Tribotechnical Characteristics of VT22 Titanium Alloy after Nitriding, Combined with Heat Treatment

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Abstract – Nitriding of VT22 titanium alloy, combined with its standard heat treatment in a single technological cycle was proposed. It was shown that after thermodiffusion saturation the microhardness and depth of the hardened surface layer of VT22 alloy increased, but the quality machined surface worsened. It was established that the increase time of nitriding process worsened the tribotechnical characteristics of friction pair nitrided VT22 alloy – BrAZhN 10-4-4 bronze.

Key words – VT22 titanium alloy, heat treatment, nitriding, surface hardening and tribotechnical characteristics.

I. Introduction

The application of the high-strength titanium alloys in the aerospace industry is expanded with each year due to their excellent combination of properties: high specific strength, corrosion resistance and lower threshold of cold brittleness. However, they have several shortcomings: the high price, low surface hardness and wear resistance. The last two factors limit using titanium alloys for work in the conditions of contact loads and friction. The anti-friction properties of titanium alloys can be increased by chemicothermal treatment. Nitriding is the most promising, efficient and cost-effective method of surface chemicothermal treatment of these alloys. It is technologically simple, provides the reliable physico-chemical and tribotechnical characteristics of hardening surfaces and does not require the additional manufacturing operations. However, nitriding of two-phase titanium alloy, according to the current technological instructions (temperature > 950 ºC and holding time > 30 h), although provides the necessary level of surface hardening, but due to increased β-phase worsens the level of mechanical characteristics of the alloy that provided by a preliminary heat treatment. In this aspect it is the great importance to develop the combined techniques, which preserving the advantages of known methods of hardening treatment and simultaneously, eliminating their disadvantages. One of the promising technologies of this hardening treatment is the combination in one process cycle of forming the nitrided layer preset properties and heat treatment of alloy with the preservation of standard strength characteristics of the material [1, 2].

II. Research and methodology

The samples of VT22 two-phase titanium alloy (Ti–5Al–5Mo–5V–1,5Cu–Fe) were investigated, since from which were manufactured power hydraulic cylinders of chassis, brackets, control system, power parts of wings, pipelines, compensators and heat exchangers of aircraft (model An).

Nitriding was conducted in the furnace which allows to reproduce the technological standard heat treatment of alloy and provide the temperature-time and gas-dynamic parameters of nitriding in a single technological cycle. The nitrogen saturation was carried out either on the first and second stages of heat treatment (mode 1) or only on the second stage (mode 2) of heat treatment of VT22 alloy (Fig. 1). We have used the commercially pure gaseous nitrogen, which before supply into the reaction chamber dried and fired from oxygen by passing it through a silica gel capsule and titanium chips heated to ~50 ºC above the saturation temperature.

Fig. 1. Standard heat treatment of VT22 titanium alloy

The phase composition of the surface layers was determined by using a DRON-3.0 X-ray diffractometer in the monochromatic CuKα radiation with focusing by the Bragg-Brentano scheme. The surface quality (roughness parameters) was analyzed by using a 170621 roughness indicator with auto-sensing mean arithmetic deviation of the profile Rm, μm. The level of near-surface hardening (surface microhardness and hardened layer depth) after nitriding was determined by PMT-3M device with a load of 0.49 N on indenter.

The tribological tests were performed by SMC-2 machine for friction of metals under the scheme «disc – block». The mode of test: friction path – 1000 m, contact load – 0.6 MPa, speed – 0.6 m/s. The discs from VT22 alloy after hardened thermodiffusion treatment were tested. The block from deformable BrAZhN 10-4-4 bronze (Cu –10Al–4Fe –4Ni) as counterbody was used. The lubrication was carried out in AMF-10 hydraulic fluid. The wear resistance of friction pairs was evaluated by the weight change of friction pair after frictional interaction, weighting on an Voyager balance (OHAUS). The microstructure analysis of the wear surface was determined by EVO 40XVP scanning electron microscope (Carl Zeiss).

III. Results and discussion

The surface is smooth, glossy, light golden after the chemicothermal treatment, combined with standard heat treatment of samples VT22 alloy. The nitrogen saturation on the first and second stages of heat treatment (mode 1) or only on the second stage (mode 2) does not affect on...
the phase composition of surface layers of the alloy. Regardless of the nitriding mode the $\text{T}_2\text{N}$ nitride film on the surface was formed, as evidenced by the results of X-ray phase analysis, fixing the presence of $\text{T}_2\text{N}$ phase reflections in the diffraction spectrum. The decreased intensity of the lines of nitride phase in the surface diffraction spectrum indicates the deceleration of nitride formation on the surface during the transition from mode 1 to mode 2.

The surface quality of samples after nitriding is worsen comparison with the initial state and after modes 1 and 2 reaches the 8th and 9th classes purity of quality class accordingly (Fig. 2, a).

![Image](image.png)

Fig. 2. Change of roughness ($Ra$) of tribounits before (a) and after (b) friction: I and II – modes of chemicothermal treatment; I – disc; 2 – block

The surface hardening of the alloy after nitriding indicates the increase of surface hardness of samples and formation of nitrided layer, depth of which was determined by microhardness method as the area the hardness of which exceeds the hardness of alloy matrix on $\delta H=0.2$ GPa. It was established that during the transition from mode 1 to mode 2 the surface hardness of the alloy is reduced from 5.6 to 4.9 GPa. The depth of hardened layer after saturation by modes I and II reaches $\sim 150 \mu m$ and $100 \mu m$ accordingly.

The tribological tests have shown that VT22 titanium alloy after nitriding by mentioned regimes in investigated range practically does not wear. At the same time the wear of counterbody (block from deformed bronze) is significant and more than by two orders greater than wear of nitrided disc (0.019…0.026 g and 0.0002…0.0001 g accordingly). In addition, the wear intensity of bronze, worked in pair with nitrided disc by mode 1, is more in 1.4 times than the one that worked in pair with nitrided disc by mode 2. This is caused by that during nitriding the characteristic surface microrelief is formed on the titanium alloy, and it the most distinct the highest saturation temperature. The formation of this relief allows to increase the height and foot-pace parameters of surface roughness. Where the hardest and highest peaks of profile during friction of nitride surfaces are the points of factual contact. During friction these peaks like abrasive scratche the softer surfaces of counterbody and leave the furrows. This is confirmed by the microstructure of the friction surface of bronze block. In both investigated tribo-pairs during the friction abrasive wear mechanism with the formation of characteristic striated relief on the friction surfaces prevails. The surface of counterbody which was worked in the pair with disk, nitrided by mode 2, has fewer quantity of furrows than the one which worked with disk, nitrided by mode 1, where the ourselves furrows and their depths are larger. The quality surfaces of the nitrided discs after friction is better than friction surfaces of bronze (counterbodies) (Fig. 2).

Due to the different roughness of friction surfaces the nitriding after mode 2 provides almost twice less run-in period of tribo-pair compared to nitriding after mode 1 (Fig. 3).

The friction coefficient of tribo-pair «disc nitried by mode 1 – block» during run-in was high (0.32), and later decreased to 0.2 and stabilized. For tribo-pair «disc nitried by mode 2 – block» the friction coefficient is approximately less on 0.06 in whole range of tests. The values of friction coefficients correlate with the temperature near the friction zone. At the lower friction coefficient in tribo-pair (2) the lower temperature (29.4 °C) near the friction zone was fixed. The temperature near the friction zone for tribo-pair (1) set at a level of 34.8 °C.

![Image](image.png)

Fig. 3. Kinetics change of coefficient friction of tribo-pair nitried VT22 alloy–BrAZhN 10-4-4 bronze: (I – nitriding by mode 1, 2 – mode 2)

**Conclusion**

Nitriding, combined with the standard heat treatment, increases the hardness and depth of hardening surface layer of the material. However, time increase of thermodiffusion saturation leads to a deterioration of the quality surface of the nitrided VT22 titanium alloy.

Duriing friction of tribo-pairs nitried VT22 alloy – BrAZhN 10-4-4 bronze by contact load of 0.6 MPa the abrasive mechanism of wear was realized. Decreasing temperature-time parameters of thermodiffusion saturation of VT22 titanium alloy provides the higher wear resistance under conditions of boundary (thin film) lubrication of those tribo-pairs. The tribotechnical characteristics of VT22 titanium alloy after mode 2 are higher and provide lower friction coefficient (0.14 vs 0.2) and temperature in near zone of friction (29 vs 38 °C) in the range of stable wear than after nitriding by mode 1.

**References**
