



Past Advances and Future Perspective of Ti-Ta Alloys

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Abstract

In the case of conventional Ti-based biomaterials, such as Ti-6Al-4V and Nitinol, the release of Al, V and Ni has been shown to be detrimental to the human body and in this context, Ti-Ta alloys have been proposed as one of the best options for biomedical devices. The main focus of this study is to review the different chemical composition of manufactured Ti-Ta alloys, their various techniques of fabrication as well as the microstructure, mechanical properties and corrosion resistance. The paper sought to give an idea of the scope of the research and effort that has gone into developing a high-quality titanium medical device.

Keywords: Ti-Ta alloys; Arc-melting; Microstructure; Mechanical properties; Corrosion; EIS

Introduction

The market request for suitable materials for permanent devices in the human body is growing as people live longer and their bones are weakening with age. The most widely used biomaterial today is titanium, whose corrosion resistance is due to the stability of the oxide film that grows on its surface and can be re-formed at human body temperature and in physiological media if injured. The use of Ti and its alloys as biomaterials is increasing due to their reduced modulus, higher biocompatibility, superior strength and increased corrosion resistance compared to conventional biomaterials such as stainless steel and Co-Cr alloys. But in the case of traditional Ti-based biomaterials such as Ti-6Al-4V and Nitinol, the liberation of Al, V and Ni has been shown to be detrimental to the human organism [1,2]. In this context, Ti-Ta alloys have been proposed as one of the best options for biomedical devices due to their exceptional biocompatibility in the human body environment,

superior strength, relatively lower elastic moduli and superior corrosion resistance [3–5].

Chemical Composition of Titanium-Tantalum Alloys

Various types of binary titanium- tantalum alloys have been designed, manufactured and analyzed as follows: Ti-10Ta [6–10]; Ti-20Ta [10]; Ti-30Ta [6–8,10–12]; Ti-40Ta [6,10,12,13]; Ti-50Ta [6,8,10–15]; Ti-60Ta [6,10]; Ti-70Ta [7,10]; Ti-80Ta [6,10].

Fabrication

To present date, Ti-Ta alloys were satisfactorily produced by arc-melting [7,11–14,16,17], powder metallurgy [17,18], mechanical alloying [19,20] and additive manufacturing [21–25]. Scientists have made enormous efforts for the production of titanium-tantalum alloys by arc melting in a high-frequency induction furnace. Because of the large discrepancies in melting point and

density values of Ti and Ta, Ti-Ta alloys used to be remelted many times to obtain a homogeneous elemental composition, which entailed a long processing time. The challenge in the production process by the melting technique suggests that fabrication of the alloy by powder metallurgy is a reasonable option because it is a complete and simple technique that implies the fractionation and synthesis of the alloy. Although melting, powder metallurgy and mechanical alloying are able to manufacture Ti-Ta alloy ingots with good performances, it is however difficult to fabricate Ti-Ta alloy products with personalized complex shapes. Selective laser melting, SLM is a powder melting additive manufacturing AM process, can fabricate complex metallic devices directly from CAD models with a layer-by-layer method.

Microstructure Characterization

Tantalum has an α -BCC crystal structure and is an isomorphous β -stabilizer of titanium, which implies that the lattice pattern of the alloying element (tantalum in this case) is identical to the lattice pattern of the body-centered β -phase of titanium, BCC [26,27]. The α' phase is a distorted, hexagonal, closed-packed crystal framework which results from the uncompleted diffusion less conversion of the β -phase to the α phase [28]. The α' phase is stabilized by the addition of up to 10% or 20% Ta [29]. The α'' phase is an orthorhombic martensitic crystal framework formed by the rapid cooling or quenching of Ti or Ti alloys from above the beta transus to below the beta transus [30]. There are experimental data that above 80%Ta a homogeneous β -phase was stabilized [6,7,27,29]. The ω phase with the closed hexagonal HCP structure can be formed as a result of either β -zone cooling or during aging of quenched Ti alloys [31].

Thus, it is well established that in binary titanium-tantalum alloys there are only two stable solid phases (α and β) and four non-equilibrium solid phases (martensite α' , α'' , ω and metastable β phase) [19,27]. The formation of one phase or other depends on Ta content and posterior treatment of the alloy.

The microstructures of the Ti-Ta alloys were analyzed by X-ray diffraction analysis (XRD), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Metallographic examinations were also carried out to determine the as received and heat-treated microstructures [13].

Mechanical Properties

The tantalum concentration plays an essential contribution to the mechanical properties of Ti-Ta alloys. It is assumed that higher Ta concentration is not necessarily better for the improvement of the mechanical properties of titanium-tantalum alloys. Hardness values as a function of aging temperature were determined [6-8,13,15,32] and varies from 175HV 7 for Ti-10Ta to 743±12.93 for Ti-25Ta heat treated at 900 °C for 30 minutes. Dynamic Young's modulus and tensile tests were carried out on Ti-Ta alloys [3,6,8-11,14,15,21,33]. The Young's modulus varies from 64 GPa for Ti-

25Ta3 to 110 GPa for Ti-10Ta obtained by selective laser melting (SLM) [8]. The ultimate tensile strength has values from 500 MPa for Ti-10Ta 5 to 1029±8 MPa for Ti-25Ta 15.

The wear resistance of Titanium-Tantalum alloys and the biocompatibility were evaluated by assessing cytotoxicity through the MTT assay [7]. Between these techniques, to detect transus beta, electrical resistivity is a very accurate tool for measuring structural variations in Ti-based alloys [34,35].

Corrosion Resistance

Corrosion resistance of Ti-Ta alloys was validated by different dc techniques as open-circuit potential measurements, linear polarization, potentiodynamic polarization and coulometric zone analysis [6,7,12,13,15,36,37].

The electrochemical impedance spectroscopy (EIS) is employed to describe the performance of various metals and alloys in diverse media and to supply new information that could not previously be acquired with traditional direct current methods [38]. Although there has been a substantial volume of research using EIS to analyze biomaterials, there are only a few with respect to EIS measurements on Ti-Ta alloys and Ti-Ta alloys [12,37,39].

It is noted that it is critical for all cases to develop proper impedance models, which can be employed to fit the experimental data and obtain the parameters that describe the corrosion process [38,39].

Conclusion

Ti-Ta alloys have not yet been widely adopted in medical applications and the primary reason is the difficulty in combining these two metals; in recent years, additive manufacturing processes have been successfully developed and approved for the fabrication of biomedical devices, including for Ti-Ta alloys. But detailed research on the effect of Ta concentration on the microstructure and performance of Ti-Ta alloys processed by additive manufacturing is still limited.

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Conflict of Interest

No conflict of interest.

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