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Sandblasting as a surface modification technique on titanium alloys for biomedical applications: abrasive particle behavior

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Abstract. The present work shows the analysis of a sandblasting process using alumina abrasive particles on Ti-6Al-4V surfaces. The metallic samples were first characterized by optical microscopy (OM), revealing an $\alpha+\beta$ microstructure with a Widmanstätten morphology. Topography of the samples was assessed by scanning electron microscopy (SEM), before and after sandblasting. The Al_2O_3 particles used had a granulometric distribution between 420 and 850 μm , with a median particle size (d50) of 670 μm , which decreased to 420 μm after sandblasting for 10 seconds. This change in the size of the particles generated a loss on particle kinetic energy by a factor of 3.5. Such variation on processing conditions induced a progressive increase on average roughness (Ra) of the Ti-6Al-4V surfaces, until the first 7 seconds were reached. From that point on, a reverse process was observed, exerting a polishing effect on the surface of the Ti-6Al-4V alloy.

1. Introduction

Ti-6Al-4V is one of the most common alloys, which belongs to the ($\alpha+\beta$) class of titanium alloys, due the presence of aluminum and vanadium. These alloying elements are used for phases' stabilization and for improving the mechanical properties and resistance to corrosion of the titanium alloy. It is well known that, for biomedical applications, Ti-6Al-4V is one of the most widely used alloys for orthopedic implants. However, it is important to create surface roughness to facilitate the process of osteointegration. There is not an optimum surface roughness, but some publications report an approximate value of 4 μm [1, 2, 3, 4, 5].

A very common technique to facilitate osteointegration through surface roughness is sandblasting with alumina particles (Al_2O_3). The size, shape, and kinetic energy of the particles, are important variables which influence the value of the surface roughness. In the sandblasting process, the particles are shooting as a consequence of the impulse provided by air pressure, allowing a gain of kinetic energy, which is directly proportional to the density, volume, and the square of the shooting velocity. The gain of kinetic energy is represented in the following equation

$$Ec = \rho \cdot \left(\frac{2}{3}\right) \cdot \pi \cdot r^3 \cdot V^2 \quad \text{Equation 1.1}$$

Where V, ρ , and r are the velocity, density, and particle radius, respectively.

Al_2O_3 has been considered one of the most commonly used abrasives for sandblasting due its hardness and acicular shape, as well as its low production cost with respect to other abrasive materials and its potential inert behavior in the osteointegration process. Nonetheless, fractures could occur during sandblasting process, as a consequence of the fragile nature of the alumina and the elevated kinetic energy of the particle stream at the time of impact.

The aim of the present work was to investigate the effect of the sandblasting treatment and the behavior of the Al_2O_3 particles in the surface modification of Ti-6Al-4V samples. This study allows the understanding of the surface properties of the Ti-6Al-4V alloy, which depend of the physical and mechanical characteristics of the employed abrasive, and also exert a great influence in the biological response of the human body.

2. Experimental Procedure

2.1. Alloy and metallographic analysis

Discs with 8 mm in diameter and 1 mm in thickness, were cut from the stem of a Ti-6Al-4V hip prosthesis. For their metallographic study, the samples were polished and attacked for 3 seconds with Kroll's solution (85 mL of H_2O , 5 mL of HNO_3 and 10 mL of HF), and their microstructure was then observed with an optical microscope (OLYMPUS PMG 3).

2.2. Sandblasting and determination of average roughness (Ra)

The surface of the titanium alloy' samples were modified using a sandblasting device. The pressurized air in the device, projects the abrasive Al_2O_3 particles at a 90° angle. The distance between the nozzle and the sample surface was 0.1 m. The air pressure was 0.3 MPa. For particle sizes between 420 – 600 μm , sandblasting was carried out for 2, 3, 4, 6, 7, and 10 seconds. At each sandblasting time, Ra was measured, employing a rugosimeter (Mitutoyo SJ-301) in three different parallel zones of the modified surface. Topography of the modified samples was analyzed by scanning electron microscopy (SEM) in a microscope (JEOL JSM-6390) with an acceleration voltage of 25 kV.

2.3. Granulometric analysis of the abrasive

Before and after sandblasting, the abrasive particles were studied by granulometric distribution, applying a sieving analysis from a representative sample of 1 kg, using a sieving machine (Gilson Inc. SS-15) for 10 min.

3. Results and Discussions

3.1. Alloy and metallographic analysis

Figure 3.1 shows a micrograph of the study alloy. This picture corresponds to a biphasic microstructure, where the lighter zone is the alpha phase and the dark zone represents the beta phase. The morphology is of the Widmanstätten type, with results from the nucleation and growth during the transformation of alpha and beta, with the alpha phase growing on the preferential crystallographic planes within the beta phase matrix. In other words, the alpha phase nucleates on the edges of the beta matrix granule and grows in the form of metastable plates. The revealed morphology indicates that the alloy possesses great resistance to tension and fluency, due to the fact that the Widmanstätten plates help in improving the mechanical behavior.

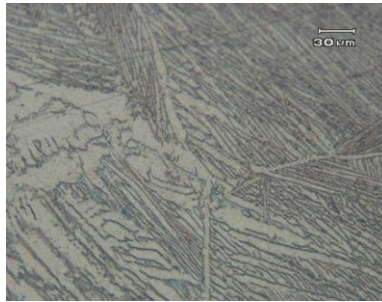


Figure 3.1. Micrograph of T-i6Al-4V alloy chemically attacked with Kroll's solution (200X)

3.2. Sandblasting process and determination of surface roughness (R_a)

Once the sandblasting process was carried out, the average R_a was measured on the metallic surfaces. The histogram presented in Figure 3.2 shows the values of R_a obtained as a function of sandblasting time, when the particle size was maintained in the range of 420-600 μm .

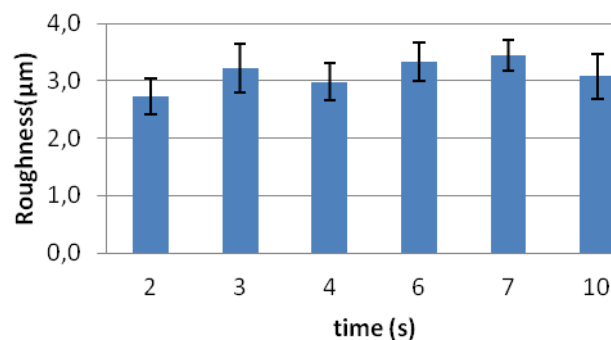


Figure 3.2. Histogram of average surface roughness of the Ti6Al4V samples ($n = 33$) as a function of sandblasting time, using a particle size in the range of 420- 600 μm

In Figure 3.2, it can be observed that there is an optimum roughness value of 3.4 μm at 7 seconds of sandblasting ($p < 0.1$). However, this value decreases to 3.1 μm when the time is increased to 10 seconds. This phenomenon is possibly a consequence of the rupture of the alumina particles when impacting the surface.

The micrographs shown in Figure 3.3 correspond to Ti-6Al-4V surfaces before and after the sandblasting treatment. Figure 3.3a shows the unmodified surface, where only grinding marks caused during sample preparation can be appreciated. Figure 3.3b shows a substantial change in surface morphology, product of the plastic deformation associated to the impact of alumina particles.

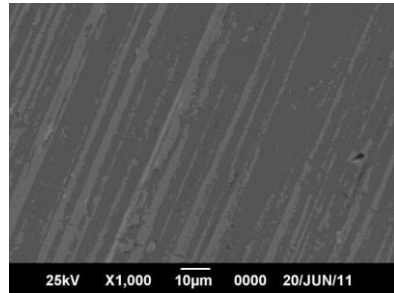


Figure 3.3a. Scanning electron micrograph of unmodified Ti6Al4V at 1000X.

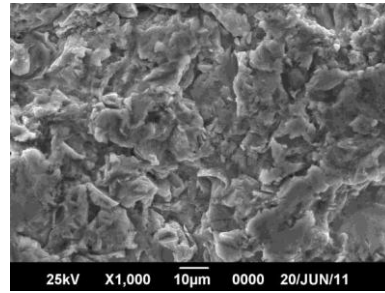


Figure 3.3b. Scanning electron micrograph of sandblasted Ti6Al4V at 1000X.

3.3. Characterization of the abrasive particles

Figure 3.4 shows the results obtained from granulometric distributions of the abrasive particles, before and after the sandblasting process.

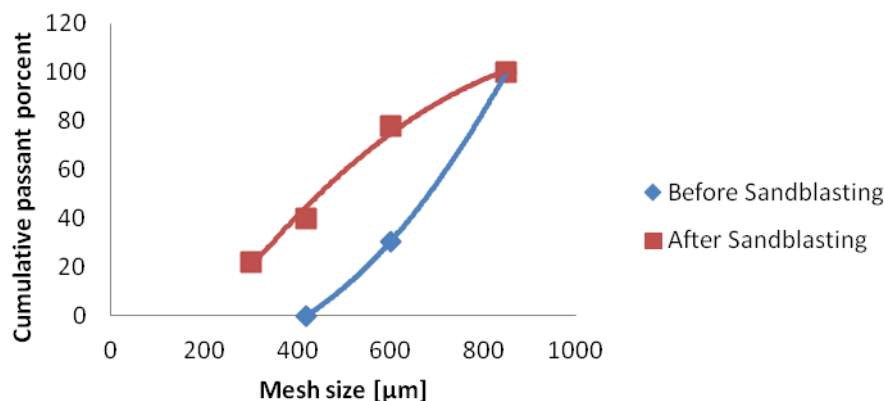


Figure 3.4. Granulometric cumulative curves showing d50 of the abrasive granulometric distributions before and after sandblasting.

Emphasizing on the granulometric curves in Figure 3.4, it is established that the medium particle size, d50, is 670 µm for a granulometric distribution before sandblasting process, and 450 µm after this process. This result indicates a clear decrease in the abrasive particle size. This fact is an empirical evidence of that the particle fracture is associated with the tendency to decrease roughness, with prolonged sandblasting times.

This phenomenon can be explained by analyzing the variation in kinetic energy of the particle stream. According to equation 1.1, the kinetic energy of the particles was reduced 3.5 times when the diameter changed from 670 μm to 420 μm . Therefore, the impact received by the Ti-6Al-4V surface was drastically reduced in time, affecting the plastic deformation of the surface. On the other hand, when the size decreases, it is also true that the number of particles projected increase in an inverse proportion to the decrease in kinetic energy. This can induce an inverse effect in surface treatment, resulting in a polishing finish. Thus, in the case of this study, the average surface roughness could decrease after 10 seconds of sandblasting, when compared to shorter processing times.

4. Conclusions

Alumina particles present ruptures during the sandblasting process, causing a significant drop of their kinetic energy. Consequently, smaller particle sizes during sandblasting generate a decrease on surface roughness of the Ti-6Al-4V samples.

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