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Original Article

Corrosion resistance of Ti-6Al-4V and ASTM F75 alloys processed by electron beam melting

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ABSTRACT

The electron beam melting (EBM) is a useful technique for fabricating alloys that are difficult to machine and require expensive tools as well as the presence of inert atmosphere for further treatments. Under vacuum, EBM provides a controlled environment, reducing the drawbacks of the alloys of their processing in a conventional manner and thereby improving their microstructure, which can enhance corrosion resistance. In the present work, the corrosion resistance of the Ti-6Al-4V and ASTM F75 alloys was evaluated by using the Tafel extrapolation technique with scan rates of 0.05, 0.1 and 0.166 mV/s. The corrosion specimens were submerged in a Hank solution to simulate the corporal fluid. The specimens were characterized before and after the corrosion tests by optical microscopy and scanning electron microscopy, as well as a chemical microanalysis by EDS. The microstructural characterization before the corrosion tests revealed a dual phase ($\alpha+\beta$) microstructure and α' martensite in the Ti-6Al-4V alloy. For the ASTM F75 (Co-base) alloy, carbides were observed on the grain boundaries. Corrosion resistance increased in the Ti-6Al-4V alloy, from 0.50 to 0.14 mpy, possibly due to the formation of a TiO_2 passive layer. For the case of the ASTM F75 alloy, the corrosion rate decreased from 0.21 to 0.14 milli-inches/year (mpy) due to the formation of Cr layer. The corrosion results were observed to be very similar for the EBM fabricated alloys in comparison with more commercially fabricated alloys.

1. Introduction

One of the main problems in orthopedic implants is the loosening of the prosthesis in the bone, and the presence of residues or wear causing malfunction of the surgical implants; these problems are directly related to the wear and corrosion surface properties of the alloys, employed for this purpose. Pure metals do not have strength, elasticity, ductility, and other properties possessed by alloys; for this reason, the addition of one or more metals to the base element is necessary to modify the crystalline structure and, therefore, its mechanical properties. There are three families of alloys widely used today in biomedicine, due to their good corrosion resistance, which plays an important role in surgical implants, such as: Co-Cr-Mo alloys (ASTM F75), Ti-Al-V (Ti-6-Al-4V) and stainless steel

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AISI 316L (Fe-Cr-Ni-Mo) [1]. All materials have a specific chemical composition, but their final properties are closely related to the crystalline structure, and this is a direct result of the manufacturing methods [2]. Metallic materials can undergo a casting process, solidification, forming, and heat treatment. Each metal has its heat treatment process in order to get the best mechanical properties, while achieving high corrosion resistance properties.

Electron beam manufacturing is a variety of rapid manufacturing (RM) for the direct manufacturing of metal products from a powder precursor melted layer-by-layer with an electron beam in vacuum. The electron beam melting (EBM) machine reads in data from a digitally scanned, 3D model, sliced into individual layers, and lays down successive, 100 μm thick metal powder layers which are gradually melted through the controlled EB scanning process to build the product model. Quality products require the development of a set of optimized processing conditions or parameters which assure uniformity and control of microstructure and associated mechanical properties and performance. Especially promising directions for EBM involve the direct fabrication of custom orthopedic implants and related biomedical applications, mainly involving the production of Ti–6Al–4V components with selected structure–property features [3]. Ti-6Al-4V is of interest as a consequence of its excellent biocompatibility, light weight, outstanding balance of mechanical properties and associated corrosion resistance and human allergic response.

With the presence of a vacuum, EBM provides a controlled environment, reducing the drawbacks of the alloys of their processing in a conventional manner and thereby improving their microstructure, which strongly affects the corrosion resistance. In addition, EBM allows complex and even porous structures to be fabricated.

There are a number of Co and Ti base alloys in biomedicine applications, processed in a conventional form and heat treated in order to obtain wide-ranging properties such as low elastic modulus, high tensile strength, excellent wear and corrosion resistance and good biocompatibility [4]. The corrosion variance of the EBM processing is important to know since it corrodes the same as more conventional materials. However, there are few studies reporting the corrosive behavior of these alloys obtained by EBM.

Ti-6Al-4V alloy is the typical two-phase titanium alloy with the most extensive and mature application. For its low density, high specific modulus and strength, excellent corrosion resistance and creep resistance [5–7], Ti-6Al-4V alloy has got the wide applications in the biomedicine field where special structural components are immediately needed. These special structure components are not only complex in structures and shapes, but also strict in requirements for microstructure and mechanical property. However, Ti-6Al-4V alloy is prone to generate porosity because of its high chemical reactivity and poor flowability at high temperature. In order to significantly increase the filling and feeding ability of liquid metal during the solidification, decrease shrinkage cavity, shrinkage porosity, and porosity to obtain sound castings with high density, enhance freezing rate to make castings obtain excellent microstructure and mechanical properties which cannot be obtained in the gravity field,

This paper describes applied research involving the manufacturing of Ti6Al-4V and ASTM F75 alloys by electron beam melting (EBM). This research concerns a comparison of the alloys corrosion resistance in corporal fluid conditions. The results are supported by a microstructural characterization before and after the electrochemical tests by using Hank's solution to simulate the biological environment to observe the corrosive attack

2. Experimental procedure

2.1. *Selection of base material (powder alloy)*

The powder alloys used in this investigation are: Ti-6Al-4V grade 5 (Arcam) and Co-28.5Cr-6Mo ASTM F75 [8]. The particle average size varied for both alloys between 40 and 100 μm. Tables 1 and 2 show the chemical composition of these alloys.

2.2. *Electron beam melting technique*

The probes were fabricated by the electron beam melting technique with an EBM Arcam A2 system shown in Fig. 1.

EBM is able to fabricate complicated geometry that in other conventional method is difficult to obtain (Fig. 2). However, in this investigation, the geometry of the samples for corrosion tests is quite simple. This test only requires 1 cm^2 of area of exposition, so a cylindrical form was preferred, with 1.5 cm and 3.0 cm of diameter in ASTM F75 and Ti-6Al-4V samples, respectively. The process parameters are listed in Table 3.

Table 1 – Chemical composition of Ti-6Al-4V alloy.

	Elements (% wt.)							
	Al	V	C	Fe	O	N	H	Ti
Arcam Ti-6Al-4V	6	4	0.03	0.1	0.15	0.01	0.03	Balance

Table 2 – Chemical composition of ASTM F75 alloy.

	Elements (% wt.)									
	Cr	Mo	Ni	Fe	C	Si	Mn	W	N	Al	Co
Arcam ASTM F75	28.5	6	0.25	0.2	0.22	0.7	0.5	0.01	0.15	0.05	Balance

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