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Influences of the Irradiation of Intense Pulsed Ion Beam (IPIB) on the Surface of Ni_3Al Base Alloy IC6

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Abstract

In this paper, we treated the Ni_3Al based alloy samples with intense pulsed ion beams (IPIB) at the beam parameters of 250KV acceleration voltage, 100 - 200 A/cm^2 current density and 60 ns pulse duration. We simulated the thermal-mechanical process near the surface of Ni_3Al based alloy with our STEIPIB codes. The surface morphology and the cross-section microstructures of samples were observed with SEM, the composition of the sample surface layer was determined by X-ray Energy Dispersive Spectrometry (XEDS) and the microstructure on the surface was observed by Transmission Electron Microscope (TEM). The results show that heating rate increases with the current density of IPIB and cooling rate reached highest value less than 150 A/cm^2. The irradiation of IPIB induced the segregation of Mo and adequate beam parameter can improve anti-oxidation property of IC6 alloy. Some craters come from extraneous debris and liquid droplets, and some maybe due to the melting of the intersection region of interphase. Increasing the pulse number enlarges average size of craters and decreases number density of craters.

1. Introduction

As an effective flash heating source, intense pulsed ion beam (IPIB) has been developed extensively, especially in the field of material surface treatments in recent years. As the beam energy of IPIB is compressed intensively via spatio-temporal axes, it could produce a fast heating, melting, vaporizing or even ablating and following a fast cooling process near the surface of target material during the irradiation. Subsequently it induced many physical and mechanical effects in the targets. Many studies focused on the developing its applications and their mechanisms in material science have been carried out by the scientists in Russia, Japan, USA, China and so on [1-3].

Fig. 1. The TEM observation of the microstructure on the surface of untreated IC6 surface.

For metallic material, the development of the intermetallic-based alloy for structural application has been an active direction around the world for more than 20 years. A high-performance λ'-Ni_3Al base casting alloy named Alloy IC6 was recently developed in the Beijing Institute of Aeronautical Materials for advanced aero-engine blades and vanes operation in

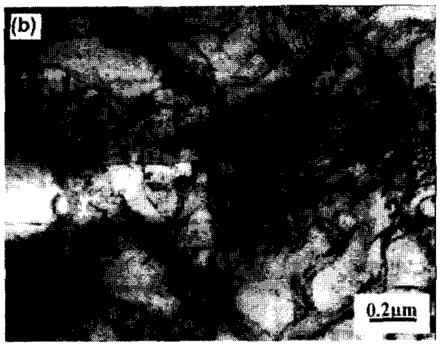

Fig. 2. The TEM observation of the microstructure on the surface of IC6 irradiated by IPIB with current density of 100A/cm^2.

the temperature range 950 to 1100℃ [4]. The alloy was composed of Ni - (7.4~8.5) Al - (12~15) Mo - (<0.1) B % (wt). IPIB irradiation was performed to improve its high temperature oxidation behavior. In this paper, we observed the influences of IPIB irradiation on the surface of IC6 alloy.

2. Experimental and Calculations Details

The IC6 samples were prepared by cutting to thin pieces out from column crystal of the original materials along the direction of its growth. Each sample was 2 mm thick and both sides were polished for the IPIB irradiation. Samples were divided into four groups: one is control sample and another three were irradiated by IPIB with different parameters. The IPIB irradiation experiments were carried out on the TEMP accelerator of Tomsk Polytechnic University, Russia, and the beam derived from its ion diode consists of 30% H^+ and 70%C^{n+}. The beam parameters in our experiment are shown in table 1.

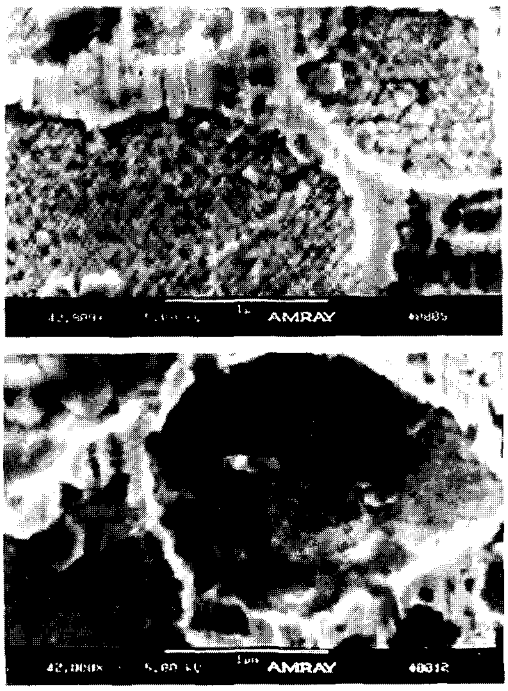

Fig. 3. SEM photo of cross-section of IC6 samples (a) untreated sample and (b) irradiated by IPIB with current density of 200A/cm^2.

After the IPIB treatment, samples were etched by the solution of 1:1:3 HNO_3 + HF + glycerin. Then the surface morphology and the cross-section microstructure of samples were observed with S-4200 SEM, the composition of the sample surface layer was determined by X-ray Energy Dispersive Spectrometry (XEDS) and the microstructure on the surface was observed by Transmission Electron Microscope (TEM) [5].

The calculation of the temperature distributions were carried out by the code STEIPIB developed in our group [6]. The Einstein model was used to evaluate the heat capacity in our calculations and energy deposition profiles were calculated by SRIM codes [7].

3. Results and Discussion

Figs. 1 and 2 manifest the microstructure changes on the surfaces of IC6 samples after the irradiation of IPIB. Fig. 1 shows the TEM photo of untreated surface and Fig. 2 shows the surface treated by IPIB with current density of 100A/cm^2. After the IPIB irradiation, there are many defects and dislocations distributing on the sample surface. There are obviously changes in the interphases especially. It could be

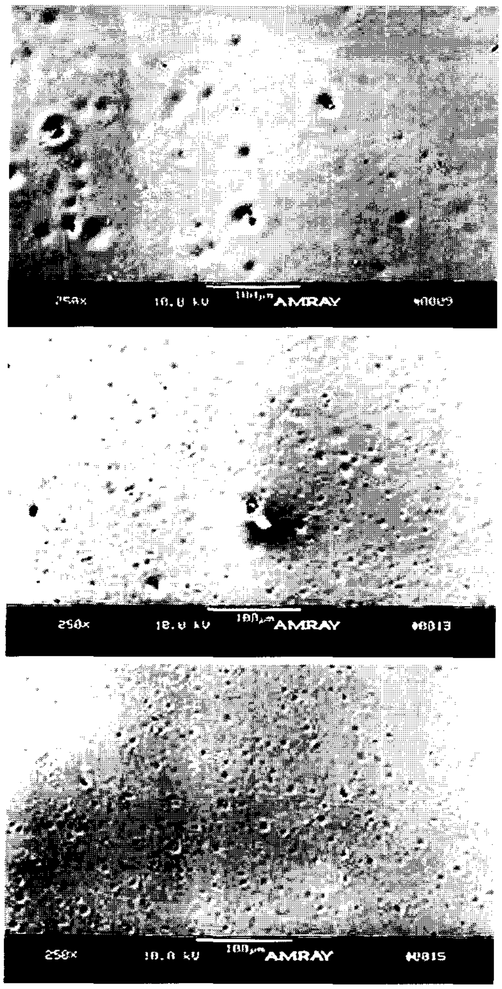

Fig. 4. Surfaces of IC6 irradiated by IPIB of 100A/cm^2 (a), 150A/cm^2 (b), 200A/cm^2 (c).

Table 1 IPIB irradiation parameters.

Sample	Acceleration Voltage (KV)	Current Density (A/cm^2)	Pulse Duration (ns)	Shot Number
Ⅰ	-	-	-	-
Ⅱ	250	100	60	24
Ⅲ	250	150	60	16
Ⅳ	250	200	60	12

deduced that heating effects were more intensive in the interphase region and melting process happened there firstly.

Figure 3 shows the SEM photos of cross-section of the IC6 samples, in which (a) is the 42800x photo of the untreated sample and (b) is the 42800x photo of the sample irradiated by IPIB of current density 200A/cm^2. We find a fine structure in (b).

Figure 4 illustrates the sizes and distributions of craters at different irradiation condition. The current density are 100A/cm^2, 150A/cm^2, 200A/cm^2, respectively. We could deduce that as the increasing of shot numbers, the size of craters also increased, but the density of craters decreased. The size and distribution of craters seems to be affected by current density slightly.

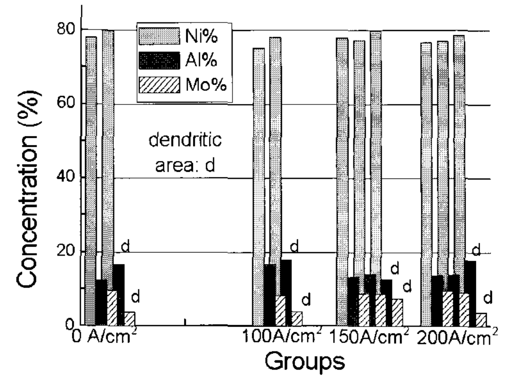

Fig. 5. XEDS results near the surface layer of IC6 sample.

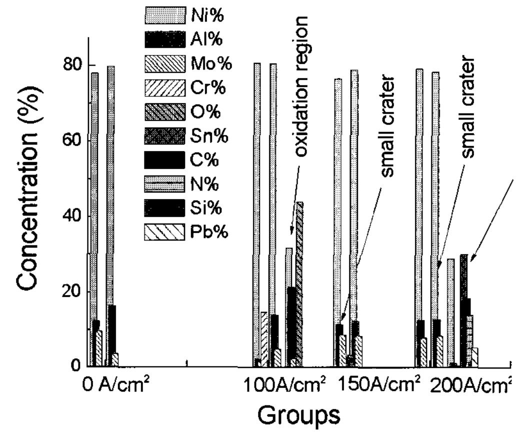

Fig. 6. XEDS results on the surfaces of IC6 samples.

Figure 5 gives the XEDS results of the IC6 cross-section near the surface layer and Fig. 6 gives the XEDS results at various points on the IC6 sample surfaces. From Fig. 5, we may conclude that for the IC6 alloy irradiated by IPIB with current density of

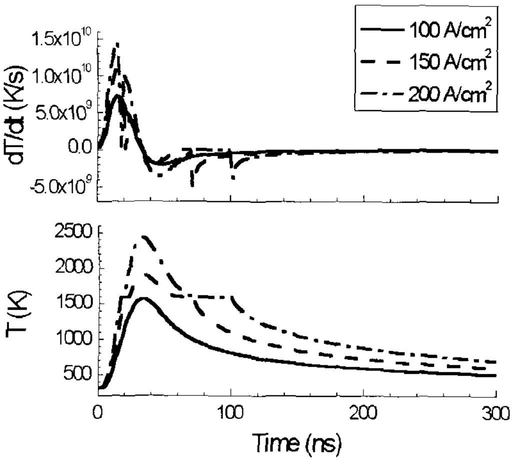

Fig. 7. Calculated Temperatures and their rates on the surfaces of IC6 samples.

150 A/cm^2, unlike the other two groups, the contents of three major components in deferent phases tent to be similar. The content of Al in the dendritic region increase obviously but the average value decreased. Contrast to Al, the content of Mo increased in both the dendritic and interdendritic region, and so the average content of Mo increases in the surface layer. This could be deduced from Fig. 6 as well. According to the experiment in Ref. [8], such changes of the composition of IC6 alloy, especially the content of Al, would led to strengthen or weaken the mechanical properties. This sample also shows the better anti-oxidation property of the alloy surface than the others [5].

Compare to the above case, the content of Al increased but the contents of Mo decreased while the IC6 sample was irradiated by IPIB of current density 100 A/cm^2. And the composition of surface layer was kept at its original value after treated by IPIB of current density 200 A/cm^2.

Figure 7 demonstrates calculated temperatures on the surface of IC6 samples while irradiated by IPIB of 250 keV at various current densities. The varying rates of temperatures are also shown in the same figure.

Through our calculation, the surfaces of IC6 samples experienced a violent thermal-dynamical process on the surface layer. At all of three current densities, IC6 samples surface reach to or nearly reach to their melting points. The heating rates reached 0.5×10^{10} to 1.5×10^{10} K/s and cooling rate reached 0.5×10^{10} K/s as well.

According to the calculation, the cooling rates at the resolidifying point were 2.0×10^9, 3.9×10^9, 5.2×10^9 K/s, respectively. So the surface melting states were recorded here, such as the wavy craters shown in Fig. 4. Figure 6 also demonstrates the large wavy craters were the droplets outside the samples of which the compositions were far deferent from the one of IC6. But comparing the groups of 150 A/cm^2 and 200 A/cm^2, we may find that there also existed the small craters keeping the composition beneath surface. It means that the craters were formed via at least two paths-outside liquid droplets and melting of intersection region of interphase.

4. Conclusions

1. Heating rate increases with the current density of IPIB and cooling rate reached highest value less than 150 A/cm^2.
2. The irradiation of IPIB with an adequate beam parameter induced the segregation of Mo and improved anti-oxidation property of IC6 alloy.
3. Some craters come from extraneous debris and liquid droplets, and some maybe due to melting of the intersection region of interphase.
4. Increasing the pulse number enlarges average size of craters and decreases number density of craters.

Acknowledgements

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