The Role of Structural Factor in the Formation of Surface-Sensitive Properties of the Titanium-Based Alloy†


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Abstract – VT6 titanium alloy was employed to different electron beam treated and the surface topography was investigated by SEM and AFM. The surface roughness was modified by electron beam treatment and the polishing mechanism was analyzed by studying the cross section microstructure of electron beam treated specimens by SEM and TEM. The remelt and nanostructurization of surface layer caused by pulsed electron beam treatment is the main polishing mechanism and reason of modification of surface topography.

1. Introduction

Titanium alloys are employed in aerospace industry because of their remarkable characteristics: high strength to weight ratio, excellent corrosion resistance and good fatigue performance. Ti–6Al–4V (VT6) alloy is the most widely used titanium alloy and it occupies 80% in titanium industry [1]. Surface integrity is a comprehensive concept considering the change of chemical and mechanical properties of materials in surface layer. It has four main categories and microstructure is one main field [2].

Pulsed electron beam treatment is a new surface modification process and can be applied in many fields [3–9]. The effect of surface nanostructure by electron beam treatment on hardness and yield strength has been less investigated and therefore it is interesting and important to study the change of hardness along surface layer by electron beam treatment and obtain the characteristics of grade nanostructure in surface layer with the nanoindent measurement.

2. Material and Experimental Procedure

A subject of research is an alloy of titanium Ti–6Al–4V (VT6). The surfaces of specimens were pulsed electron beam treated by “Solo” type pulsed electron beam machine. The parameters of pulsed electron beam treatment are the pulsed time \( t = 50 \mu s \), pulsed times \( N = 1 \); 3 pulses, pulsed energy \( E_S = 12, 15, 18, 21, 25 \text{ J/cm}^2 \). The surface topography was analysis by scanning electron microscopy (SEM) and atomic force microscopy (AFM) to show the change of surface integrity by pulsed electron beam treatment.

Fig. 1. Microstructure of VT6 titanium alloy

Fig. 2 Microstructure of VT6 titanium alloy treated by pulsed electron beam (the parameters of pulsed electron beam treated are the pulsed time \( t = 50 \mu s \), pulsed times \( N = 3 \) pulses, pulsed energy \( E_S = 25 \text{ J/cm}^2 \))

3. Results and discussion

VT6 titanium alloy was used and its microstructure (α- and β-phases) was illustrated in Fig. 1.

The microstructure of pulsed electron beam treated specimens is shown in Fig. 2 and α- and β-phases are also shown in Fig 2. It can see that the β-phase size is smaller than the reference specimens shown in Fig. 1. The length of β-phase in reference specimens is about 10–0 μm, as shown in Fig. 1, and the length of β-phase in pulse electron beam treated specimens is about 0.1–0.2 μm illustrated in Fig. 2.

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Figure 2 shows two zones, melt layer and affected layer along the cross section surface of pulse electron beam treated specimens. In the melt layer, nanostructure is found and the β-phase cannot be seen because of great resistance of corrosion in nanostructure layer shown in Fig. 2.

Figure 3 illustrates the change of two dimension surface with the different surface pulsed electron beam treatments by SEM. It can be seen that the surface roughness is getting smaller with the high intensity of pulsed electron beam energy (Fig. 3, a, b). Although the pulse times can affect the surface topography, the effect of intensity of pulsed electron beam energy on surface topography is greater than the pulse times, as shown in Fig 3, b, c.

The images of AFM illustrate the similar changes in Fig. 4. It can be seen that the surface roughness is getting better with the high intensity of pulsed electron beam energy and pulsed times. Although the pulse times can affect the surface topography, the effect of intensity of pulsed electron beam energy on surface topography is greater than the pulse times, as shown in Fig. 4.

Fig. 3. Microstructure of VT6 titanium alloy treated by pulsed electron beam (the parameters of pulsed electron beam treatment are the pulsed time $t = 50 \, \mu s$, pulsed times $N = 3$ pulses (a, b), and pulsed times $N = 1$ pulses (c), pulsed energy $E_s = 12 \, J/cm^2$ (a) and $E_s = 21 \, J/cm^2$ (b, c))

Fig. 4. 3D AFM images of specimens of VT6 titanium alloy of referenced (a) and treated by pulsed electron beam (b, c) (the parameters of pulsed electron beam treatment are the pulsed time $t = 50 \, \mu s$, pulsed times $N = 3$ pulses (a, b), pulsed energy $E_s = 25 \, J/cm^2$, pulsed times $N = 1$ pulses (b), and $N = 3$ pulses (c))
To determine the characteristics of grade nanostructure in surface layer and effect of nanostructure on hardness in surface layer, the nanoindent measurement was made by nanoindent microhardness tester. The hardness along cross section surface of pulsed electron beam specimens is illustrated in Fig. 5. The matrix hardness is about 5.56 GPa and the surface hardness of pulsed electron beam specimens is about 7.11 GPa, the increment of hardness is about 1.55 GPa and increase percentage is 28%. The characteristics of grade nanostructure in surface layer and effect of nanostructure on hardness in surface layer can be determined by nanoindent measurement technology. It can be seen that the gradient of hardness in surface layer about 20 μm as shown in Fig. 5 is greater and this depth is equal to the depth of melt layer illustrated in Fig. 2. The gradient of hardness under the melt layer between 20 to 60 μm is smaller and the gradient of hardness after the distance of 60 μm from surface to 100 μm is also greater.

![Fig. 5 Hardness along cross section surface of pulsed electron beam specimens](image)

The increase in hardness of surface melt layer should be related to the fine grain size and nanostructurization during pulsed electron beam treatment. The higher the hardness with smaller grain size because of greater yield strength, and nanosized width of martensite lathe can be found in the melt layer, as shown in Fig. 6.

![Fig. 6 TEM of pulsed electron beam treated specimens (the parameters of pulsed electron beam treatment are the pulsed time \(t = 50\,\mu s\), pulsed times \(N = 3\) pulses, pulsed energy \(E_5 = 25\,J/cm^2\))](image)

### 4. Conclusion

Completed electron-beam treatment of titanium alloy VT6 in a wide range of beam parameters. Revealed the formation of gradient structure, characterized by regular changes of phase composition and defect substructure of the distance from the surface exposure. A significant (at \(\sim\)20-fold) decreasing of surface roughness processing; average grain size of the surface layer (\(\sim\)4-fold); increasing of microhardness (by \(\sim\)28%). The analysis of structural-phase state of the surface layer and revealed the formation of submicro- and nanocrystalline structure \(\alpha \Rightarrow \beta\) transformation occurring on the martensitic mechanism.

### References


