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MECHANICAL PROPERTIES OF Ti6Al4V WITH PLASMA SURFACE Mo-N Co-DIFFUSING LAYER

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Abstract. Titanium alloys have exhibited a great application potential in modern industrial. However, the poor tribological behavior is a major drawback to their actual uses. To improve the wear resistance of Ti6Al4V, a plasma Mo-N alloying layer was prepared on its surface. The strengthening layer was composed of two sub-layers, Mo-N depositing layer and diffusing layer, with a total depth of 8 μm. XRD analysis shows that Mo_2N, Ti_2N, and TiN are the major phases of the surface-modified layers. Nano indentations tests indicate The modified specimens exhibited a bigger elastic modulus and much larger nano-hardness than that of the untreated substrate. The tribological behaviors of the modified layers are investigated by ball-on-disc sliding at room temperature, 300 °C, and 500 °C, respectively. The results indicated that the friction coefficients of the modified specimens recorded a lower friction coefficient at room temperature and 300 °C. At 500 °C Mo-N surface-modified specimen exhibited a higher friction coefficient. Under all the three temperatures the specific wear ratios of the modified specimens decreased greatly comparing to those of the bare metal. After plasma Mo-N co-diffusing the tensile strength of Ti6Al4V decreased slightly.

1. INTRODUCTION

Titanium alloys have been widely used in modern industrial fields such as aircraft and aerospace, chemistry, bioengineering and marine engineering, because of their excellent properties, including high ratio of strength to weight, corrosion resistance and biologic compatibility [1-4]. However, there are also some disadvantages that limited their actual uses. Among which the poor tribological behavior of titanium alloys is still a major drawback. Numerous efforts have been reported that the tribological properties of titanium alloys can be improved by surface modification technologies, such as thermal oxidation, nitrogen-ion implantation, carburizing and hard coatings [5-8]. In general, it do works under conditions of low stresses and velocities, but cracking and debonding have often occurred at the modified layers at high shear stresses [9]. To support a heavy load a strengthening layer with thickness as bigger as possible has been pursued. But it is difficult to gain thick modified layers by ways of ion implantation. Carburizing and nitriding had been considered suitable, but traditional processes may result brittleness induced by hydrogen. Another way to solve the problems is to obtain multi-layer coatings on titanium alloys surface. However, only a fairly low number of papers has been devoted to the multi-layer as an effective way for improving the wear resistance of titanium alloys [10-13].Therefore, a Mo-N co-diffusing was carried out on Ti6Al4V alloy using plasma alloying technique [9-10]. The mechanical properties of the diffusing layer were investigated in this paper.

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Table1. Chemical composition of Ti6A4V (wt.%).

Ti	Al	V	Fe	C	N	O	H
Bal.	6.00	4.30	0.16	0.01	0.01	0.18	0.004

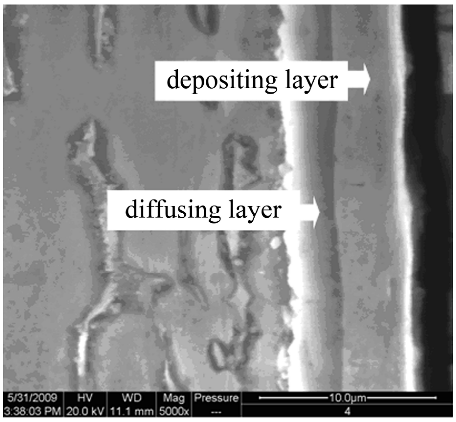

Fig. 1. Cross-section morphology of the Mo-N alloyed layer on Ti6Al4V.

2. MATERIALS AND EXPERIMENTS

A commercial Ti6Al4V alloy was subjected in this study. The chemical composition of this alloy is given in Table 1.

The Mo-N co-diffusing layer was prepared by ways of double glow plasma surface alloying [9]. A molybdenum plate with a purity of 99.95% was used as the target material. The working gas was an Ar-N2 mixing gas with a ratio of 1:3.

The major process parameters were as below: the bias voltage of target, -1000 V; the bias voltage of substrate, -400V; working pressure, 35 Pa; the parallel distance between the target and substrate, 15 mm; diffusing was carried out at 950 °C for 3 hours.

3. RESULTS AND DISCUSSION

3.1. Microstructures and compositions

The morphology on the cross section of the Mo-N alloyed layer on Ti6Al4V are shown in Fig. 1. The total depth of the alloying layer is about 8 μm, consists of a 5 μm depositing layer and a 3 μm diffusing layer. In depositing layer, EDS analysis reveals that the content of Mo and N elements are 75 wt.% and 20 wt.%, respectively. In the diffusing layer, both elements exhibit a gradient distribution. The atom quantity of N element was much more than that of the Mo element because the radius of N is smaller than that of Mo, which causes N atom much easily to diffuse into the substrate.

Fig. 2 shows the X-ray diffraction patterns for the Mo-N alloyed layer on Ti6Al4V. The major phases of Mo-N alloyed layer are Mo_2N, Ti_2N, and TiN. All this nitrides have high hardness, contributed a supporting to heavy loading and an improvement of wear resistance.

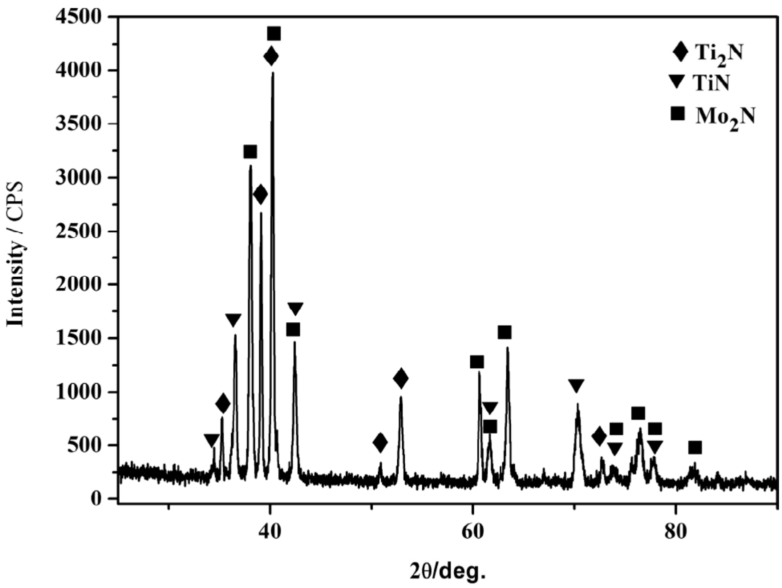

Fig. 2. XRD patterns of Mo-N alloying layer on Ti6Al4V.

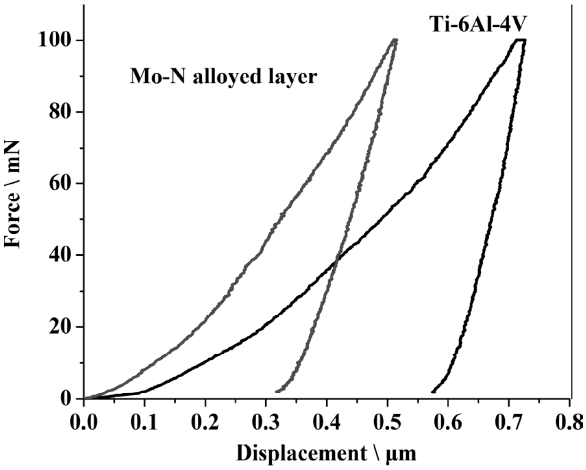

Fig. 3. Curves of force vs. displacement of the Mo-N alloyed layer and bare Ti6Al4V by nano-indentation.

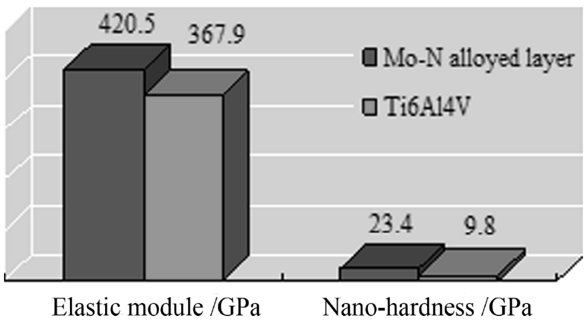

Fig. 4. Elastic modulus and nano-hardness of the Mo-N alloyed layer and bare Ti6Al4V.

3.2. Nano-indentation and adhesive strength tests

The elastic modulus and nano-hardness of the Mo-N alloying layer was investigated by nano-indentation test. A diamond Berkovich indenter with a tip angle of 115° was adopted in the experiments. The applied force is from zero to 100 mN with a loading speed of 0.2844 mN/sec. holding time is 5 sec.

Fig. 3 shows the curves of force vs. displacement of the Mo-N alloyed layer on Ti6Al4V as well as bare substrate. Comparing the curve of substrate, the Mo-N alloyed layer recorded a much small displacement. This indicates that after unloading much more elastic recovering took place for the Mo-N alloyed layer. According to Tuck *et al.* [14], no cracking occurred for the Mo-N alloyed layer as the curve was smooth. The calculated elastic modulus and nano-hardness are graphically illustrated in Fig. 4. The value of nano-hardness for the Mo-N alloyed layer is twice more than that of Ti6Al4V substrate, which could be attributed to the forming of hard nitrides.

3.3. Tribological behaviors

To investigate the tribological behaviors a serious of ball-on-disc sliding experiments were done under the condition of lubrication-free and room temperature, 300 °C, 500 °C, respectively. Si_3N_4 balls with a diameter of 3mm were chosen as the

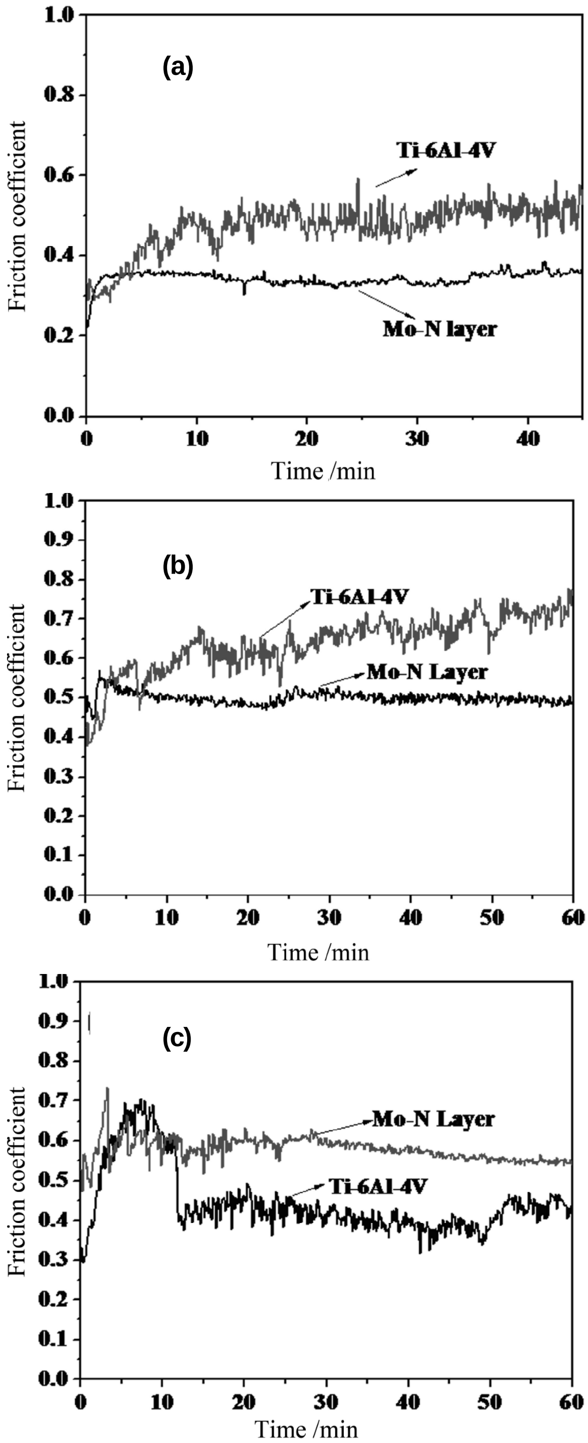

Fig. 5. Friction coefficients of the Mo-N alloyed layer and bare Ti6Al4V at different temperature, (a) room temperature, (b) 300 °C, (c) 500 °C.

counter rubbing poles. The applied load is 280 g. The rotating speed is 560 r/min with a radius of 3 mm. The total sliding time is 20 min.

Fig. 5 shows the friction coefficients of the alloyed layer and bare Ti6Al4V at three test temperatures. At room temperature and 300 °C, the Mo-N alloyed specimens recorded apparent friction coefficients comparing to substrate, representing a well anti-friction characteristic. These may attribute to the increase of surface hardness which resulted in the decrease of contact area in the thorough course of sliding. However, at 300 °C, bare Ti6Al4V exhibited a lower friction coefficient. The result may be explained by the lubrication of the soften metal at elevated temperature.

Fig. 6 shows the specific wear ratios of Ti6Al4V with / without Mo-N diffusion at different temperature. It is clear that the surface modification has remarkable improved the wear resistance of the titanium alloy.

3.4. Tensile properties

As introduced above, after plasma Mo-N co-diffusing, the surface hardness of Ti6Al4V has been increased largely. The wear resistance of this alloy has also improved greatly. However, as the specimens had been subjected to a high temperature for hours, it is unavoidable that the microstructure of the matrix must be changed. Thus, an influence on the strength can be foreseen.

To investigate the effect of the surface alloying on the mechanical properties a series of static tensile tests had been managed. Fig. 7 illustrates the test results. The tensile strength of the alloyed specimen decreased about 6.7%. Its plasticity increased slightly.

Fig. 8 and Fig. 9 are the macro and micro morphologies of the fracture of the tensile sample with Mo-N co-diffusing. The broken section is much coarse but straight-line, with an angle of 45° to the tensile direction. Micro observes revealed that the fracture had typical ductile features, as many ductile nests distributed continually.

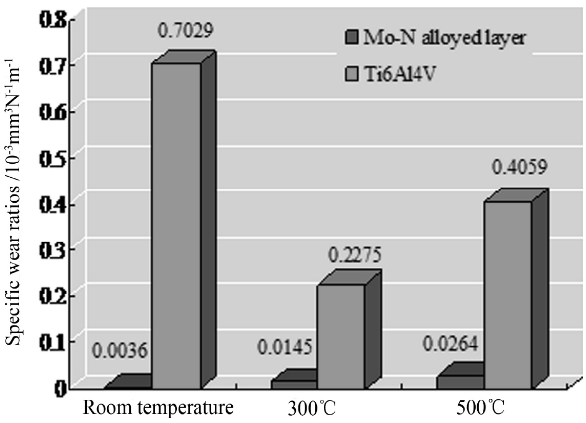

Fig. 6. Specific wear ratios of the Mo-N alloyed layer and bare Ti6Al4V at different temperature.

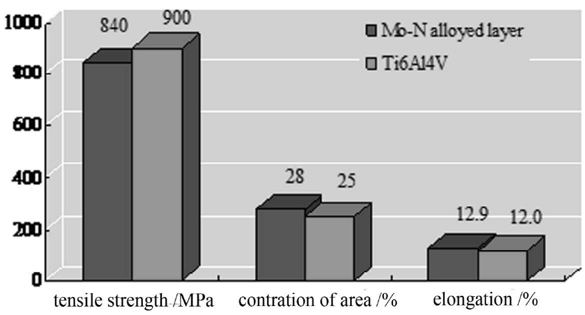

Fig. 7. Results of tensile tests of Ti6Al4V with / without Mo-N co-diffusing.

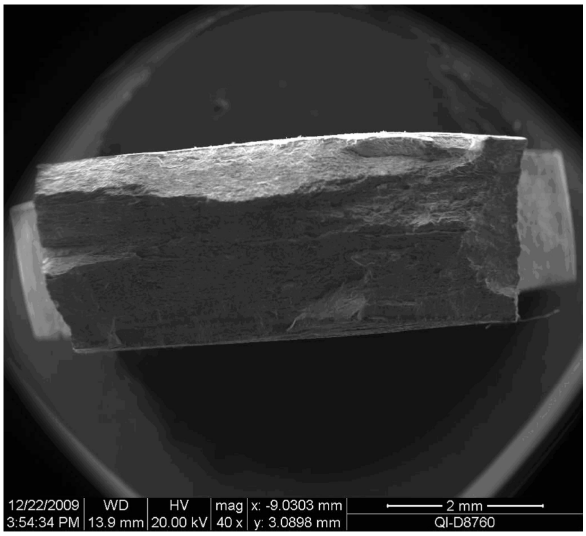

Fig. 8. Macro morphology of the fracture of the Mo-N alloyed sample.

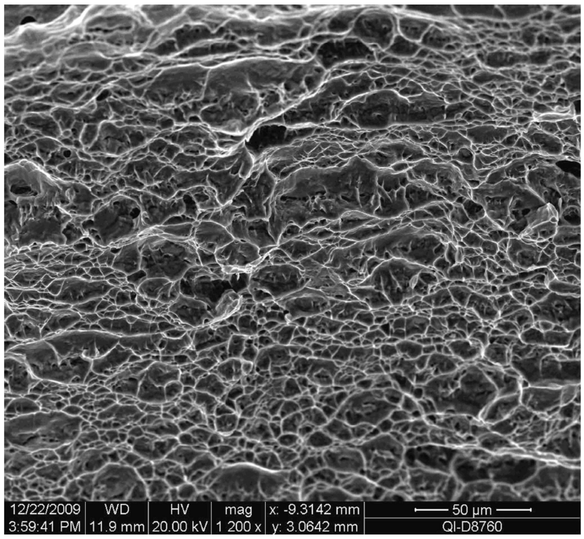

Fig. 9. Micro morphology of the fracture of the Mo-N alloyed sample.

4. CONCLUSIONS

Using plasma alloying technique, the Mo-N co-diffusing on Ti6Al4V has the potential to increase the wear resistance while maintaining a lower friction coefficient. The alloying layer was composed of a deposition sub-layer and a diffusion sub-layer. The deposition layer is consisted of three nitrides just like a hard coating. More importantly, the diffusion layer offers mechanical support to the hard coating, so that a robust adhesion was guaranteed. Although subjected at high temperature, the treatment would not results an intolerable strength loses if the cooling speed were controlled appropriately. For applications in aircraft manufacture, the requirements on fatigue life-span are more restrict. Farther more relative works are already scheduled.

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