Research on depositing Ni45 alloy on titanium alloy surface by electrospark deposition

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Abstract: Taking Ni45 bar as electrode, a strengthened layer of thickness up to 50 μm was built up on BT20 titanium alloy matrix by means of electrospark deposition. Results of phase analysis by using of X-ray diffraction confirmed that the deposition layer was composed mostly of three phases, NiTi, $NiTi_2$ and Ti. The surface microhardness of the deposition layer was up to 910 HV0.05, about 2.7 times as high as that of the matrix. The hardness at the cross-section of the entire deposition layer showed a gradient distribution. The effects of capacitance and deposition time on thickness of deposition layer were also studied, and results showed that with relatively low capacity and short deposition time the deposition layer without cracks can be obtained.

Key words: titanium alloy; electrospark deposition; Ni45

CLC number: TG 146.2$^+$3 Document code: A Article ID: 1672-6421(2008)04-0244-05

Titanium alloy is widely used in aviation, spaceflight, military and chemical industries for its advantages such as low-density, high specific strength and high corrosion resistance [1]. However, titanium alloy is of low hardness, high friction coefficient and low wear resistance, and when being used as sliding parts, there would be adhesive wear between its surface and other materials. The low wear resisting property has been seriously restricting the application of titanium alloy [2]. Therefore, how to improve the surface hardness and wear resistance has become another focus on research and application for titanium alloy. Electrospark deposition is a surface improvement process developed from electrospark machining technology in recent years. It makes electrode material deposit on the surface of metal matrix by the electrical pulse discharge. In such process, the metallurgical reaction between the electrode material and matrix creates a strengthened coating of low friction coefficient and high hardness on the surface of titanium alloy that can improve the wear resistance and corrosion resistance of the alloy [3].

Recently, many scholars at home and abroad have applied YG8, YT15, graphite, Ni and some conductive composites as electrode materials in the electrospark deposition process on titanium alloy, and have received different hardening effects. As a Ni-based alloy, Ni45 was often being used as coating material in thermal spray treatment for metal materials to improve their surface resistance to high temperature, wear and corrosion environments. In the present study, Ni45 alloy was used as electrode and deposited on the surface of BT20 titanium alloy. The microstructure and microhardness of deposition layer were analyzed.

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Received: 2008-04-25; Accepted: 2008-08-02

1 Experimental procedures

In this experiment, BT20 is selected as the matrix alloy, the chemical composition of which is listed in Table 1. Test samples were cut to the size of 15 mm × 15 mm × 4 mm by linear cutting, ground using #1000 sand papers to remove the surface oxidation layer, then cleaned with acetone and dried. The Ni45 alloy bar with about 5 mm in diameter was used as electrode, and its chemical composition is given in Table 2.

Table 1 Main chemical composition of BT20 alloy (wt.%)

Element	Ti	Al	Zr	Mo	V
Content	Bal.	5.5–6.8	1.5–2.5	0.5–2.0	0.8–2.5

Table 2 Main chemical composition of Ni45 alloy (wt.%)

Element	Ni	Cr	B	Si	Fe	C
Content	Bal.	8.9	1.8	4.0	3.0	0.35

The experiment equipment was a 3H-ES surface hardening machine equipped with argon protective device, with an adjustable capacity ranging 60-1,200 μF. The D/max 2500PC X-ray diffractometer was employed to analyze the phases of the deposition layer, and S-3400N scanning electron microscope for microstructure and chemical element analysis. OLYCIAm3 optical microscope was used for microstructure observation over the cross section of the deposition layer. The 10 ml HF + 5 ml HNO_3 + 85 ml H_2O aqueous solution was selected as reagent. Microhardness of the deposition layer was measured using a JIMT-3 hardness-testing device with 50 g load level and 15 s loading time.

2 Results and Discussion

2.1 Surface morphology of the deposition layer

Observing the surface morphology of Ni45 deposition layer under SEM (as shown in Fig.1), countless overlaps can be seen in a pattern like sunflower. The reason was that during the strengthening process there were a lot of pulse discharges between matrix and electrode, the time duration of pulse discharge was extremely short (about 20 μs) [4], and the energy highly centralized on a very small discharge area. Then the high temperature generated by discharges made matrix and electrode melt instantaneously, and the droplets sputtered under the plasma jet generated by discharges, resulting in many deposition spots after solidification. Deposition spots were constantly remelted and interlaped during the deposition process, gradually forming a deposition layer with final thickness.

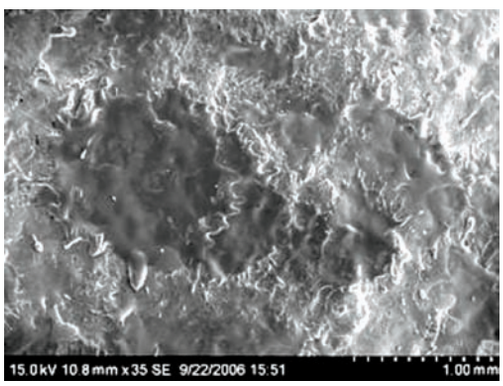

Fig.1 Surface morphology of Ni45 deposition layer

The element analysis on the surface of deposition layer was carried out, and the result is shown in Fig.2. The analysis result indicated that the electrode element content in the deposition layer was high, while the Ti content was lower than that of matrix, suggesting that during the deposition process the material of electrode transferred to the surface of matrix and reacted with matrix element to form alloy layer.

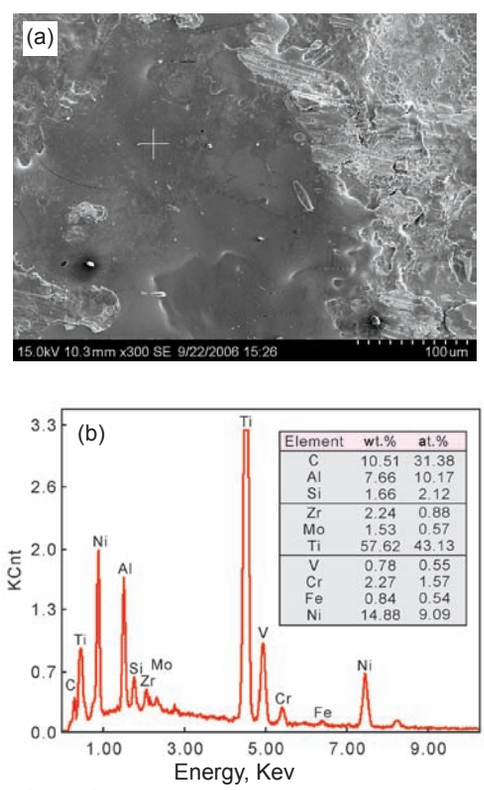

Fig.2 Surface of Ni45 deposition layer (a) and element point analysis (b)

2.2 Phase analysis of the deposition layer

The result of phase analysis at the deposition layer using X-ray diffraction (XRD) is shown in Fig.3. It can be seen that the deposition layer mainly contained three phases including NiTi, $NiTi_2$ and Ti. The NiTi and $NiTi_2$ were the new phases generated by the reaction between Ni from the electrode and Ti in the matrix in the deposition area, while the Ti phase was directly from the matrix. Obviously, the phase structure of the matrix surface changed under the electrospark deposition treatment, and the deposition layer was not simple accumulation of electrode material, but a product generated by alloying reaction between electrode and matrix in the micro-scale discharge area.

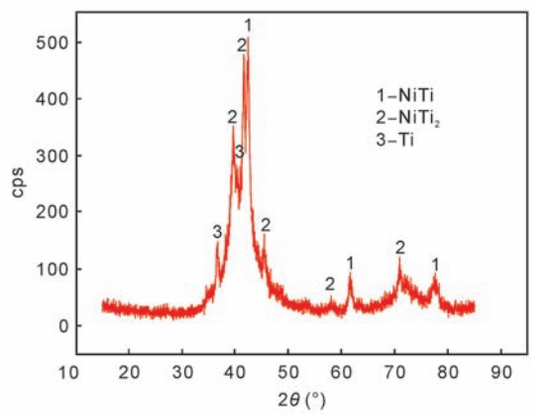

Fig.3 XRD spectrum of Ni45 deposition layer

2.3 Microstructure and element distribution of the deposition layer section

Through observation over the cross section of deposition sample under optical microscope, the surface of matrix was seen covered with a white-bright layer, or the deposition layer with a thickness of about 20–50 μm (as shown in Fig.4). The molten alloy of deposition layer solidified rapidly at high cooling rate (about 10^8℃/s) after sputtered on the matrix, then the rapidly solidified alloy formed the structure of fine-grain and even microcrystal. The compact fine-grain structure was hardly corroded by HF so the deposition layer looked white-bright under optical microscope [5].

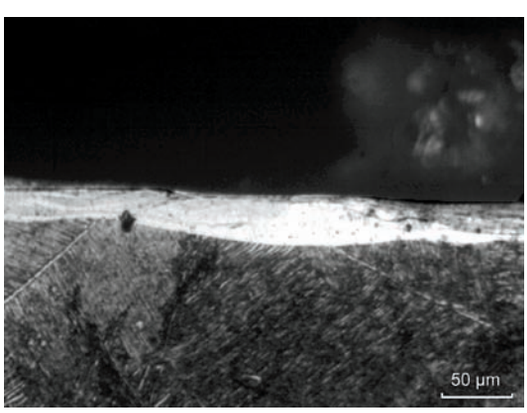

Fig.4 Metallurgical structure of Ni45 deposition layer

Spot element analysis was conducted at points 1, 2 and 3 on the cross section of the sample as shown in Fig. 5. Point 1 was located in the middle of deposition layer where the electrode element content was up to 35wt.% and the matrix element content was at about 65wt.%, indicating that there was material migration between electrode and matrix under discharge. Point 2 was at the interface where the electrode element content was slightly reduced (about 28wt.%) but the Ti content increased. Point 3 was within the matrix area, so there was virtually no electrode element content.

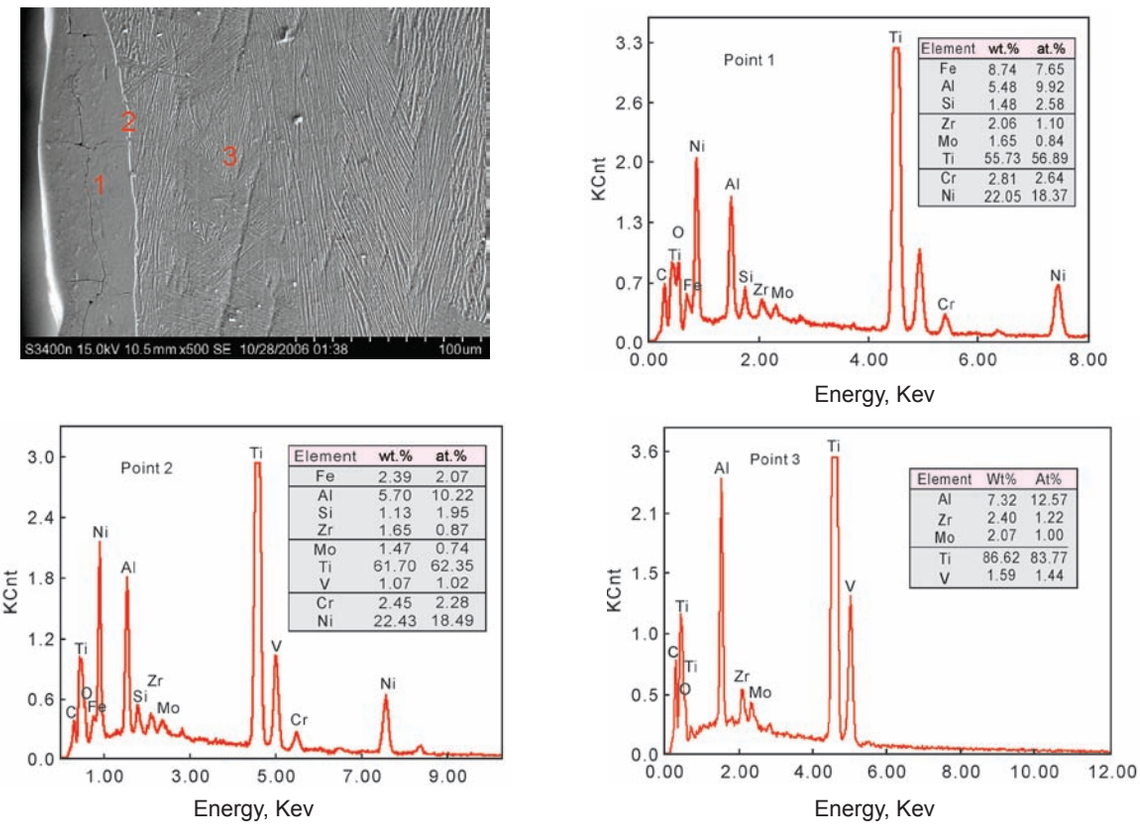

Fig.5 Element point analysis of Ni45 deposition layer section

Line scanning method was also applied during the element analysis to examine the element distribution from the deposition layer to the matrix (as shown in Fig.6), showing that the content of electrode elements in deposition layer was higher and gradually decreased towards matrix. The results of the combined spot and line element analysis demonstrated that there existed an element transition zone with a width of only several microns between matrix and deposition layer, and that in this transition zone the elements content changed gradually.

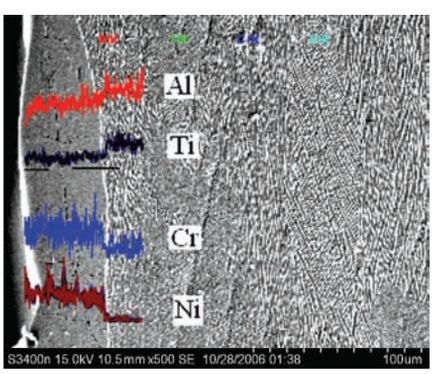

Fig.6 Element line analysis of Ni45 deposited layer section

2.4 Hardness of deposition layer

The purpose of electrospark deposition treatment is to form a strengthened layer of high-hardness on the surface of matrix so as to improve the wear resistance of matrix. Since the hardness of deposition layer is a very important indicator for strengthening effect, the microhardness was measured at different positions of the Ni45 deposition layer to evaluate its hardness distribution. Figure 7 is the hardness distribution curve of deposition layer section, showing that the hardness of matrix was only 330 HV0.05, but the surface hardness of deposition layer was as high as 910 HV0.05. Compared with matrix, the hardness of deposition layer had increased by 1.7 times. The hardness of whole deposition layer in cross section was basically in a gradient distribution, which avoided hardness mutation at interface and reduced the

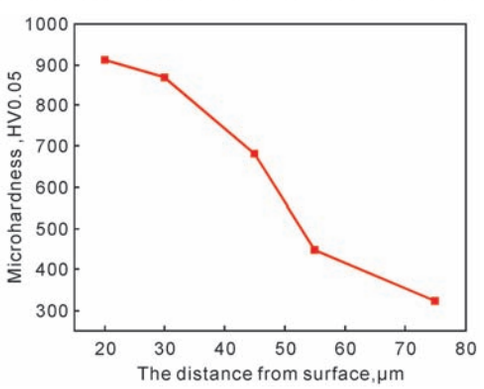

Fig.7 Hardness distribution curve of Ni45 deposited layer

contradiction between hardness and toughness [6, 7]. The higher hardness in deposition layer than matrix was mainly due to the high content of electrode materials and hard phases such as NiTi and $NiTi_2$ generated by discharge. The fine-grained microstructure of deposition layer was another reason for the increased hardness.

2.5 Effects of process parameters on the thickness of deposition layer

The capacity and deposition time are important parameters in the electrospark deposition process. In this study, the effects of these two parameters were analyzed on the thickness of deposition layer as other parameters were fixed as constant. Because of the color difference of the deposition layer from that of the matrix under optical microscope, the thickness of deposition layer could be measured by metallographic method.

(1) Effect of capacity on deposition layer thickness

In order to analyze the effect of capacity on deposition layer thickness, different capacity levels were chosen for deposition treatment along with the fixed parameters as selected in Table 3.

Table 3 Parameters of deposition under different capacity

Voltage V	Deposition time min•s^{-1}	Argon flow rate L•min^{-1}	Frequency discharge Hz
40	3	12	2,000

Figure 8 is the correlation curve between capacity and deposition layer thickness, showing that under different capacities the deposition layer thickness had a parabola distribution, and reached its maximum at the capacity level about 1,000 μF. The regression equation of the fit curve was $Y = 17.37047 + 0.06622X - 3.29217E - 5X^2$. Ni45 alloy has a melting point at about 1,100 ℃ [8], substantially lower than that of titanium (about 1,665℃), and the Ni45 alloy is also very stable in the air melting, so the Ni45 alloy was relatively easy

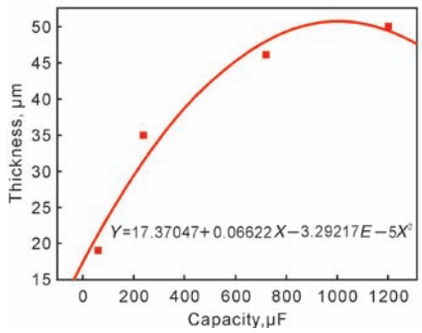

Fig.8 Correlation curve of deposition layer thickness and capacity level

to be melted and deposited on matrix under discharge. However, when capacity level was increased to 240 μF, several cracks were formed on the layer (as shown in Fig.9 (b)). With the increase of capacity, the cracking formation also increased, eventually causing spalling and falling-off of the deposition layer in micro blocks. As a result, the increase in deposition layer thickness slowed down and even switched to a negative rate. Therefore, in order to obtain thick deposition layer, a relatively high capacity level should be selected; but to avoid cracking in the deposition layer, the capacity level should kept under 240 μF.

(2) Effect of deposition time on deposition layer thickness

The effect of deposition time on thickness of deposition layer was analyzed by using different deposition times in deposition treatment on a certain area (15 mm × 15 mm) with other parameters selected as shown in Table 4. Figure 10 shows the relationship between deposition time and thickness of deposition layer.

Table 4 Parameters of deposition under different time

Voltage V	Capacity μF	Frequency discharge Hz	Argon flow rate L•min^{-1}
40	240	2,000	12

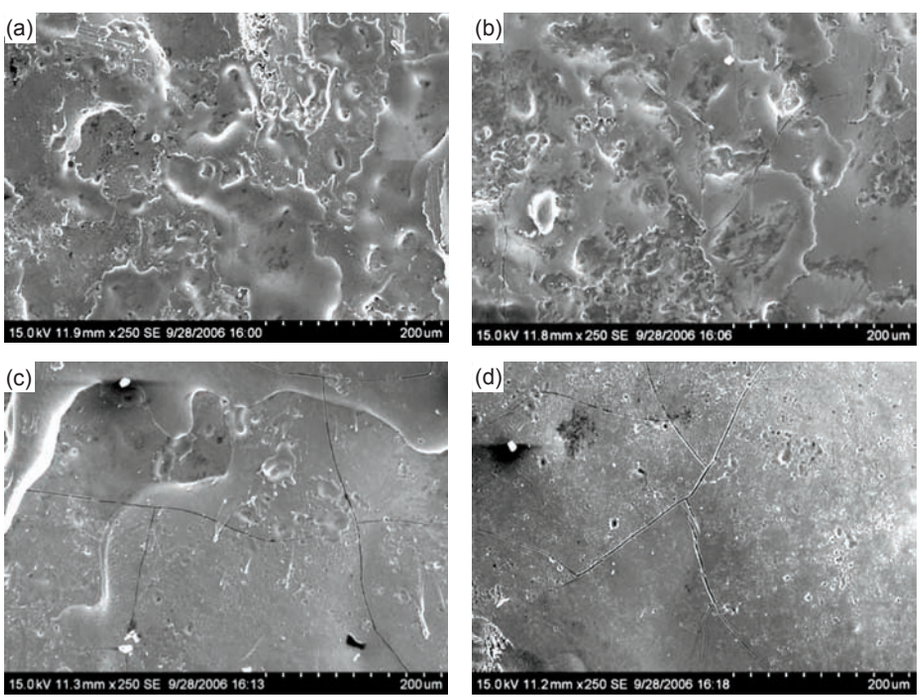

Fig.9 Surface cracks of deposition layer under different capacity levels: 60 μF (a); 240 μF (b); 720 μF (c); 1,200 μF (d)

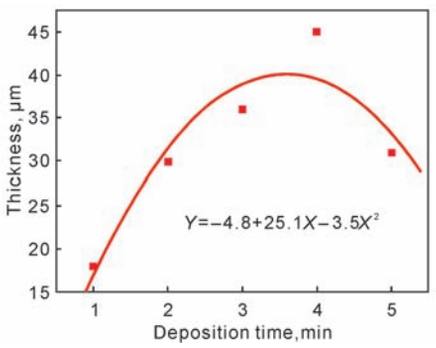

Fig.10 Relation curve of deposition layer thickness and deposition time

The fitting curve shows that the thickness increased first then decreased with deposition time, and the peak value appeared at the deposition time of 3.6 min, corresponding to the specific deposition time of 1.6 min /cm^2. Its regression equation was y = -4.8 + 25.1X - 3.5X^2. The reason for such trend was that there were cracks on the deposition layer, and the cracks increased and expanded gradually with increase of deposition time (as shown in Fig.11).

3 Conclusions

(1) By using Ni45 alloy bar as electrode, a strengthen layer with a thickness about 50 μm could be deposited on BT20 alloy. The deposition layer was an alloying product of pulse discharge between electrode and matrix, and it consisted of three phases including NiTi, $NiTi_2$ and Ti.

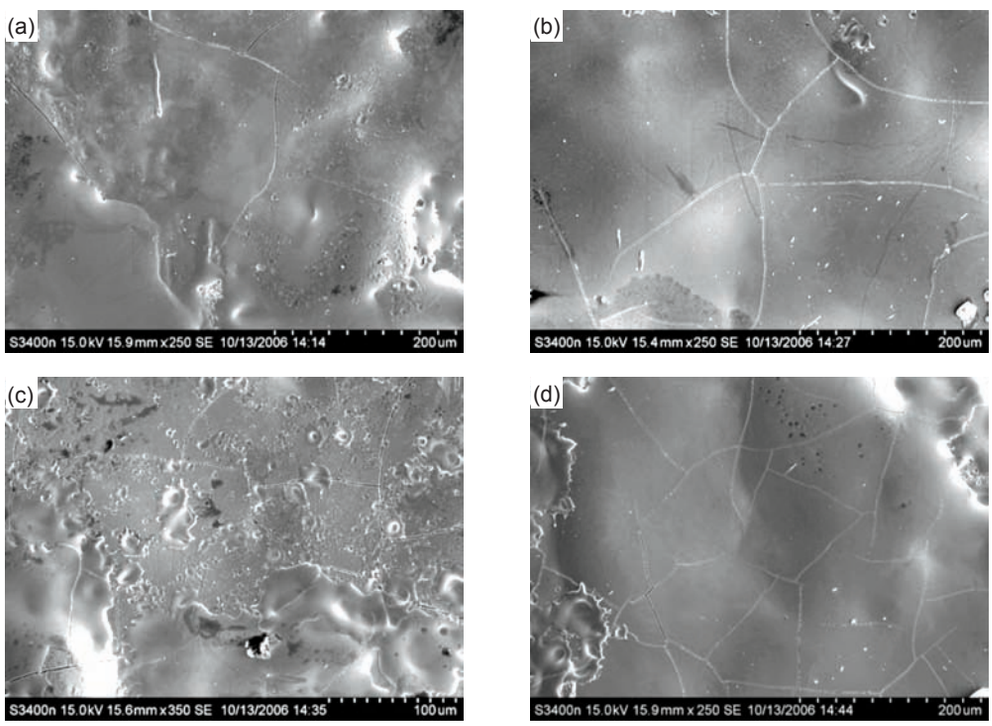

Fig.11 Surface cracks of deposition layer under different deposition time: 1 min (a); 2 min (b); 4 min (c); 5 min (d)

(2) The maximum microhardness of the deposition layer was up to 910 HV0.05, about 1.7 times higher than that of the matrix. The hardness in the cross section of the entire deposition layer presented a gradient distribution. There existed an element transition region between the matrix and the deposition layer, and its width (or thickness) was only several microns.

(3) The variation curves of deposition layer thickness with different capacities and deposition time showed a parabola distribution. A deposition layer without cracks can be obtained with relatively low capacity and short deposition time.

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