Surface hardening of steel 20H13 for friction pair with carbon plastic by ion-plasma Ti-Al-N, Ti-Al-Ni-N coatings deposition

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Abstract. The paper presents the results of comparative studies of Ti-Al-N and Ti-Al-Ni-N coatings deposited on 20H13 (DIN 1.4021) steel, used as bearings in shipbuilding and working in a friction pair with UGET (carbon epoxy fabric) carbon plastic. It was found that the addition of nickel into the coatings composition significantly improves the corrosion resistance of the coatings in sea water. The study of tribological characteristics indicates an increased wear of steel and Ti-Al-N coating, determined by the corrosion destruction of the samples, which accompanies the process of friction.

Chromium stainless steels and antifriction carbon plastic are used as elements of sliding bearings for friction units of ship mechanisms [1]. As studies [2] and the experience of operating sliding bearings made of antifriction carbon plastic have shown, the wear resistance of friction pairs depends on the composition and properties of the material of the counterbody (the surface of the counterbody). In this way, by changing the properties of the surface of the metal counterbody, it is possible to achieve an increase in the wear resistance of antifriction carbon plastic and rubbing parts of ship mechanisms in general. The paper considers the possibility of increasing the operating time of a friction pair of steel 20H13 (DIN 1.4021) and carbon plastic of the UGET (fabric epoxy carbon) grade by depositing wear-resistant coatings on the steel using the method of ion-plasma vacuum-arc deposition. The Ti-Al-N and Ti-Al-Ni-N systems were tested as hardening coatings. The addition of nickel into the composition of the Ti-Al-N ceramic coating, which does not interact with nitrogen and is slightly soluble in titanium nitride, as was shown in [3] during the deposition of coatings on carbide substrates, leads to a refinement of the structure of the ceramic phase and a transition from columnar to equiaxed nanoscale structure by blocking the growth of the nitride component and transferring the process of grain growth along the (100) or (111) directions into the nucleation process. This effect is accompanied by an increase in hardness while maintaining the viscosity of the coatings.

The deposition of coatings was carried out on an installation of the "Bulat" - "NNV 6.6-II" type, equipped with two separators of the droplet phase. For the deposition of nickel-containing coatings, cathodes were made from nitinol (Ti 45 wt%, Ni 55 wt%) and Ti-Al alloy (Ti 95 wt%, Al 5 wt%). The current at the cathodes was 120 and 135A, respectively. The bias potential on the substrate is -120 V. The partial pressure of nitrogen is 0.4 Pa, argon is 0.8 Pa. Application time 90 minutes. The deposition modes were selected based on previous studies [4].
The obtained coatings Ti$_{49}$Al$_{5}$N$_{46}$ and Ti$_{48}$Al$_{5}$N$_{41}$Ni$_{6}$ (at.%) were characterized by a columnar and equiaxial structure with nanosized grains for the first and second compositions, respectively.

The analysis of physical and mechanical properties was carried out on a Micro-Hardness Tester (CSM Instruments, Switzerland) by the method of measuring indentation at low loads (according to the method of Oliver and Pharr) [5]. The results are shown in table 1. The analysis of physical and mechanical properties was carried out on a Micro-Hardness Tester (CSM Instruments, Switzerland) by the method of measuring indentation at low loads (according to the method of Oliver and Pharr) [5]. The results are shown in table 1.

**Table 1.** Physical and mechanical properties of the obtained coatings.

| Coating          | $H_{it}$, GPa | $E_{it}$, GPa | $h_m$, nm | $W_p$, % | $H^3/E^2$, GPa | $H/E$ |
|------------------|---------------|---------------|-----------|----------|-----------------|--------|
| Ti-Al-N          | 16.0 ± 0.4    | 590 ± 55      | 229 ± 12  | 55 ± 1   | 0.013           | 0.028  |
| Ti-Al-N-Ni       | 17.1 ± 0.4    | 530 ± 50      | 222 ± 11  | 65 ± 2   | 0.020           | 0.035  |

$H_{it}$ – microhardness; $E_{it}$ – elastic modulus; $h_m$ – the penetration depth of the indenter; $W_p$ – the relative work of plastic deformation; $H^3/E^2$ – resistance to plastic deformation; $H/E$ – resistance to elastic deformation.

An increase in the resistance to plastic and elastic deformation in nickel-containing coatings is most likely associated with the presence of a branched grain boundary and a large number of triple joints that prevent the movement of point defects [6].

The adhesion strength of the coating to the substrate was estimated by scratching with a diamond indenter with an increasing load. Both coatings are characterized by a cohesive fracture mechanism. On the micrographs of the indenter path (figure 1) in the range of 10 - 20 N loads, chevron cohesion cracks ($L_{c1}$) were found. With an increase in loads over 20 N, the appearance of local openings of the substrate and a decrease in the amplitude of acoustic emission (AE) pulses ($L_{c3}$) are noted (figure 2). Complete abrasion of the coating did not occur up to a load of 90 N.

![Figure 1](image)

**Figure 1.** Micrographs of scratches areas at the specified load on the indenter of coatings: (a) Ti-Al-N; (b) Ti-Al-N-Ni.

Taking into account the work of the investigated steel-carbon plastic friction pair in sea water conditions, the electrochemical behavior of the coatings on 20H13 steel in a 3% NaCl solution was studied. The corrosion characteristics of the coatings were obtained using an IPC-Pro MF potentiostat (Volta, Russia) using a three-electrode electrochemical cell. The results of the conducted studies show that steel 20H13 without coating and with Ti-Al-N coating actively corrode with the formation of pitting and the absence of a passive state area. The Ti-Al-N-Ni coating begins to passivate at a potential of -340 mV. No pitting was found on the surface of the nickel-containing coating. The results obtained indicate an increased corrosion resistance of the latter samples.
Tests on the tribological characteristics of steel samples without and with applied coatings were carried out on a Tribometer device (Nanovea, USA) in a medium in a 3% NaCl solution according to the “rod-disk” scheme. The counterbody in the form of a ball with a 6 mm diameter was made of UGET carbon plastic. The load and rotation speed of the sample were 10 N and 10 cm/s, respectively. The number of revolutions was 6000.

The average values of the friction coefficients for uncoated steel and with Ti-Al-N and Ti-Al-N-Ni coatings are at the same level and amount to about 0.25. The obtained profilograms of samples after tribological tests characterize significant wear of steel without and with Ti-Al-N coating. The calculated values of the wear rate for these samples were equal to 19.24 \cdot 10^{-5} and 109.21 \cdot 10^{-5} mm^3/N\cdot m, respectively. No wear marks were observed on samples coated with Ti-Al-N-Ni. Increased wear of steel and Ti-Al-N coating is determined by the corrosion destruction of the samples, which accompanies the friction process.

Based on the foregoing, the use of Ti-Al-N-Ni coatings is preferable over the Ti-Al-N coating for hardening a metal counterbody (steel 20H13) in a pair of friction with carbon plastic reinforced plastic (UGET), taking into account a higher corrosion resistance of 3% NaCl solution, emitting seawater, which determines increased wear resistance.

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