Estudio metalográfico del efecto de la velocidad de corte en la microestructura del Ti-6Al$_4$V ELI para la empresa Quirúrgicos Especializados

Metallographic study of the cutting speed effect on the Ti-6Al$_4$ V ELI microstructure for the company Quirúrgicos Especializados

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Resumen— Los actuales procesos de conformación mecánicos, utilizados en la fabricación de dispositivos Ti6Al-$_4$V ELI quirúrgicos, crean un efecto microestructural que reduce las propiedades mecánicas del material, lo que afecta su rendimiento en circulación. En este trabajo se estudia el efecto de la microestructura que tiene lugar en el proceso de corte de Ti6Al-$_4$V ELI con el objetivo de seleccionar las mejores condiciones de corte disponibles para las necesidades de la empresa Quirúrgicos Especializados. El proceso de corte ofrece dos condiciones que controlen la rotación y la velocidad de avance lineal en la herramienta de corte. Para este trabajo cortamos 6 muestras de Ti6Al-$_4$V ELI; cada muestra tuvo diferentes condiciones para ser analizados metalográficamente mediante microscopía óptica. Se observó una modificación de la microestructura Ti6Al-$_4$V ELI y se ha estimado un efecto cualitativo sobre las propiedades mecánicas, lo que permite seleccionar las condiciones más eficientes en el proceso de corte.

Palabras clave— Biomateriales, Efecto microestructural, Metalografía, Proceso de corte, Ti6Al-$_4$V ELI

Abstract— Current mechanical forming processes used in the production of surgical Ti6Al-$_4$V ELI devices create an undesired microstructural effect that reduces the mechanical properties of the material, thus affecting its performance while in service. In this work we study the microstructural effect that take place in the cutting process of Ti-6Al$_4$V ELI with the goal of selecting the best available cutting conditions for Quirúrgicos Especializados company needs. The cutting process offers two conditions to control rotation and lineal feed speed in the cutting tool. For this work we cut six samples of Ti-6Al-$_4$V ELI, each sample had different conditions to be metallographically analyzed via optical microscopy. We observed a modification on the Ti-6Al-$_4$V ELI microstructure and a qualitative effect on the mechanical properties have been estimated, allowing the selection of the more efficient conditions in the cutting process.

Keywords— Biomaterials, Cutting Process, Metallography, Microstructural effect, Ti6Al$_4$V ELI.1.

1. INTRODUCTION

The effect of mechanical processes on metallic materials has been researched in the last decades with the aim of establishing better conditions that will allow optimizing the production without compromising the mechanical properties of materials [1]-[5]. Astakhov have recommended performing specific studies of both processes and materials, appart from only determining general parameters in mechanical properties of a material [1]. In the case of metals and alloys, their microstructure as well as the relationship with their mechanical properties is widely documented [6]. Metallography is the microstructural study of metals and alloys that allow identifying through a chemical etching followed by an optical analysis of the microstructural characteristics that indicate, in the most of

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the cases, the alloy's microstructural condition. In other cases, metallography has been used to identify microstructural modifications in mechanical processes for some specific materials [2], [4]. In this study, we evaluated the effect of the cutting conditions on the microstructure by metallographic characterization of cut samples under different conditions.

2. TI ALLOYS AND MECHANICAL PROCESSES

2.1. Ti-6Al-4V ELI extra low interstitial

Ti alloys are materials for high technology applications, mainly for the biomedical and aerospace industries among others. Titanium (Ti) is a polymorphicelement. Titanium (Ti) has two crystal phases in nature, HCP at room temperature (alpha phase) and BCC at 700-1050 C (beta phase). Alpha phase is fragile and betha is a ductile and meta-stable phase and a fine dispersion of both o them in the net allows a good combination of its biomechanical properties [7], [8], [9]. Ti alloys are classified in 3 types according to their microstructure:

- α type Ti alloys
- β type Ti alloys
- α+β type Ti alloys

α+β type Ti alloys are widely applied, particularly $Ti6Al_4V$ alloy known as Ti alloy grade 5 [9]. This alloy is broadly applied in the surgical and aerospace industries. However, for surgical applications its cast process is modified to obtain a better microstructural quality, enhancing its biomechanical and physicochemical properties. This alloy is known as $Ti6Al_4V$ Extra Low Interstitial (ELI) [10]-[11]. The alloys for biomedical application undergo all kind of cyclic loads; wear damage, fritting damage and other mechanical stresses.

2.2. Mechanical processes effect

The biomechanical properties in surgical industry must be controlled during mechanical processes to avoid its premature failure in service. Because this kind of process produces an effect on the microstructure, it could affect the mechanical properties of the alloy enough to allow a failure. Due to this, researchers have extensively studied the effect of processing the mechanical behavior of the finished biomedical devices to improve their performance without affecting their production on an industrial scale [1]-[5].

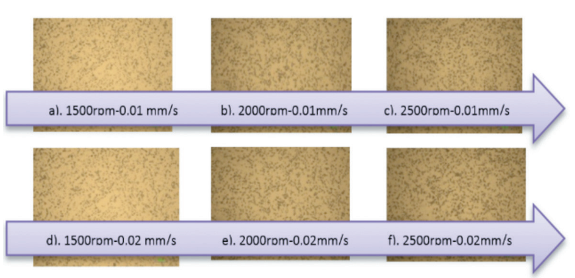
In the case of the $Ti6Al_4V$ ELI one study was carried out by W. Niu in 2013, where the effect of increasing the rotation speed in cutting process was evaluated, finding that the mechanical properties to mill annealed alloy do not undergo a representative reduction of its fatigue life [2]. However, the feed rate effect on the microstructure or mechanical properties have not yet been studied.

2.3. Methodology

Six cylindrical samples of Ø 12 mm and 0,6 mm of height were cut under the following conditions:

- Rotation speed 1500 rpm and feed rate 0,01mm/s (Fig.1a).
- Rotation speed 2000 rpm and feed rate 0,01mm/s. (Fig.1b).
- Rotation speed 2500 rpm and feed rate 0,01mm/s. (Fig.1c).
- Rotation speed 1500 rpm and feed rate 0,02mm/s. (Fig.1d).
- Rotation speed 2000 rpm and feed rate 0,02mm/s. (Fig.1e).
- Rotation speed 2500 rpm and feed rate 0,02mm/s. (Fig.1f).

Fig 1. MICROGRAPHS OF $TI6AL_4V$ ELI, CHANGING CUTTING CONDITIONS



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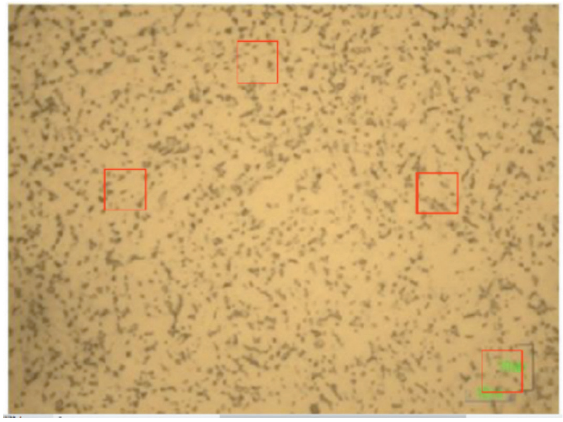
Metallographic preparation of specimens was performed according to standard specifications of ASTM E-3-11 manual method [12]. Chemical etching was performed according to standard specifications of ASTM E-407-11 with 1c reagent that consists of 1 mL HF dissolved in 200mL of distilled H_2O and the application via immersion during 3 to 5 seconds [13]. Optical analysis was performed using a BX51 Olympus microscope at 1000X magnification in (Grupo de Investigaciones en Corrosión) GIC's laboratory. Images of 10x10 μm^2 were taken to perform a grain count in order to estimate the sample grain size, repeated for 4 images (Figure 2). The averages from these measures are registered in table I and the analysis of this measures are described in the Figs. 4, 5, 6 and 7.

TABLE I

AVERAGES OF MICROSTRUCTURAL PARAMETERS ESTIMATED EXPERIMENTALLY FOR EACH CUTTING CONDITIONS

Conditions	Grain Quantity	Grain Size [μm]	Conditions	Grain Quantity	Grain Size [μm]
1500rpm-0.01mm/s	17	0.1567	1500rpm-0.02mm/s	14	0.1727
2000rpm-0.01mm/s	16.25	0.16	2000rpm-0.02mm/s	11.75	0.2247
2500rpm-0.01	16	0.1645	2500rpm-0.02mm/s	10	0.248

Fig 2. MICROGRAPHS OF $TI6AL_4V$ ELI, CHANGING CUTTING CONDITIONS



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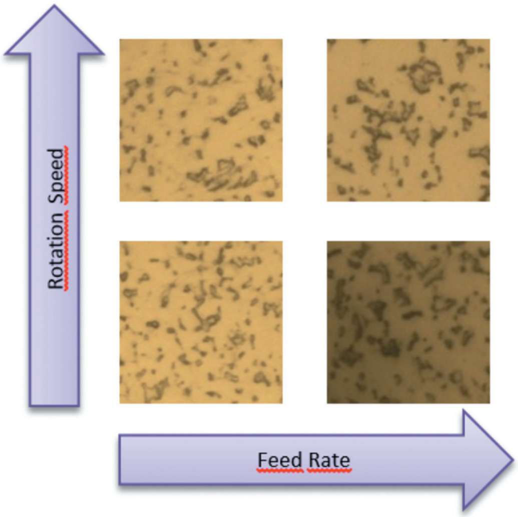
3. RESULTS AND DISCUSSION

In table I the quantitative change's estimation related to the samples' conditions is presented. It is possible to state that there is an evolution in the grain size that is related with the cutting conditions and it can be appreciated that the feed rate condition modification has a bigger effect than the rotation modification.

Figures 4, 5, 6 and 7 represent an increase in the grains' size and a decrease in the grains' number, proportional to the improvement of both cutting conditions, but the change at higher feed rate is more remarkable than the higher rotation speed (Fig. 3 and 4).

Fig.3. COMPARATIVE SCHEMES OF CRITICAL ZONES IN SAMPLES THAT REVEAL THE MICROSTRUCTURAL EFFECT OF BOTH MODIFIED CONDITIONS IN CUTTING PROCESSES TO MAGNIFIED IMAGES IN SOME ZONES WITH AREA 10X10 MM2 FROM THE RESPECTIVE CONDITIONS



Source: authors

This behavior could be explained by the thermal activation diffusion phenomena of aluminum (Al) through the crystalline network for the cutting temperatures reached to alpha grain's boundaries. When the atoms of Aluminum were warmed up they let the smallest diffused from the small grain across the crystal network due to more thermodynamically favorable state, which in most of the cases are close to the alpha phase boundaries. So here, the Al contributes to the growth of the alpha phase while decreasing the number of small grains [14], [15]. This is shown in table I.

Fig. 4. PERCENT VARIATION OF GRAIN NUMBER WHEN ROTATION SPEED IS ENHANCED AND FEED RATE IS CONSTANT

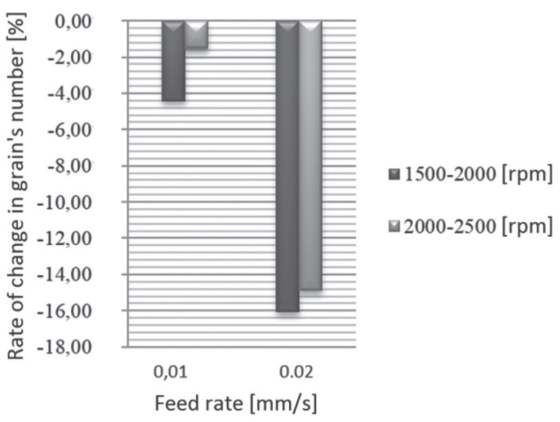


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Fig. 5. PERCENT CHANGE OF GRAINS NUMBER WHEN FEED RATE IS ENHANCED AND ROTATION SPEED IS CONSTANT

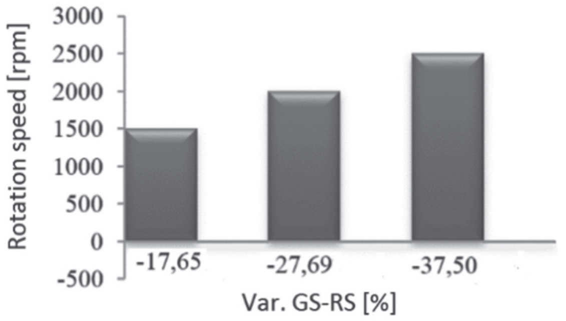

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Fig. 6. PERCENT VARIATION OF THE GRAIN SIZE WHEN FEED RATE IS ENHANCED AND ROTATION SPEED IS CONSTANT

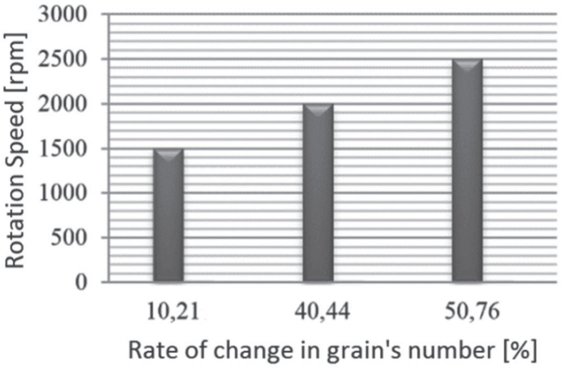

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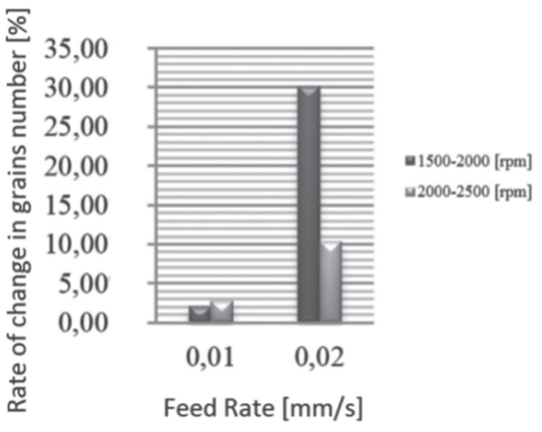
Fig. 7. PERCENT VARIATION OF GRAIN SIZE WHEN ROTATION SPEED IS ENHANCED AND FEED RATE IS CONSTANT



Source: authors

The rotation speed effect was studied for Niu [2] and it was found that it does not have a considerable effect on mechanical properties. The effect of the feeding rate is larger than the rotation speed, as described in table 1, and has not been studied until now.

Thermal activation by diffusion phenomena allows the growth of alpha grains but implicate the vanishing of smaller grains to Al displacement, because Al is an alpha stabilizing element and it has a small atomic size, enough to travel across networks. This detriments the biomechanical properties and affect the performance of alloy in service.

4. CONCLUSIONS

With an increase in the rotation speed and feed rate in the cutting process of $Ti6Al_4V$ ELI it was found that: The microstructural effect of increasing the feeding rate is higher than the rotation speed effect, reaching values of 50% in grain size increase (Table I). It is probable that diffusion by the thermal activation process of Al develops when $Ti6Al_4V$ ELI is cut. The increase of both conditions allows a growth in the alpha grain size and a decrease of the alpha grains number.

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