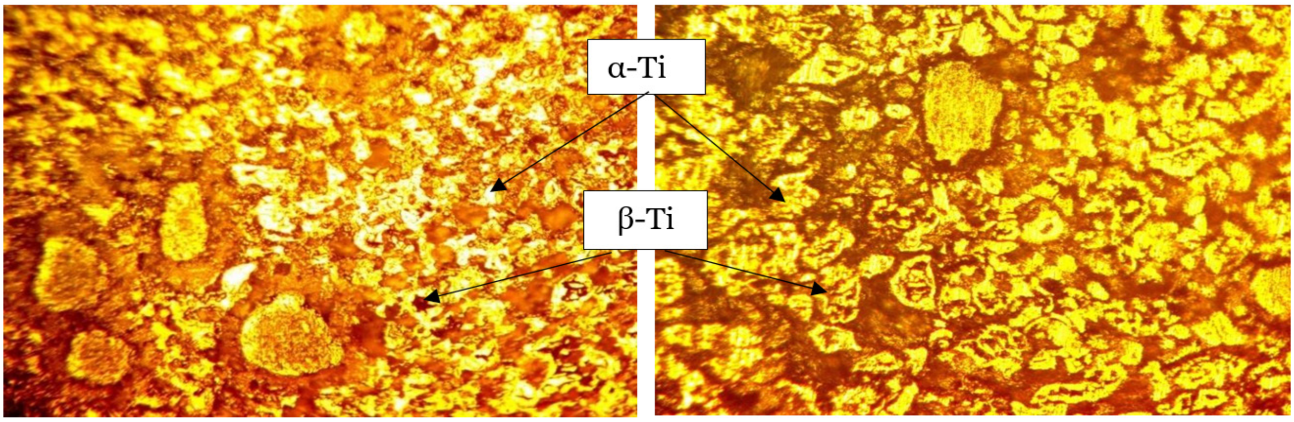
ρ = density (g/cm^2).

0.13 = metric and time conversion factor.

i_{corr} = current density ($\mu A/cm^2$).

RESULTS AND DISCUSSION

The figure 2 shows the microstructure of the etched alloys Ti6Al4V and Ti6Al4V-XTe after the sintering process where all specimens alloys consisting of two regions (a duplex microstructure), represents the regions of the light (bright) (α-Ti phase) and the other regions are dark which indicates β-Ti phase. Generally compared with the base alloy, the addition of Te element leads to increase the (α - phase) due to the effect of Te as the α stabilizer elements.(13)

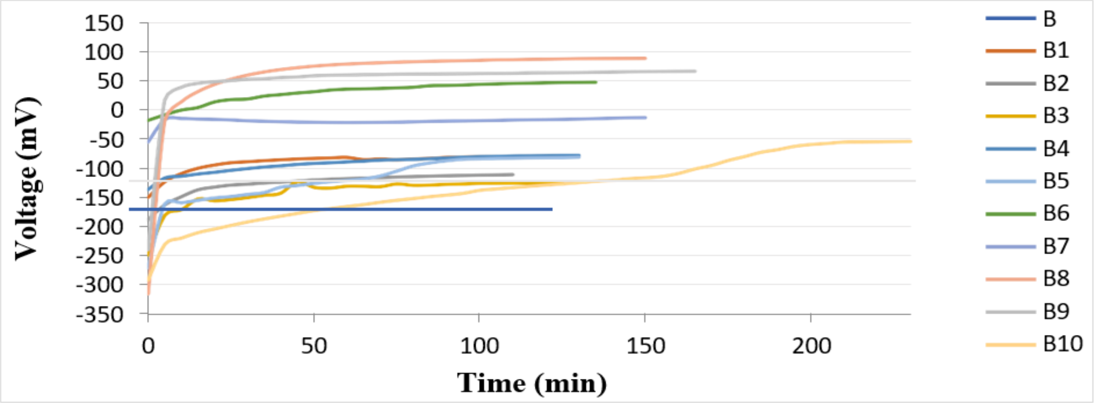


(B) (B 10)

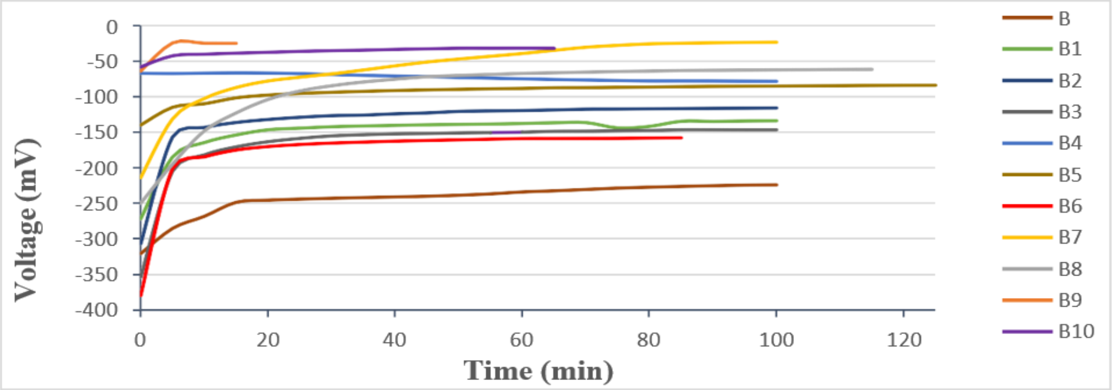
Figure 2. Microstructure for (B and B 10) (200X)

Figure 3 shows the OCP - time measurement. The test duration time for saliva solution is (100 to 230) minutes. Based on the observation of figure 3-A, it is shown that the potential move to positive direction due to the formation of the oxide film on the metallic surface. The OCP will be nearly in constant value, when deposition and dissolution are in equilibrium. The reported OCP for Ti6Al4V-XTe alloys (B, B1, B2, B3, B4, B5, B6, B7, B8, B9 and B10) are (-161,8, -79, -110, -124,1, -77, -80, +48,8, -12, +89,9, +67,7, -53) respectively, and for Hank's solution, the test duration time is (100 to 125) minutes. The OCP of alloys behaves as shown in figure 3-B, where the potential move to positive direction, which is the same behavior of the alloys in the saliva solution. The reported OCP for Ti6Al4V- XTe alloys (B, B1, B2, B3, B4, B5, B6, B7, B8, B9 and B10) are

(-224,2, -134, -116, -146,8, -78,4, -84, -158, -23,3, -61,6, -24,9, -31,9) respectively. some conclusions can be obtained: Ti6Al4V-XTe more noble than Ti-6Al-4V, so the tellurium addition improves corrosion resistance. The final potential values of all alloys tested in the synthetic saliva and Hank's solution with improvement percentage of alloy with tellurium particles are shown in the tables 5 and 6 respectively. Figure 3 shows an abrupt EOCP movement towards positive direction during the initial stages of immersion. The formation and thickening of the oxide film on the metallic surface, which enhances its ability to prevent corrosion, appears to be responsible for the initial increase.(14) After that, a gradual increase in EOCP indicates that the film has grown onto the metallic surface. During an exposure to the solutions for more than 100 minutes, the investigated samples did not show any potential decreases linked with surface activation. Such behavior is highly suggestive of that the native oxide generated in the air is chemical dissolution-resistant in a thermodynamic sense in Hank and saliva solutions. These results are in agreement with.(15)



(A)



(B)

Figure 3. OCP-Time of alloys in **(A)** prostheses saliva, **(B)** Hank's solution

Table 5. EOCP and Improvement Percentage % for All Alloys in Artificial Saliva

Alloy	EOCP. (mV)	Improvement percentage %
B	-161,8	-------
B1	-79	51,17
B2	-110	32,01
B3	-124,1	23,3
B4	-77	52,41
B5	-80	50,55
B6	+48,8	130,16
B7	-12	92,58
B8	+89,9	155,56
B9	+67,7	141,77
B10	-53	67,24

Table 6. E_{OCP} and Percentage Improvement for All Alloys in Hank's Solution

Alloy	E_{OCP}. (mV)	Improvement percentage %
B	-224,2	-------
B1	-134	40,23
B2	-116	48,2
B3	-146,8	34,52
B4	-78,4	65,03
B5	-84	62,53
B6	-158	29,52
B7	-23,3	89,60
B8	-61,6	72,52
B9	-24,9	88,89
B10	-31,9	85,77

Figure 4 and 5 illustrates polarization tests of Ti6Al4VxTe alloy in Hank and saliva solutions. In case of saliva solution, the obtained corrosion parameters are shown in table 7 (E_{corr}, I_{corr}, and corrosion rate) of Ti6Al4V-XTe alloys (B, B1, B2, B3, B4, B5, B6, B7, B8, B9 and B10). $I_{corr.}$ for specimens are graded in decreases from 8,14(μA/ cm^2) for (Ti6Al4V-0,5Te) alloy to 2,92(μA/ cm^2) for (Ti6Al4V-5Te) alloy which are lower than $I_{corr.}$ for Ti6Al4V base alloy which is 9,66(μA/ cm^2). However, the $E_{corr.}$ values for (Ti6Al4V-XTe) alloys is graded in increases from (73,3 mV) for (Ti6Al4V-0,5Te) to (216,4 mV) for (Ti6Al4V-5Te) which are higher than $E_{corr.}$ for Ti6Al4V base alloy which is (75,4 mV). In Hank's solution, from table 8 it shown the gradual improvement of corrosion resistance for Ti6Al4V base alloy with gradual increasing of different addition (0,5,1,1,5, 2, 2,5,3,3,5,4,4,5 &5) %wt from (Te). $I_{corr.}$ for (Ti6Al4V-XTe) specimens are graded in decreases from (8,43 μA/ cm^2) for B1 alloy to (1,08 μA/ cm^2) for B10 alloy which are lower than I_{corr}. for B alloy which is 11,65 (μA/ cm^2). However, the $E_{corr.}$ value for the (Ti6Al4V- XTe) alloys are increase graded from (41,2) mV for B1 to (189,1) mV for B10 which are higher than $E_{corr.}$ for B alloy which is (25,3) mV. From tables 7 and 8 show an increase in corrosion resistance of Ti6Al4V-XTe, as result the increasing in Te content leads to make the base alloy Ti6Al4V more noble and improve the corrosion resistance. Also the corrosion rate and the corrosion current density decreases when (Te) content increase for all specimens in two corroded solutions is especially in saliva solution as compared with Hank's solution, as shown in Figures 4 and 5, means in saliva and Hank solutions that Te addition made the Ti6Al4V alloy more noble. This results in agreement with (16,17).

Titanium's high affinity to even a slight trace of oxygen in aqueous environment creates a highly resistant and self- regenerating passive film, which is largely responsible for the material's excellent corrosion resistance in porous titanium compacts. Studies using polarisation, however, showed that when porosity decreased, the final $E_{corr.}$ value did, as well. This is because ionic species are trapped inside the small, isolated pore morphology, depleting the available oxygen during the passivation process. This is because ionic species are trapped inside the small, isolated pore morphology, depleting the available oxygen during the passivation process. Highly porous compacts with an open, interconnected pore morphology produced a material with substantially greater resistance to pitting as a consequence of the open flow of species. These findings are promising from a biomedical standpoint because they provide further evidence of the excellent corrosion characteristics of titanium despite the presence of pores.(18)

From the two tables below it can be seen, that there is a clear decrease in corrosion current density and corrosion rate for (Ti6Al4Vand Ti6Al4V-XTe) specimens in artificial saliva solution as compared to specimens in Hank's solution at 37C° ,this was related to the chloride content (NaCl 8 g/L) in the Hank's solution higher than chloride concentration (NaCl 0,4 g/L) in saliva solution is able to dissolve products of corrosion and layers, which causes the breakdown of protective layers to further promote corrosion, These results are in agreement with (19).

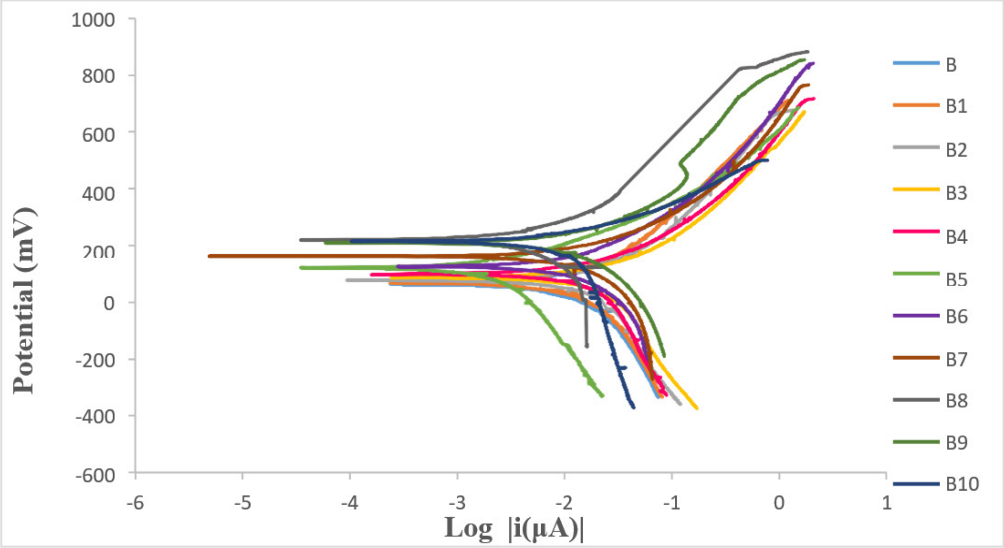


Figure 4. Potentiodynamic polarization for Ti6Al4V-XTe in saliva solution

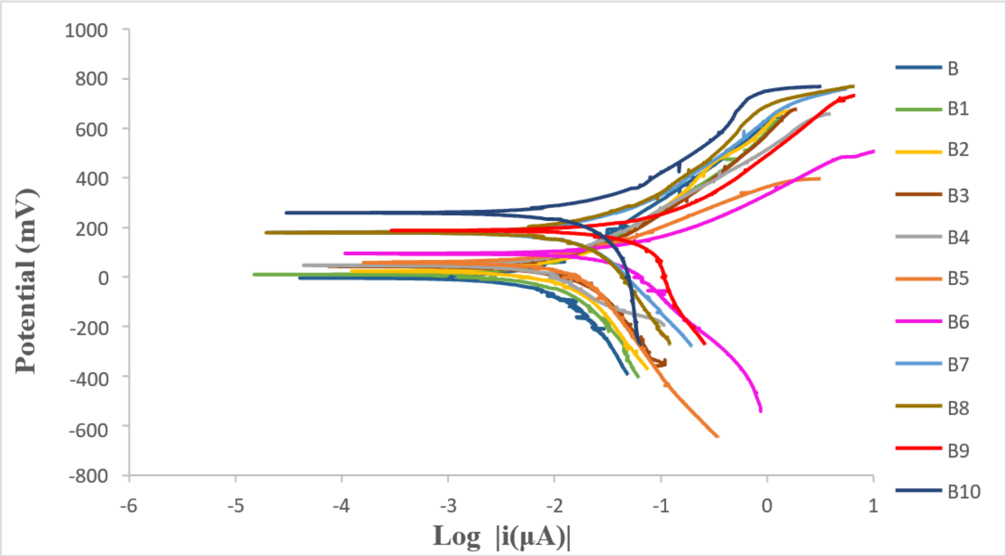


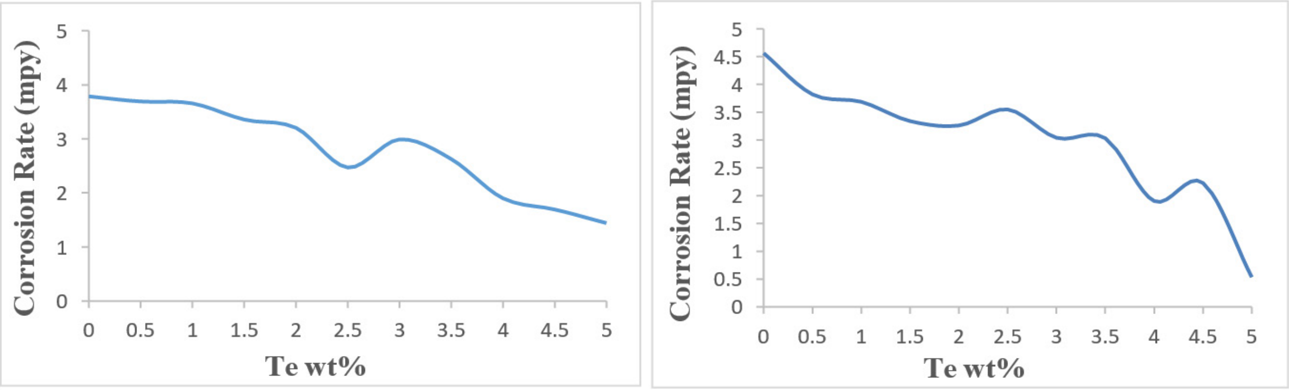
Figure 5. Potentiodynamic polarization for Ti6Al4V-XTe in Hank's solution

Table 7. Rate of corrosion (C.R.), potential of corrosion (Ecorr.), and density of corrosion current(Icorr.) for all used alloys in saliva solution

Samples	I corr. (µA/cm2)	Ecorr. (mV)	Corrosion rate(mpy)	Improvement percentage %
B	9,66	75,4	3,7855	------
B1	8,14	73,3	3,6908	2,50
B2	7,94	73,3	3,6565	3,40
B3	7,27	91	3,3558	11,35
B4	6,92	102,9	3,2032	15,38
B5	5,35	129	2,4711	34,72
B6	6,39	127,7	2,9894	21,03
B7	5,49	160,8	2,6258	30,63
B8	3,89	216,5	1,9002	49,80
B9	3,46	207,8	1,6938	55,25
B10	2,92	216,4	1,4412	61,92

Table 8. Rate of corrosion (C.R.), potential of corrosion (Ecorr.), and density of corrosion current (Icorr.) for all used alloys in Hank's solution

Samples	I corr. (μA/cm2)	Ecorr. (mV)	Corrosion rate(mpy)	Improvement percentage %
B	11,65	25,3	4,5653	------
B1	8,43	41,2	3,8223	16,27
B2	8,01	46,2	3,6887	19,20
B3	7,24	-1,4	3,3420	26,79
B4	7,05	63,9	3,2633	28,53
B5	7,69	64	3,5519	22,19
B6	6,50	11,6	3,0408	33,39
B7	6,34	260,3	3,0323	33,57
B8	3,90	180,9	1,9042	58,28
B9	4,55	181,5	2,2274	51,21
B10	1,08	189,1	0,5330	88,32



(A)

(B)

Figure 6. Corrosion Rate (mpy) vs. Tellurium Content (%) in **A:** saliva Solution, **B:** Hank's Solution

CONCLUSIONS

- Addition of tellurium element leads to an increase in the α-phase due to the effect of Te as the α stabilizer element.
- The open circuit potential of Ti6Al4V alloys was reduced by adding tellurium, making the alloys more noble.
- Addition of tellurium improves corrosion resistance by lowering the density of corrosion current.
- Addition of tellurium improves corrosion resistance by a range of (2,50 % - 61,92 %) in saliva solution and (16,27 %) to (88,18 %) in Hank's solution.

REFERENCES

1. D. F. Williams, "Definitions in biomaterials: proceedings of a consensus conference of the European Society for Biomaterials, Chester, England, March 3-5, 1986," (No Title), 1987.

2. Å. Leonhardt, C. Bergström, and U. Lekholm, "Microbiologic diagnostics at

3. titanium implants," Clin. Implant Dent. Relat. Res., vol. 5, no. 4, pp. 226–232, 2003.

4. C. A. Engh Jr, A. M. Young, C. A. Engh Sr, and R. H. Hopper Jr, "Clinical consequences of stress shielding after porous-coated total hip arthroplasty," Clin. Orthop. Relat. Res., vol. 417, pp. 157–163, 2003.

5. Z.M. Huang and S. Ramakrishna, "Engineering Materials for Biomedical Applications." pp. 257–305, 2004.

6. M. Kaur and K. Singh, "Review on titanium and titanium based alloys as biomaterials for orthopaedic

applications," Materials Science and Engineering C. 2019.

7. "J. M. S. Al-Murshdy,N.M.Abdulkadhim Radhi,"Effect of Mo and Ta on Mechanical and Corrosion Behaviour of Porous Ti+5Al+2.5Fe Biomaterials,.' University of Babylon, 2019 A.D."

8. M. Peters, J. Hemptenmacher, J. Kumpfert, and C. Leyens, Structure and properties of titanium and titanium alloys. 2003.

9. S. Practice, "STANDARD, A. S. T. M. E407-07: Standard Practice for Microetching Metals and Alloys. ASTM International., West Conshohocken, PA, 2012, 1-21.".

10. "ASTM, G. Standard practice for calculation of corrosion rates and related information from electrochemical measurements. G102-89, ASTM International, West Conshohocken, USA, 2004.".

11. "Al-DEEN, H. H. J. EFFECT OF ZIRCONIUM ADDTION ON CORROSION RESISTANCE OF ALUMINUM-BRONZE ALLOYS IN (3.5% NaCl AND 2M HCl) SOLUTIONS.".

12. Z. A. A. K. Mohammed and H. H. J. (Ph.D.), "Modification of CoCrMo Alloy (F75) by ZrO 2 Additions Used in Biomedical Applications.," Univ. Babylon, 2022.

13. A. Amer and M. Mohammed, "Improvement of Mechanical and Electrochemical Properties of Biomedical Ti6Al4V alloy by Ta and Zr addition." 2021.

14. H. Okamoto, "Te-Ti (tellurium-titanium)," J. phase equilibria, vol. 17, no. 4, p. 373, 1996.

15. "CANAY, Sû, et al. Evaluation of titanium in oral conditions and its

16. Electrochemical corrosion behaviour. Journal of oral rehabilitation, 1998, 25.10: 759-764.".

17. "JIMÉNEZ, Y. Santana, et al. Interpretation of open circuit potential of two titanium alloys for a long time immersion in physiological fluid. Bulletin of the Transilvania University of Braşov, 2009, 2: 51.".

18. S. Ozsahin, "Some Effects of the Addition of Tellurium to Lead Alloys," 1941.

19. "H. H. J. J. Al-Deen and E. A. R. Hassani, 'Effect of Te addition on the properties of CoCrMo (F75) alloy using P/M technique,' J. Eng. Appl. Sci., vol. 13, no. Specialissue12, pp. 9497–9502, 2018, doi:".

20. "SEAH, K. H. W.; THAMPURAN, R.; TEOH, S. H. The influence of pore morphology on corrosion. Corrosion Science, 1998, 40.4-5: 547-556.".

21. "MODABBER, Ali, et al. Impact of wound closure on the corrosion rate of biodegradable Mg-Ca-Zn alloys in the oral environment. Materials, 2020, 13.19: 4226.".

FINANCING

None.

CONFLICT OF INTEREST

None.

AUTHORSHIP CONTRIBUTION

Conceptualization: Haydar H.J. Jamal Al-Deen, Basmal H. Abdul Amir.
Research: Haydar H.J. Jamal Al-Deen, Basmal H. Abdul Amir.
Writing - original draft: Haydar H.J. Jamal Al-Deen, Basmal H. Abdul Amir.
Writing - revision and editing: Haydar H.J. Jamal Al-Deen, Basmal H. Abdul Amir.