The Corrosion Behavior of Ni-Based Superalloy Irradiated by Intense Pulsed Ion Beam

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The Corrosion Behavior of Ni-Based Superalloy Irradiated by Intense Pulsed Ion Beam

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Abstract: Intense pulsed ion beam (IPIB) has been extensively used in the surface strengthening of metal materials in the past decades. Quite a lot of these materials need to be operated in the corrosive environment. Therefore, it is of significance to research the corrosion behavior of metal materials after IPIB irradiation. In this work, the corrosion behavior of Ni-based superalloy irradiated by IPIB in NaCl solution was studied. Compared to the original samples, after IPIB irradiation the corrosion resistance of samples were improved, and craters were formed on the surface of Ni-based super alloys. It is found that micro-areas with craters would be eroded prior to other areas in caustic solutions. The analysis revealed that craters play an important role in the corrosion process of the metal after irradiation. This research would help understand the influence of craters induce by IPIB on the operational performance of metal materials.

1. Introduction

Intense pulsed ion beam (IPIB) is a kind of flash heat sources, which has been extensively used in material surface modification, especially for engineering materials [1]. Because of the short pulse duration and high energy density of the beam, after IPIB irradiation the temperature of the marital surface will rise rapidly (heating rate 10^8 -10^{11} K/s) accompanied by the shock waves being ignited by the thermal shock in the target [2]. In past works, it has been shown that the corrosion resistance of some materials such as steels, magnesium alloys can be increased by IPIB irradiation. There are many explanations to comprehend the improvement of corrosion resistance for materials after irradiation, including grain refinement, the ablation of alloy components with low melting point, the formation of amorphous structure and so on [3,4]. However, the corrosion behavior of micro region in irradiated material is not clear.

Ni-based superalloy is commonly used in engines vanes, cartridge receiver and other aviation parts due to its excellent property of high strength and oxidation resistance [5]. They always have to be in touch with corrosive liquids during manufacture and operation [6]. Once the corrosion happened on the material surface, the surface properties of materials will deteriorate rapidly. Therefore, the corrosion resistance of Ni-based superalloy is very important for its performance.

In this work, we studied the electrochemistry corrosion behavior of Ni-based superalloy before and after IPIB irradiation and explored the mechanism of electrochemistry corrosion process. The result will be helpful for the application of Ni-based superalloys.

2. Experiments

2.1 Materials

The compositions of Ni-based superalloy used in this study are shown in Table 1. The dimension of samples is 10×10×3 mm. Before irradiation, the samples were polished by 3000# silicon carbide sandpaper using ultrasonic cleaning in alcohol.

Table 1. Composition of Ni-based superalloy samples (in wt.%).

Cr	Fe	Mo	Mn	Al	Ti	S	C	Ni
17.0~20.0	≤4.0	4.0~5.0	≤0.5	1.0~1.5	2.2~2.8	≤0.01	≤0.08	based

2.2 Irradiation parameters

Irradiation experiments were performed on TEMP-4M accelerator at Tomsk polytechnic university. The parameters used in this work are as follows: ion beam composition of 70% C^{n+} and 30% H^+, accelerating voltage of 250kV, energy density of 2 J/cm^2 and pulse duration of 60 ns. The morphology of the samples was studied in Nova NanoSem 430 scanning electron microscope and the analysis of the element was carried out by the affiliated EDS accessory.

2.3 Electrochemistry test

Irradiation experiments were performed on TEMP-4M accelerator at Tomsk polytechnic university. The parameters used in this work are as follows: ion beam composition of 70% Cn+ and 30% H^+, accelerating voltage of 250kV, energy density of 2 J/cm^2 and pulse duration of 60 ns. The morphology of the samples was studied in Nova NanoSem 430 scanning electron microscope and the analysis of the element was carried out by the affiliated energy dispersive spectroscopy (EDS) accessory.

3. Results

3.1 Surface morphology after IPIB irradiation

Fig.1 displayed the change of sample's surface morphology after IPIB irradiation. As shown in Figure 1. (a), there are wispy scratches left on the original sample after polishing. After IPIB irradiation, these scratches began to smooth and disappear owing to the effect of melting and flowing of the surface material. In the meanwhile, craters appeared (Figure 1. b). The result of EDS (Table.2) revealed that

Mg, S, C and other impurity elements gathered on the center of crater. It has been proved that the eruption of alloy components with a low melting point can generate craters on material surface [7]. Cracks were also found in the center of craters (Figure 1. c), which were the result from the thermal stress induced by energy deposition and shrinkage during surface material solidification.

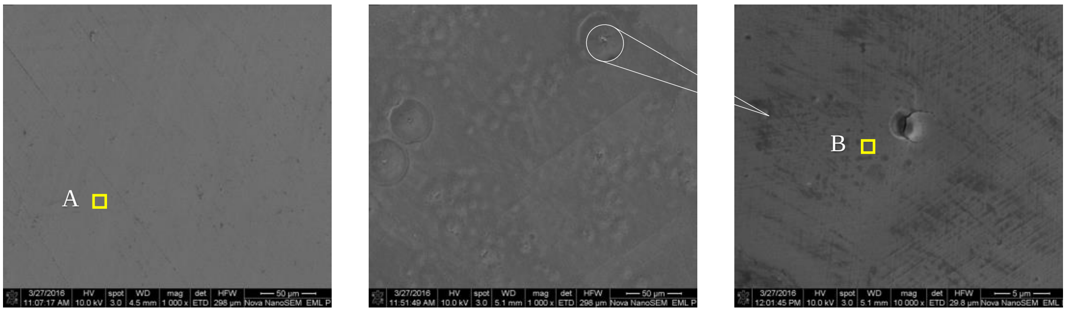

Figure 1. Surface morphology of samples: original sample (a); 2.0J/cm^2, 1 shot (b); enlarged image of crater (c)

Table. 2 Compositions of region marked in Fig. 1 (*Atom %).*

Region	C	O	Ti	Cr	Ni	Al	Mo	Mg	S
A	5.99	2.39	2.50	18.81	67.27	1.00	2.03	——	——
B	22.24	30.67	3.10	4.82	11.65	——	——	20.85	6.66

3.2 Electrochemistry test result

Figure 2 shows the polarization curves of samples in 3.5 wt. % NaCl solutions. The shapes of curves compared, the similar variation tendency revealed that the mainly eroded components between the original and irradiated samples were similar. The test results were given out Table. 3 and the corrosion current density was conducted by Tafel extrapolation. The increase of corrosion potential and decrease of corrosion current density illustrated that the corrosion resistance of Ni-based superalloy was improved after IPIB irradiation. The improvement of corrosion resistance can be caused by the grain refinement induced by IPIB irradiation.

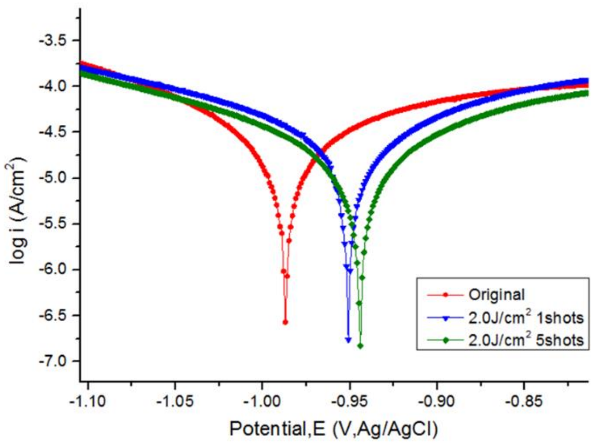

Figure 2. The polarization curves of original, 1shot and 5shots with 2.0J/cm^2 samples.

3.3 Morphology of samples after corrosion

Fig. 3 shows the morphology of the original sample after 5 min corrosion. Large cracks and corrosion damage appeared and the granular corrosion products were found. Compared with the original sample, the corrosion behavior of the irradiated sample was non-uniform (Fig. 4). Clearly, craters would be prior to be eroded than other regions and a deeply corrosion hole appeared in the center of the crater (Fig. 5). This phenomenon can be specified by three major factors. Firstly, the crack in the center of the crater will accelerate the corrosion process. The specific surface area of the micro-region increased due to the cracks. Moreover, narrow space inside cracks were insufficient for the adequate exchange of ions in the solution. Secondly, impurity elements Mg, S, C which were concentrated on the center of craters were more active than other alloy elements. So, they would precede to be oxidized and dissolved into solution. Thirdly, the curvature of the edge of the crater was larger than other regions, it meant that charges in the solution would be relative gathered to promote the corrosion process.

Table. 3 Comparison of electrochemistry corrosion parameters of samples.

Sample	Corrosion Potential（V）	The Logarithmic of Corrosion Current Density (A/cm^2)
original	-0.987	-4.547
2.0J/cm^2, 1shot	-0.951	-4.585
2.0J/cm^2, 5shot	-0.944	-4.652

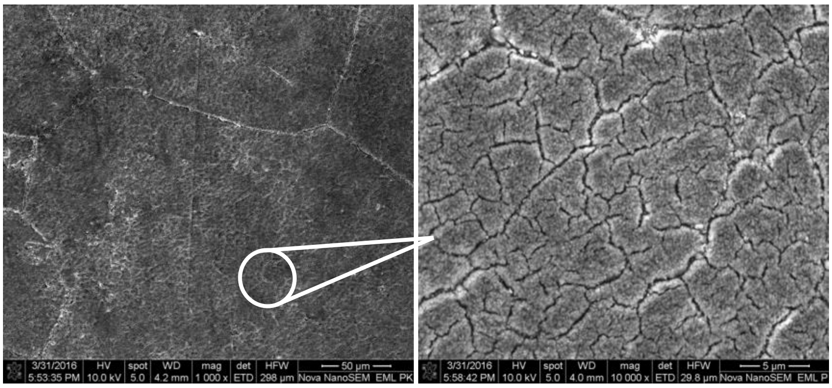

Figure 3. The morphology of the original sample after 5 min electrochemistry corrosion. (The right one is the enlarged image on the left).

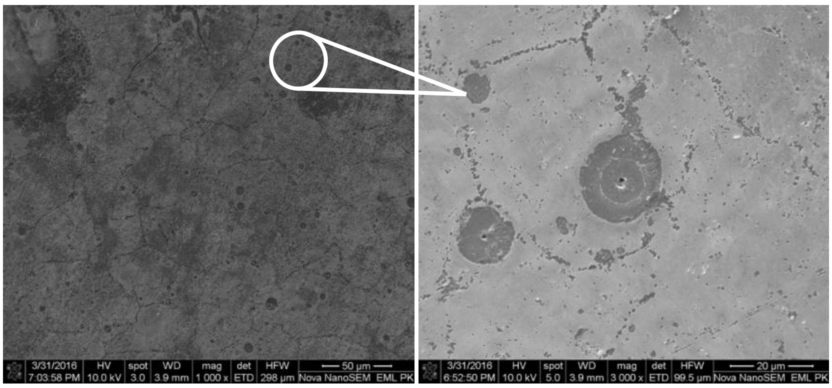

Figure 4. The morphology of the sample irradiated by 2J/cm^2, 1shot and 5 min electrochemistry corrosion. (The right one is the enlarged image of the left)

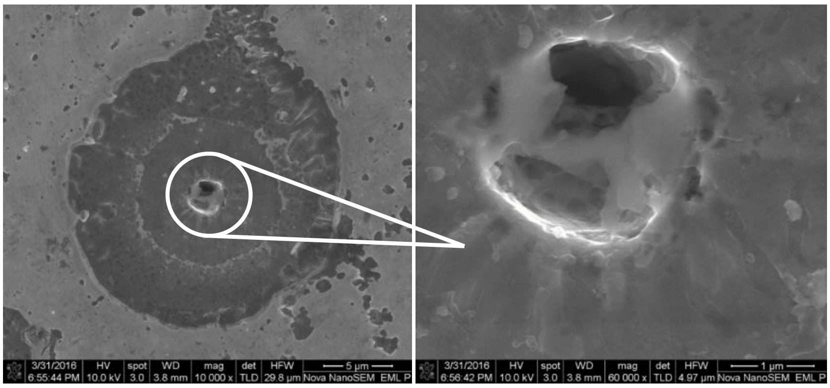

Figure 5. Enlarged images of craters after corrosion. (The right one is the enlarged image on the left)

4. Conclusion

Under the irradiation of IPIB, craters appear on the surface of the Ni-based superalloy. Through the analysis of electrochemistry corrosion process, it is found that the corrosion resistance in 3.5 wt. % NaCl solution of Ni-based superalloy will be improved after IPIB irradiation. In the meanwhile, the corrosion behavior becomes non-uniform compared with the original sample due to that fact the craters will be the first regions to be eroded.

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