Influence of IPIB Irradiation on Ti-Al Alloy[1]

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Abstract – Ti base alloy was irradiated by intense pulsed ion beam (IPIB) with 250 kV acceleration voltage, 80 ~ 250 A/cm^2 current density and 60 ns Pulse duration. The surface morphology was observed with optical microscopy and the roughness was measured remarkably. The compositions of corresponding typical morphology were characterized by XEDS. Based on this, the phase transformation was tested by XRD. The results showed that the craters and micro-cracks are induced by IPIB irradiation, which is one of the major factors affecting the irradiated surface roughness; IPIB irradiation leads to composition changes and the appearance of new phase on the surface of Ti base alloy. This may improve some mechanical properties of Ti base alloy.

1. Introduction

Intense pulsed ion beam (abbreviated IPIB) is characterized high current density, high power density, high energy density and short pulse duration. The metal material surface is rapidly heated (~ 10^{11} K/s), melted, gasified and ablated by IPIB irradiation. After the short pulse, it was cooled (~ 10^9 K/s), re-solidification and so a large temperature grads (10^9 K/m), heat stress, stress wave, even shock wave are caused. A series of non-equilibrium induces surface physical, chemical and mechanical property changes. It has been proved that metal surface services properties may be improved remarkably by IPIB irradiation with proper parameters including current density and pulses number [1–3]. On the other hand, Ti base alloy as an important structural metal material was developed in fifty years of 20 century. Then, it is widely used in the fields of aeronautics and astronautics with the advantages of high intensity density, good anti-corrosion, high anti-heating and easy-jointing. Especially, the type of TC Ti base alloy is applied for turbine engine blade and tray with its special advantages of super obdurability, treated with heat, good anti-fatigue et al. It has been the indispensable structural material for modern airplane [4–5]. In this paper, Ti base alloy blade used was irradiated by IPIB with different beam parameters including current density and pulse number and then tested with different methods to find a group of appropriated IPIB irradiation parameter for the mechanical property improvement of Ti base alloy.

2. Experiment

The Ti base alloy was cut into small disk with the size of 10×10×(1–4.5) mm. To study the surface, the original sample was not polished. Then it was cleaned out by ultrasonic in alcohol for about 15 min. The IPIB irradiation was carried out on TEMP-II accelerator of State Key Laboratory for Materials Modification by Laser, Ion and Electron Beams in Dalian University of Technology. The IPIB beams consisted of 30% C^{n+} and 70% H^+. The beam parameters were as follows: 250 kV of accelerating voltage, 80~250 A/cm^2 of current density and 60ns of pulse duration, 1, 5, and 10 pulses. After the irradiation, the morphology and corresponding roughness of surface were observed by optical microscopy and Sloan Dektak II surface profiler; the compositions and phase changes were tested by X-ray energy dispersive spectrometry (XEDS) and X-ray diffraction (XRD).

3. Results and discussions

3.1. Surface morphology observation

Figure 1 gives the optical microscopy photos of the surface morphology of Ti base alloy samples the unirradiated sample (Fig. 1, *a*) and irradiated sample at current density of 80, 150, and 250 A/cm^2 (Figs. 1, *b–i*), respectively.

It can be seen that the irradiated surface was melted and some flat small craters appeared with lower current density of 80 A/cm^2, 1 pulse. But after 5 pulses, the crater density was increased greatly (Fig. 1, *c*).

The surface was melted greatly and the crater with lager size formed at middle current density of 150 A/cm^2, 1 pulse; however, the surface is smoothing only with some small maculae after 10 pulses (Fig. 1, *f*). With higher current density of 250 A/cm^2 and 1 pulse, some wavy lower crater but with larger size were randomly distributed on the surface; but after 5 pulses, the surface is smoothing greatly (Fig. 1, *h*). Noticeably, the deep craters with large size appeared again and some micro-cracks were formed (Fig. 1, *i*), which is a bad result. So, IPIB irradiation with proper beam parameters leads to roughness or smoothing of target surface. With current density increasing, the pulses number needed for the surface smoothing is decreased.

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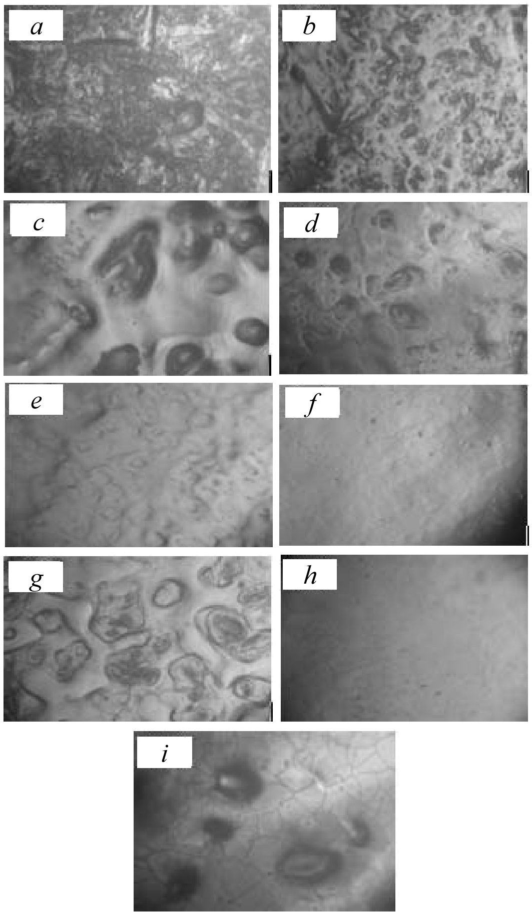

Fig. 1. The optical microscopy images of Ti base alloy irradiated by IPIB: 0 A/cm^2, 400× (*a*); 80 A/cm^2, 1 pulse, 400× (*b*); 80 A/cm^2, 5 pulses, 400× (*c*); 150 A/cm^2, 1 pulse, 400× (*d*); 150 A/cm^2, 5 pulses, 400× (*e*); 150 A/cm^2, 10 pulses, 400× (*f*); 250 A/cm^2, 1 pulse, 400× (*g*); 250 A/cm^2, 5 pulses, 400× (*h*); 250 A/cm^2, 10 pulses, 400× (*i*)

3.2. Surface roughness measurement

In correspondence with Fig. 1, surface profiles are demonstrated in Fig. 2 with horizontal scanning distance of 300 um.

In Fig. 2, we can obtain that surface profile of un-irradiated sample changed greatly. It owned the highest crater density and roughness about 109 um irradiated by IPIB of 80 A/cm^2, 5 pulses (Fig. 2, *c*).The crater density on the surface irradiated at 150 A/cm^2, 10 pulses and 250 A/cm^2, 5 pulses had the minimum value resulting in surface smoothing obviously and the roughness is about 30 um (Figs. 2, *f* and *h*). On the other hand, formation of craters appeared at lower, middle, higher current density means all of the irradiated surfaces melted in the experiment. The roughness measurement results show that IPIB irradiation with proper current density and pulses number leads to the roughness and smoothing indeed and craters become the major reason affecting the roughness of irradiated surface. This result is consistent with the surface morphology observation.

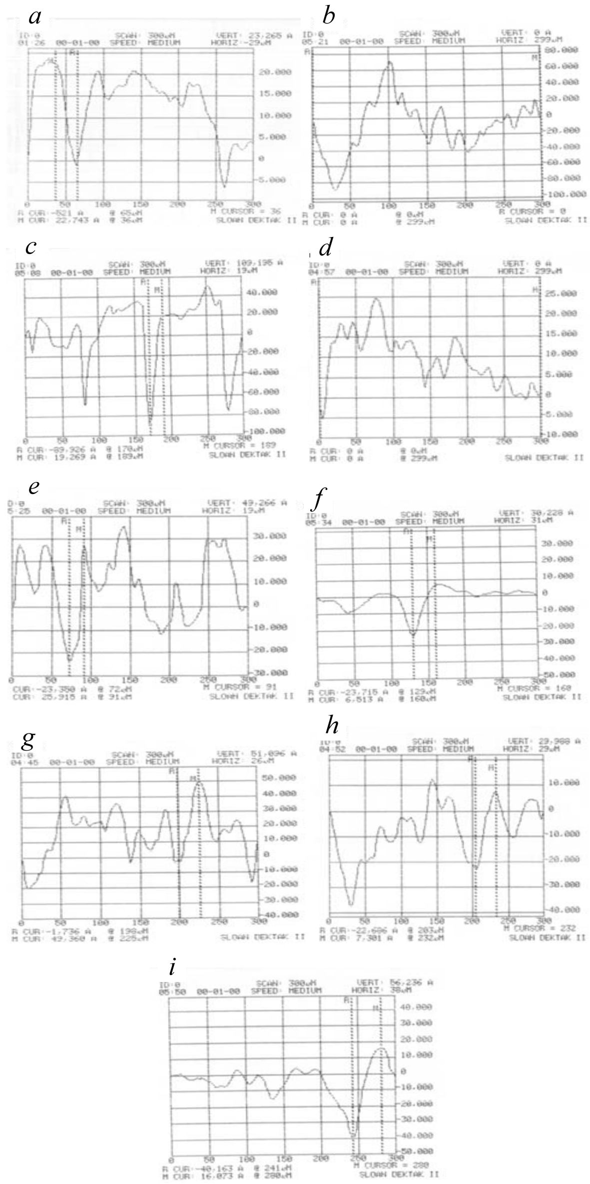

Fig. 2. Roughness on the surface irradiated by IPIB: 0 A/cm^2 (*a*); 80 A/cm^2, 1 pulse (*b*); 80 A/cm^2, 5 pulses (*c*); 150 A/cm^2, 1 pulse (*d*); 150 A/cm^2, 5 pulses (*e*); 150 A/cm^2, 10 pulses (*f*); 250 A/cm^2, 1 pulse (*g*); 250 A/cm^2, 5 pulses (*h*); 250 A/cm^2, 10 pulses (*i*)

3.3. Composition analysis

Table 1 gives the chemical element composition of Ti base alloy.

Table 1. The composition of un-irradiated sample surface

Element	Ti	Al	Mo	Si	C
Wt%	82.07	7.92	0.88	1.15	7.97
At%	62.97	10.78	0.34	1.51	24.40

Ti as substrate element, Al as α-phase stable element, Mo as β-phase stable element and C, Si as impurity element are included. So, the original sample belongs to the type of TC-($\alpha + \beta$) Ti base alloy.

After IPIB irradiation, the typical morphology appeared and the corresponding composition changed obviously. The contents of C is increased to some extent at the area of crater, white heave and hole area, which indicates these areas were polluted by C because of IPIB irradiation. Supposing that C element is from vacuum target chamber, C pollution on all the irradiated surfaces at the different beam parameters should be observed and C element should distributed averagely on the surface not located in the local area, which is not consistent with the SEM photos. So, we think that these C grains from anode adulterated in beam current were irradiated on target surface with the beam current. In addition, with the current density increasing, the size of grains becomes larger. One possible reason is C, O as extra elements contained in diode producing IPIB were irradiated on the molten surface with beam current. However, its speed is lower than that of ion, it is melted on the surface by the next pulse. Moreover, the appearance of this extra elements may improve the anti-oxidation of the sample surface. Besides, the content of Mo element is increased greatly at the white dots area, which indicates the Mo element is enriched obviously on the irradiated surface. In addition, Fe is also appeared; but it is not existed in the other irradiated samples. So, it is possibly from target chamber or grinding material induced by incising.

The composition of surface changed obviously after IPIB irradiation with different parameters. Especially Al and Mo contents change may result in phase transformation and then affects some mechanical property. Particularly the content of Al changes. Because Al as the main α-phase stable element, plays the same important part as the role C plays in the steel. It is mainly to restrict β-phase section and then improve the transformation temperature and increase the solubility of β-phase stable element such as Mo in the α-phase. However, the content of Al should not too much (Wt% < 8–9%); otherwise, the metal compounds such as Ti_3Al are formed. Although the working temperature is able to reach 900 °C, Ti_3Al will greatly reduce the model property and tenacity of the Ti base alloy [6–7]. But in our experiment, the Al contents of all the typical areas induced by IPIB irradiation and the un-irradiated sample are no much than 8% as illustrated in Tables 1 and 2.

So, the model property and tenacity of Ti base alloy are not reduced by IPIB irradiation. Besides, the hardness and wear resistance of IC6 alloy samples irradiated by IPIB at the current density 150A/cm^2 have been increased. Moreover, the increase in contents of Al and O element means the formation of Al_2O_3, which is favorable for anti-oxidation improvement [8].

Table 2. XEDS results of various typical area on the Ti base alloy irradiated by IPIB

Irradiation parameter	Area	Element	Wt %	At %
80 A/cm^2, 5 pulses	Crater area	Ti	88.93	82.08
		Al	7.64	12.52
		Mo	*	*
		Si	3.43	5.41
		C	*	*
	White dot area	Ti	32.26	21.74
		Al	5.29	6.32
		Mo	33.50	11.27
		Fe	2.91	1.68
		Si	*	*
		C	9.62	25.86
		O	16.42	33.13
150 A/cm^2, 1 pulse	White heave area	Ti	42.23	16.07
		Al	3.13	2.12
		Mo	0.49	0.09
		Si	0.54	0.35
		C	53.61	81.37
250 A/cm^2, 5 pulses	Hole area	Ti	66.45	36.64
		Al	5.95	5.83
		Mo	0.14	0.04
		Si	0.44	0.41
		C	22.73	49.99
		O	4.3	7.09

* Denotes the exact content of element is not calculated in this experiment.

3.4. Phase transformation

XRD diffract grams of the un-irradiated and irradiated samples are shown in Fig. 3. The un-irradiated sample mainly consisted of α-Ti and β-Ti as illustrated in Fig. 3, *a*. So, the sample belongs to the type of (α + β) that is consistent with the XEDS results of Table 1.

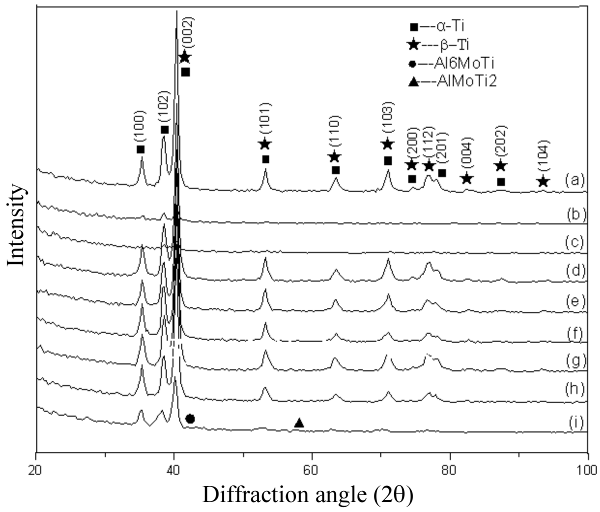

Fig. 3. XRD diffract grams of the sample surface irradiated by IPIB of 0 A/cm^2 (*a*); 80 A/cm^2, 1 pulse (*b*); 80 A/cm^2, 5 pulses (*c*); 150 A/cm^2, 1 pulse (*d*); 150 A/cm^2, 5 pulses (*e*); 150 A/cm^2, 10 pulses (*f*); 250 A/cm^2, 1 pulse (*g*); 250 A/cm^2, 5 pulses (*h*); 250 A/cm^2, 10 pulses (*i*)

While after irradiated by IPIB at low current density of 80 A/cm^2, only 3 diffraction peaks (101), (002), and (100) of the α-phase and (002) of the β-phase remained but intensity decreased remarkably as Figs. 3, *b–c* illustrated. This is related to the roughness of the surface and analyzed result is consistent with the surface morphology observation and roughness measurement. After irradiated by IPIB at the moderate current density of 150 A/cm^2, the intensity of diffraction peak (101) holds the line; but after 10pulses, diffraction peak (200), (112), and (201) has been broadened obviously and even disappeared (Fig. 3, *f*). It suggested the formation of minor amorphous phase on the surface of samples under IPIB irradiation with a moderate current density 150 A/cm^2. And the amorphous layer is also formed on the surface irradiated by a high current density of 250 A/cm^2, 5 pulses (Fig. 3, *h*). Noticeably, the new phase Al_6MoTi and $AlMoTi_2$ appeared on the surface by IPIB irradiation at 250 A/cm^2, 10 pulses (Fig. 3, *i*). We think that the heating and cooling rate (10^{11} and 10^9 K/s) on the surface of irradiated sample increases with the increasing power density of IPIB. The temperature of surface area rise quickly to a higher level with the current density increase to 250 A/cm^2, which promoted the redistribution of the chemical elements in the surface layer. Thus, the new phase formed.

4. Conclusion

1. IPIB irradiation with proper beam parameters leads to roughness or smoothing of a target surface. With current density increasing, the pulses number needed for the surface smoothing is decreased. And craters are major reason affecting the roughness of irradiated surface.

2. The surface irradiated by IPIB of 80 A/cm^2, 5pulses owned the highest crater density and roughness. And it becomes smoothing greatly by IPIB irradiation with 150 A/cm^2, 10 pulses or 250 A/cm^2, 5 pulses. The pulses number needed for the surface smoothing at current density of 80 A/cm^2 is to be further investigated in the future.

3. IPIB irradiation leads to variations in typical morphology area. Mo element is enriched on the irradiated surface and C element content is increased. The contents of Ti as substrate element and main alloy elements Al, Mo changed that makes phase transformation.

These results show that IPIB is an effective method for material surface processing. The experimental results and theoretical consideration showed that it was the most effective condition at the current density of 150 A/cm^2, 10 pulses or 250 A/cm^2, 5 pulses that affects the surface and its mechanical properties of Ti base alloy.

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