Effect of the surface nanocrystallization on the gas nitriding of two-phase titanium alloy

Lavrys S.M., Pohrelyuk I.M.

Karpenko Physico-Mechanical Institute of the NAS of Ukraine. (Lviv, Ukraine)

E-mail: lavrys92@gmail.com

Introduction

Due to their excellent mechanical and anti-corrosion properties, high-strength two-phase titanium alloy (Ti–5Al–5Mo–5V–Cr–Fe) is widely used in the aircraft industry. However, this titanium alloy has low wear resistance, which limits its use in tribo-pair without additional surface treatment and, therefore, determine the need to develop effective methods of surface engineering. For these reasons, gas nitriding is a promising, technologically simple and economically efficient method of surface engineering for wear resistance enhancement of titanium alloy. Generally, the treatment temperature for the conventional gas nitriding of the titanium alloy is near 950°C with a processing time of several tens hours, resulting in high energy consumption and a significant negative effect on the matrix microstructure and mechanical and fatigue properties reduction of titanium alloy. Therefore, the issue of intensification of nitriding of titanium alloy becomes especially relevant.

In the work, the intensification of gas nitriding is provided by pre-surface nanocrystallization of titanium alloy. Ball burnishing was performed on titanium alloy to form surface nanostructures.

Experimental procedures

The high strength two-phase titanium alloy Ti–5Al–5Mo–5V–Cr–Fe (also known as VT22) was investigated because it is widely used in the aircraft industry.

Table 1. Chemical composition and mechanical properties of VT22 titanium alloy (kβ=1,2)

Chemical composition according to GOST 19807-74											
Element	Master Alloy					Impurities					Matrix
	Al	Mo	V	Cr	Fe	Si	C	O	N	H	Ti
Contain, wt.%	4.4…5.7	4.0…5.5	4.0…5.5	0.5…2.0	0.5…1.5	0,15	0.1	0.2	0.05	0.015	Balance

Mechanical properties according to GOST 26492-85				
HB·10^{-1}, MPa	$\sigma_в$, MPa	δ, %	ψ, %	KCU, кJ/m^2
285	1080…1280	7…10	17…30	250…300

Surface treatment:

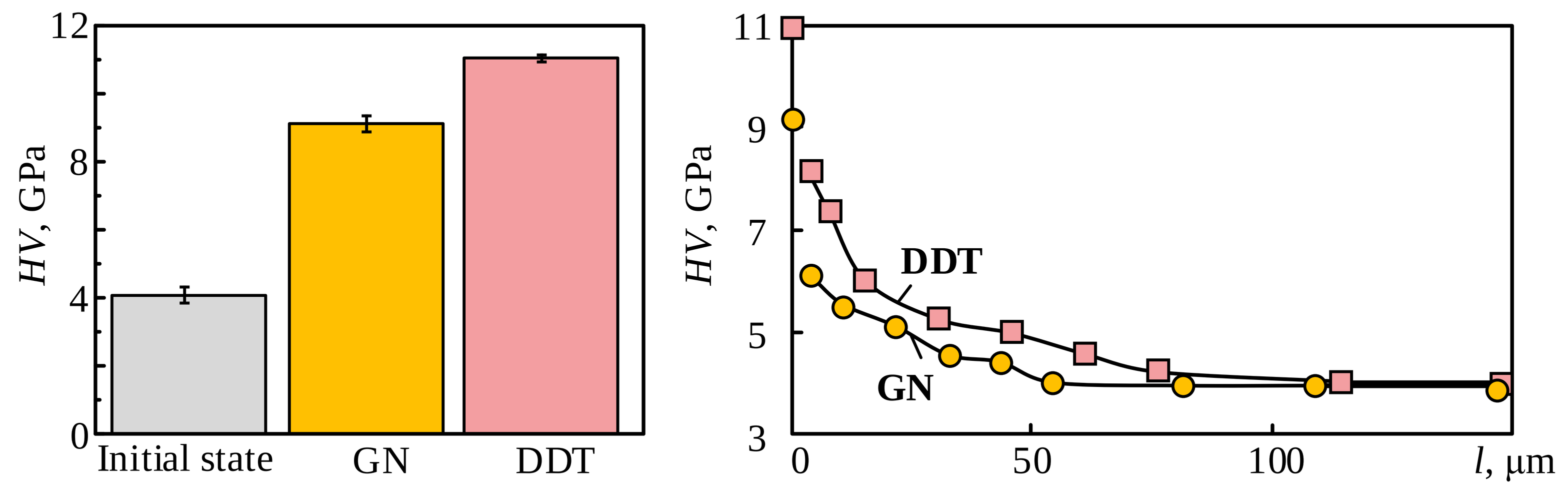
Ball burnishing. Ball burnishing was carried out using 1K62 universal screw-cutting lathe at a room temperature. A ball with a diameter of 5 mm was made of diamond polycrystalline composite material C_d–Co–34Ni [27]. Lubrication type – boundary lubrication in an industrial oil I-20A. Regime of BB: force – 200 N; number of passes – 11; rotating frequency – 200 rpm; feed – 0.07 mm/rev.

Gas nitriding. The GN was combined with the SHT of the titanium alloy in the one technological cycle. This combination allows to form a hardened surface layer and provide an optimal complex of mechanical characteristics of the titanium alloy [25, 28]. Both the GN and the SHT were carried out usinh equipment, which allows to reproduce the technological parameters for both treatments (cooling and heating rate, temperature, holding time and the provided controlled vacuum or gaseous nitrogen environment) in the one technological cycle. The GN was carried out according to the same time-temperature regime as the SHT at an atmospheric pressure of commercially pure gaseous nitrogen.

Deformation-diffusion treatment. The DDT included a combination of the previous BB with the subsequent GN in an accordance with the above mentioned regimes.

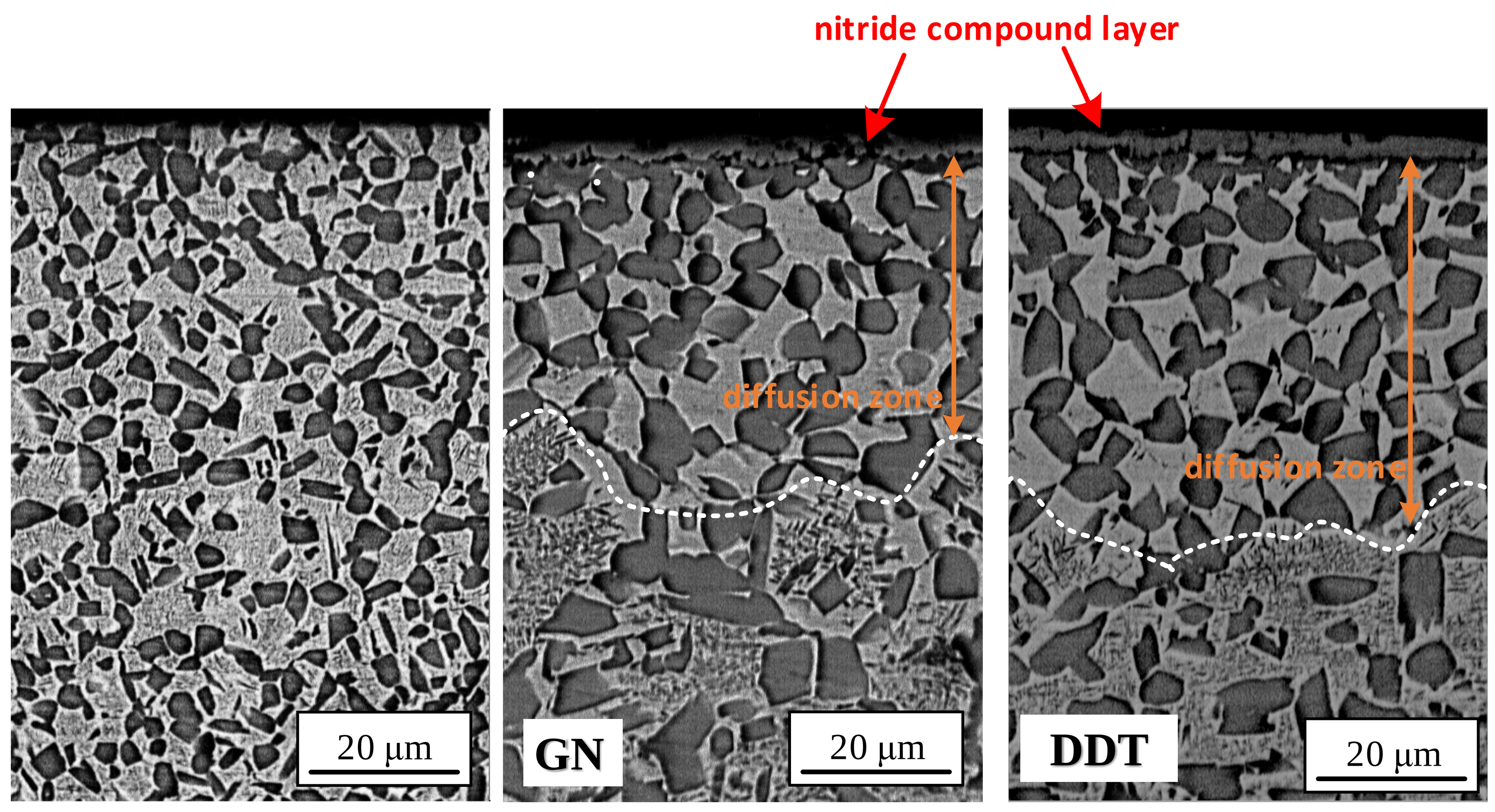
Results and discussion

The intensification of nitride formation as a result of DDT is also evidenced by the results of durometric and metallographic analyses. The previous ball burnishing during DDT contributes to an increase in surface microhardness and thickening of the hardened layer by 30 and 20%, respectively, compared to GN without pre-ball burnishing. It should be noted that after DDT the characteristic microhardness distribution curve is located in the region of higher values microhardness compared to GN, which indicates a greater degree of alloying of the surface layer of the alloy with nitrogen, as well as a higher degree of gas saturation during treatment.



Surface microhardness and hardness distribution on the cross-section of the VT22 titanium alloy after gas nitriding (GN) and deformation-diffusion treatment (DDT)

According to metallographic analysis, it was established that as a result of diffuse saturation with nitrogen during GN and DDT, a thin compound nitride layer is formed on the surface of the titanium alloy, under which there is a diffusion layer Ti(N). After DDT compared to GN, it was fixed thicker nitride layer (~5 μm vs ~3 μm) and deeper diffusion layer (~50 μm vs ~40 μm), which is in good agreement with the durometric analyses.



Microstructure of the surface layer of the VT22 titanium alloy in the initial state and after nitriding and deformation-diffusion treatment

A deeper diffusion layer after DDT compared to GN indicates the intensification of nitrogen gas saturation of the surface layer of the titanium alloy due to pre-plastic deformation. Such an increase in the mass transfer of nitrogen atoms in the deformed layer is possible due to the implementation of additional mechanisms, different from the interstitial mechanism, which is inherent in traditional nitriding. In the deformed layer, the intensification of nitriding occurs due to grain boundary diffusion (including along small-angle boundaries), upward diffusion (under the influence of the stress gradient), transfer of atmospheres of impurity atoms by mobile dislocations (according to the dislocation-dynamic mechanism), etc.

Conclusions

A new solution to the scientific and technical problem of intensification of gas nitriding of two-phase titanium alloys by pre-surface plastic deformation (nanocrystallization) is proposed. For example, for the VT22 titanium alloy, the surface microhardness increases by 30%, and the depth of the hardened layer thickens by 20% compared to nitriding without pre-surface nanocrystallization.