Study of the Mechanical Properties of Ti-3Al-2.5V after Surface Plasma Gas Treatment with Indirect Plasma Torch

Rosen Vasilev

Technical University - Varna, Str. Studentska 1, Varna, Bulgaria

Abstract **–Commercial titanium alloy Ti-3Al-2.5V became one of the most widely used titanium alloys after its introduction in the early seventies. It has a very attractive combination of tensile strength, creep strength, toughness and high-temperature stability for long-term applications up to 425ºC. It is used for gas turbine components and in other applications where this good combination of properties is required [1]. At the same time it has poor tribological properties that are typical of most of the titanium alloys. It has low surface hardness and wear resistance. These disadvantages of the material limit its application [1], [2]. Ti-3Al-2.5V was chosen for this experimental work because it showed a good plasma gas nitriding performance in comparison with the other alloys during the tests.**

Keywords **– Ti-3Al-2.5V, surface roughness, plasma gas treatment, indirect plasma torch.**

1. Introduction

The objective of this part of the experimental work is to study how the surface morphology of Ti-3Al-2.5V alloy changes as a result of the surface treatment with plasma gas nitriding in chamber with indirect plasma torch, with 18kWfor 1, 2 and 3 min, and how this change influences its surface properties. The influence of the processing parameters of plasma nitriding on the surface roughness, phase modifications and the microstructure of the nitrided layers has been investigated.

2. Experimental procedure

Two sets of samples of Ti-3Al-2.5V were used in this work. The first set includes samples with initial surface preparation using different sizes of abrasive Struers waterproof silicon carbide paper, all plasma gas nitrided at 18kW for 3min. Their brief description is given in Table 1.

The treatment was performed in chamber with pure N2 with a purity of 99.998% using a flow rate of 100 ml/min. The samples were plasma gas nitrided with indirect plasma torch without melting on the surface.The second set of samples consists of four initially polished samples, nitrided with different processing parameters (see Table 2).

Table 1. First set of samples with different initial roughness

Sample	Initial surface preparation-ISP	P (kW)	t (min)
A1	P-220	18	3
A2	P-2400	18	3
A3	polished	18	3

Table 2. Second set of initially polished samples

Sample	Initial surface preparation-ISP	P (kW)	t (min)
B1	polished	18	1
B2	polished	18	2
B3	polished	18	3
B4	polished	25	3

Before and after the plasma gas nitriding experiments the surface roughness of all samples was measured using an atomic force microscope (AFM). At least five measurements before nitriding and five after were performed at different areas with a size of 70 x 70 μm for each measurement. Average values of Ra have been used. The term Ra is defined later in the text.

AFM images were acquired using a Digital Instruments Dimension 3000 machine operating in Contact mode. Image scan rate was typically 1 Hz and consisted of 256×256 data points.

The phase constitution at the surface of the samples was determined using X-ray diffraction (XRD) with a Philips diffractometer using Cu Kα1+α2 radiation from an angle of 30 to 75 deg (2θ), with a step size of 0.017 deg (2θ) and a counting time of 150 sec/step.

In order to study the microstructure of the surface layers after gas nitriding, the cross sections were etched and studied by using optical microscopy at different magnifications.

The microhardness profiles were obtained using a hardness testing machine Mitutoyo HM-124 by applying a Knoop indenter with a load of 0.1 kg for 10 sec. The measurements were performed on cross sections from the surface to the middle of the samples with a step of 25 μm. The

microhardnessprofiles were prepared using at least 60 test readings per sample.

3. Results and discussion

Surface morphology

The first set of samples was used in order to study the influence of the initial surface roughness on the final surface morphology and characteristics of the material. For that reason measurements were performed before and after nitriding of samples A1, A2 and A3. For quantifying the surface roughness of the samples the most frequently used parameter Ra has been adopted. This value is the arithmetic mean of the deviations of the height from the image mean value.

After plasma gas nitriding all samples had compound layers formed on the surface of the samples, mainly consisting of titanium nitrides that are discussed in the next section. On the top of that layer a thin oxide film was formed. These films had a very high surface roughness, >1 μm, that was impossible to be measured by AFM. That is the reason why they had to be removed in order to perform the roughness measurements. The results for Ra of the first set of samples are given in Table 3.

Table 3. Results for Ra for the first set of samples

Sample	Average values of Ra (μm)	
	Before nitriding	After nitriding
A1	$0.201^{+0.126}_{-0.115}$	$0.249^{+0.270}_{-0.097}$
A2	$0.067^{+0.025}_{-0.023}$	$0.167^{+0.021}_{-0.017}$
A3	$0.046^{+0.007}_{-0.006}$	$0.190^{+0.074}_{-0.087}$

The results show that there is an increase of the surface roughness after gas nitriding at 18kW for 3 min. For the initially roughest sample A1 the increase of Ra is not significant whereas for samples A2 and A3, which were with lower initial roughness, Ra increases up to eleven times.

After nitriding the A2 and A3 samples showsimilar values of Ra whereas the initiallyroughest sample A1 has much higher roughness, obviously due to the difference in the initial roughness of the samples.

The surface morphology of these samples is presented in Fig. 1. The surface roughness after different types of nitriding and other thermo-chemical treatments has been discussed by other research groups [3], [4], [5], [6].

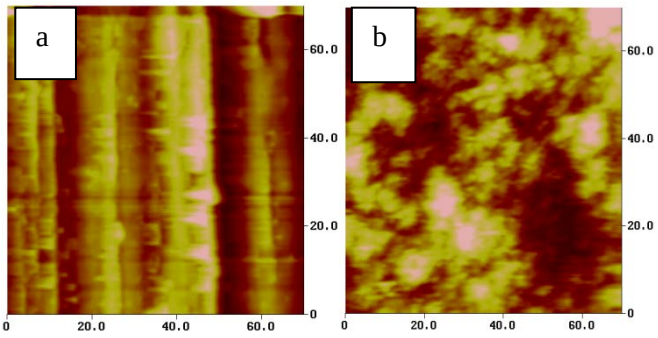


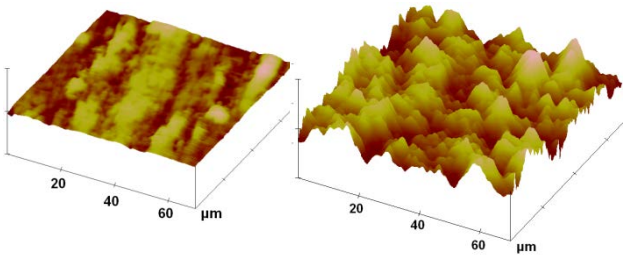
Figure 1. Surface morphology of the samples from the first set before (a) and after (b) plasma gas nitridingwith indirect plasma torch at18kW for 3 min.

The second set of experiments show the influence of the processing parameters on the surface morphology after gas nitriding. The results for Ra are given in Table 4. The results show that the surface roughness increases with the time prolongation from 1 to 3 min at 18kW. There is no significant change of the surface roughness with the increase of the power from 18kW to 25kW. At the same time sample B1 showed a huge increase of Ra (27 times) after treatment. This is because the surface oxide layer and the layers underneath had a good adhesion so it was difficult to remove the very top layer.

Table 4. Results for Ra for the second set of samples

Sample	Average values of Ra (μm)	
	Before nitriding	After nitriding
B1	$0.042^{+0.019}_{-0.010}$	$0.894^{+0.081}_{-0.091}$
B2	$0.041^{+0.012}_{-0.007}$	$0.167^{+0.015}_{-0.019}$
B3	$0.026^{+0.007}_{-0.006}$	$0.290^{+0.074}_{-0.087}$
B4	$0.035^{+0.006}_{-0.010}$	$0.282^{+0.032}_{-0.017}$

These results show that the surface oxide layers have much higher surface roughness. The surface morphology of these samples is presented by 3D images in Fig. 2.



a) b)

Figure2. 3D images of the surface morphology of the samples from the second set before (a) and after (b) plasma gas nitriding at 25kW with indirect plasma torch for 3 min.

The change of the surface roughness is related to the phase transformations that took place during gas nitriding. Diffraction patterns for samples B1 to B4 are given in Fig. 3.

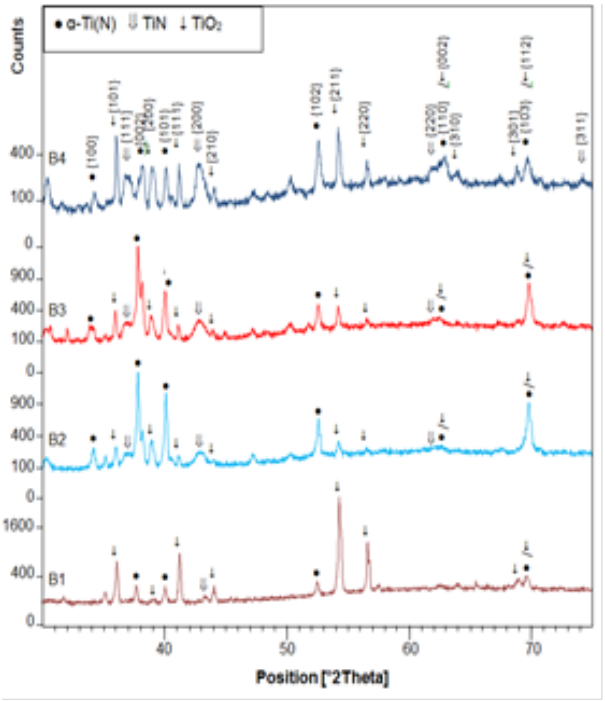


Figure 3. X-ray diffraction patterns for samples B1, B2, B3 and B4 after plasma gas nitriding with indirect plasma torch

For samples B2, B3 and B4 the compound layers consist of titanium nitride and a small amount of titanium oxide.It can be seen that for sample B1 the surface layer mainly consists of TiO2, because as it was mentioned above, the top oxide film was not removed. There are two possible reasons for this oxide film formation and they are discussed in the work[7].

Optical images of the microstructure of the same samples from B1 to B4 are given in Fig. 4. They show the difference in the microstructure of the samples nitrided at different temperatures and for different times– Table 2.

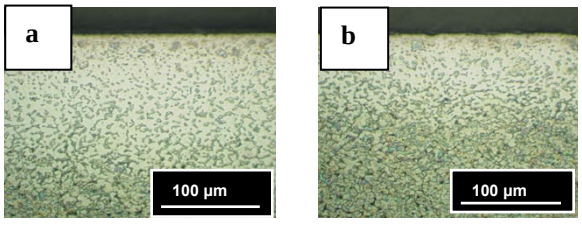


Figure 4. Microstructure of Ti-3Al-2.5V alloy. after plasma gas nitridingwith indirect plasma torch (a) B1; (b) B3 - Table 2.

As discussed earlier in the work [7], after plasma gasnitriding of the samples at 18kW, the nitrided layers have homogeneous microstructure and the thickness of these layers increases with the increase of the nitriding time. This can be seen from the micrographs in Fig. 4. By increasing the power at 25kW, an irregular needle structure was formed. In this case it is difficult to define the layer thickness from the microstructure. The grain growth that can be seen at the higher nitriding temperature can be explained by the fact that at 25kW power the temperature of the plasma gas nitridingis above the β-transus temperature for this alloy Fig. 5.

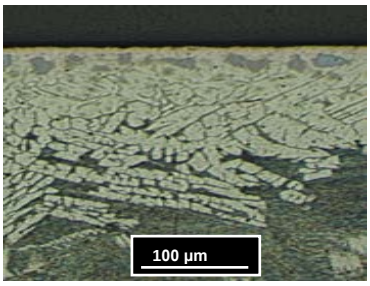


Figure 5. Microstructure of Ti-3Al-2.5V after plasma gas nitriding with 25kW with indirect plasma torch for 3 min - B4.

Microhardness profiles

The microhardness profiles (HK0.1) in the cross-section of samples A1,A2 and A3 are shown in Fig.6. The microhardness is very high near the surface and falls gradually with the distance from the surface.

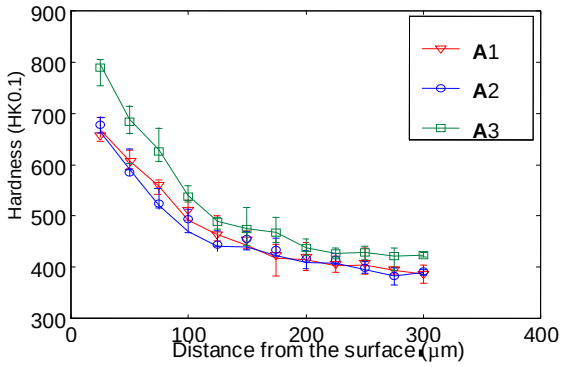


Figure 6. Microhardness profiles of Ti-3Al-2.5V alloy after plasma gas nitriding with 25kW with indirect plasma torch for 3 min for samples A1, A2 and A3.

It decreases through the diffusion zones and approaches the base microhardness of the matrix in the unsaturated core.

These microhardness profiles were prepared in order to study the influence of the initial surface roughness on the characteristics of the nitrided layers. It can be seen that there is no significant difference in the microhardness values for these samples.

The thickness of the nitrided layers can be estimated from the microhardness profiles. As it was discussed earlier in it can be supposed that the nitrided layer ends where the microhardness value approaches the core microhardness. For Ti-3Al-2.5V plasma gas nitrided at 18kW for 3 minnitrided layers of about 200 μm have been obtained.

4. Conclusion

The results from the roughness measurements, XRD analysis and the hardness measurements of plasma gas nitridedwith indirect plasma torch in chamber of Ti-3Al-2.5V have brought to the following conclusions:

1. Plasma gas nitridingwith indirect plasma torch significantly increases the surface roughness of Ti-3Al-2.5V titanium alloy, except for the samples with high initial roughness.The surface roughness after plasma gas nitriding depends on the initial surface roughness of the material. It increases with the increase of the initial roughness of the samples.

2. The surface roughness increases with the increase of the nitriding time and there is no significant change of the surface roughness with the increase of the power from 18kW to 25kW. The increase of the surface roughness after plasma gas nitriding with indirect plasma torch is caused by the formation of titanium nitrides and titanium oxides on the surface of the materials.

References

[1]. Boyer. R., Welsh G. & Collings E. W. (1994). *Materials Properties Handbook - Titanium Alloys*. ASM International, Materials Park, OH.

[2]. Collings E. W. (1984). *The Physical Metallurgy of Titanium Alloys*. American Society for Metals, Metals Park, OH.

[3]. Jacquot P., Buvron M. & Souchard J. (1992). "Plasma Nitriding and Plasma Carburizing of Pure Titanium and Ti-6Al-4V Alloy". *Materials Science Forum*, Vol. 102-104(1), 301-315.

[4]. Xue L., Islam M. U., Koul A. K.,Wallace W. & Bibby M. (1997). "Laser Gas Nitriding of Ti-6Al-4V Part 2: Characteristics of Nitrided Layers". *Advanced Performance Materials*, Vol. 4, 389-408.

[5]. Venugopalan R., George M., Weimer J. & Lucas L. (1999). "Surface Topography, Corrosion and Microhardness of Nitrogen-diffusion-hardened Titanium Alloy". *Biomaterials*, Vol. 20, 1709-1716.

[6]. Wilson A., Leyland A. & Mathews A. (1999). "A Comparative Study of the Influence of Plasma Treatments, PVD Coatings and Ion Implantation on the Tribological Performance of Ti-6Al-4V". *Surface and Coatings Technology*, Vol. 114, 70-80.

[7]. Skulev H., & Malinov S. (2005). "Phase Composition and Microstructure of Titanium Alloys after Surface Plasma Gas Nitriding". *Second International Scientific Congress on Mechanical and Electrical Engineering and Marine Industry*, Varna, Bulgaria, 07 - 09 October 2005, 92-196.