

Diffusion Saturation of USA Steel in a Mixture of Metal Powders with the Chloride Ammonia

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Influence of the composition of the saturated mixture of the titanium, aluminum, chromium and chloride ammonia powders, the previous nitriding in a dissociation ammonia medium, titanium nitride layer saturated before the titanium alumina by the method of physical deposition from the gas phase on the phase, chemical composition and properties of the coatings was established. The main differences in the phase composition of the obtained coatings from the ordinary ones are due to the presence of a barrier layer, in which TiN titanium nitride was used. It has been established that the barrier properties of the titanium nitride layer are the inhibition of the diffusion penetration into the aluminum base, which prevents the formation of the Fe_α(Al) layer, hence positively affects the properties of the coatings. In this work, two groups of coatings were investigated: the first – TiN, TiC, FeTi, TiAlCr, σ-phase; the other is TiN, TiC, Cr₇C₃. The highest microhardness was found for titanium carbide layers – 32.1-35.6 GPa and for titanium nitride – 20.5-24.5 GPa. The resulting coatings contribute to the growth of wear resistance of USA steel in the conditions of slip friction without lubrication increases compared with the original (61HRC) 3.1-13.3 times. The phase composition of titanium nitride and carbide and chromium carbide coatings showed the best results. The obtained coatings showed high heat resistance due to the formation of complex oxides on the surface with the participation of the titanium, aluminum, chromium. The highest heat resistance at a temperature of 1000 °C for 100 h was detected for USA steel coated with TiN, TiC, FeTi, TiAlCr, σ-phase (layers listed from the base to the surface) with a concentration of chromium and aluminum on the surface, respectively, of 50.0 and 14.5 % by mass. The resulting coatings can be used to increase the service life of the USA steel tools.

Keywords: Diffusion coatings, Titanium, Aluminum, Chromium, Microstructure, Phase composition, Wear resistance, Microhardness.

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1. INTRODUCTION

Solid multilayer coatings on steels, solid alloys based on carbides, nitrides, transition metal borides, oxides are widely used today to improve the service properties of products [1-3]. Coatings are obtained by using such methods as physical deposition from the gas phase, chemical deposition from the gas phase, as well as methods of chemical and thermal treatment. The expansion of the range of coatings, the growth and complexity of their properties put forward new requirements for methods of application [3-4].

In the method of chemical deposition from the gas phase of refractory titanium compounds, chemical reactions involving titanium TiCl₄ and aluminum Al₂Cl₆ chlorides, hydrogen H₂, methane CH₄, nitrogen N₂ are used. As a result, TiN, TiC, Al₂O₃ compounds are formed on the product surface due to reactions that are effective at a temperature of 1000-1050 °C. The order of the layers of individual coating's compounds determines the optimal properties of the composition. For instance, the presence of Al₂O₃ on the outside part of the layer contributes to high thermal stability. This is due to the fact that the free energy of the Al₂O₃ formation is – 378 kcal/mol and 325 kcal/mol, respectively, at a temperature of 298 and 1000 K; for TiN compound – is 74 kcal/mol and 58 kcal/mol; for TiC – 43 kcal/mol and 41 kcal/mol.

The hardness of individual layers should be addi-

tionally described. In the range of room temperature for TiN, TiC, Al₂O₃ compounds the highest hardness is set for TiC carbide – about 30.0 GPa; for TiN, Al₂O₃ compounds – 20.0 GPa.

There are chemical-heat treatment methods, which allow obtaining coatings on the surface of products on the basis of carbides, transition metal nitrides with the use of a sodium tetra borate as a liquid phase [5]. In the case of saturation, sodium tetra borate melts are used involving aluminum (as a reductant), as well as carbide-forming elements such as titanium, vanadium, chromium, etc. or their compounds. The carbide coating is formed when the saturated metal in the salt bath has relatively low carbide formation energy and the metal oxide formation energy is higher than that of the B₂O₃ oxide. If these conditions are not met, the boron atoms are not oxidized, but freely diffused into steel, which forms a boride coating from the layers of FeB, Fe₂B compounds.

At present, there are methods of coating processing, which combine several methods, for example, nitration in ammonia followed by titanium diffusion, titanium alumination [3, 4]; processing by a method of physical deposition of a TiN layer followed by titanium diffusion [4]. Simultaneous saturation of carbon steels with titanium and aluminum is accompanied by the formation on the surface of the TiC and Fe_α(Al) layers, the second one adhered to the base. Microhardness of the Fe_α(Al)

layer on U8A steel is 1.9-2.6 GPa, of TiC layer – 30.0-35.0 GPa. The presence of a solid solution layer greatly degrades the properties of the coatings in the conditions of slip friction due to forcing and breaking the TiC. The heat resistance of this coating is insignificantly greater than the heat resistance of the TiC layer after titanium-plating. The analysis of the results showed the requirement of coatings with TiN, TiC layers and heat resistance at the level of alloys with significant aluminum content.

In the scientific-technical literature considerable attention is paid to the study of the structure, properties of alloys based on alloyed chromium intermetallide Al_3Ti with the structure of $L1_2$ triple system Al - Ti - Cr and to study the possibility of using these alloys in coating materials [6-8]. The highest heat resistance of Al - Ti - Cr alloys is considered [6, 8] to have an alloy based on Lavase-phase. During oxidation of this alloy, the film of Al_2O_3 oxide is formed on the surface. Simultaneously, the presence of the TiAl binary component causes the brittleness of the alloy [7]. It should be noted that the coating with titanium, aluminum, chromium with a barrier layer in the scientific-technical literature is not described.

The aim of the work is to obtain on the base of U8A steel the multicomponent coatings involving titanium, aluminum, chromium; to determine the influence of nitriding of U8A steel, to apply the surface by the method of physical deposition from the gas phase of the TiN layer on the structure and properties of the coatings.

2. EXPERIMENTAL TECHNIQUE

As a research object, the U8A instrumental steel was used, which is used for production of minor cutting tools. Titanium aluminum chrome plating was carried out in steel containers with a fusible shutter in powder mixtures of the following composition: mixture No 1: Ti (25 %); Al (10 %); Cr (25 %); NH_4Cl (5 %); Al_2O_3 (35 %); mixture No 2: Ti (15 %); Al (15 %); Cr (25 %); NH_4Cl (5 %); Al_2O_3 (40 %) at temperatures of 950, 1000, 1050 °C for 2 and 4 h. Nitration was carried out at a temperature of 550 °C for 15 h in an atmosphere of dissociated ammonia (25-35 %). Titanium nitride was deposited by the method of physical deposition on the VU1B device with a titanium cathode.

X-ray diffraction analysis was carried out at the DRON-UM1 installation in copper monochromatic radiation. The diffractograms were processed using the Powder Cell 2.2 program. The chemical composition of the coatings was determined on a scanning electron microscope Jeol JSM-6490LV with a spectrometer. Microstructural studies were performed on an optical microscope of Neophot 21. The thickness and microhardness of the coatings were determined on the PMT-3 device.

At the first stage of the complex steel processing, there was diffusion nitriding or applying of a TiN layer by the method of physical deposition from the gas phase.

Nitration was carried out in an atmosphere of ammonia at the level of its dissociation 25-35 % at a temperature of 540 °C for 20 h. On the U8A steel surface, a diffusion layer consisting of Fe_4N , $Fe_{2.3}N$ compound zones and internal nitriding zone is formed. In addition, the presence of Fe_3O_4 iron oxide, which is typical for ni-

tration in ammonia, was observed in the nitrated layer.

Part of the samples before the titanium aluminum chromium plating was subjected to a method of physical precipitation from the gas phase, TiN nitride with a thickness of 4.5-5.0 μm was applied.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In a light microscope, the TiN layer has a yellowish-golden color indicating that the composition of nitride is close to the stoichiometric. This is confirmed by an X-ray diffraction analysis, according to which the period of the FCC lattice of the TiN compound is 0.4245 nm.

Research results of phase and chemical compositions and some structures of coatings on U8A steel are given in Table 1 and Fig. 1.

The main differences in the phase composition of the obtained coatings from the ordinary ones are due to the presence of a barrier layer, in which TiN titanium nitride (Fig. 1b, c) was used. In coatings with a barrier layer there is no diffusion zone $Fe_\alpha(Al)$, which is usually formed during titanium alloying of carbon steels [9]. The titanium-plated coatings consist of FeTi, TiC, $Fe_\alpha(Al, Cr)$ layers (Fig. 1a). A layer of a solid solution of Fe (Al, Cr) is formed during the chemical heat-treatment by diffusion of Al and Cr into steel. When content of Al in austenite during chemical heat-treatment reaches 1.2 to 1.7 % of mass, $\gamma \rightarrow \alpha$ transformation occurs [10]. The solubility of carbon in the ferrite is modest. Obviously, the growing layer of Fe(α) displaces carbon to the base.

Significant concentrations of Cr and Fe on the sample surface (2, 3 Table 1) are attended by the formation of a layer of σ -phase (Fe, Cr). In the samples 4 of table 1, the absence of a barrier layer enables Cr and Al to be readily diffused through the TiC layer into the transition zone, where their concentration in the steel directly behind the TiC layer reaches 4.0 to 4.5 % by mass. In specimens No 5, with a barrier layer, chromium is concentrated externally in a layer of Cr_7C_3 compounds. Formation of carbides layers according to this technology occurs at carbon extraction to the surface of adsorbed atoms of carbide-forming elements. The TiN layer inhibits the diffusion of carbon to the surface. In the examined samples No 2, 3 of Table 1 inhibition of carbon diffusion by TiAlCr, FeTi layers is significantly more effective, which contributes to the formation of σ -phase (FeCr) layers.

Aforementioned, the formation of layers by this method of chemical heat-treatment is carried out by diffusion, which confirms the study of the kinetic growth of coatings (Fig. 2). Meanwhile, during the diffusion mechanism of growth, the carbon submerge to the surface in the initial stages of chemical heat-treatment occurs quickly. Adsorbed on the surface, titanium atoms interact with carbon ones to form a TiC carbide. When saturated with pre-nitrated steel, TiC, TiN layers (sample 3 in Table 1) are formed. Diffusion carbon stream of the base to the surface is inhibited by a TiN layer. Sample 2, Table 1, a TiN layer was applied before titanium aluminum chromium plating. The phase composition and properties of samples 2, 3 in Table 1 of the obtained coatings are similar.

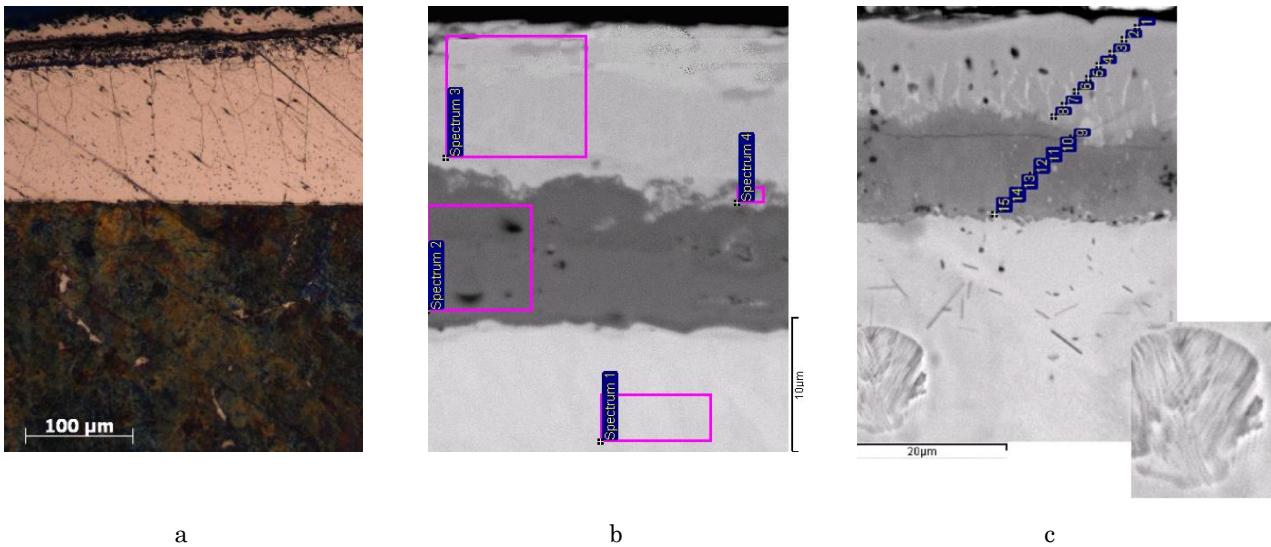


Fig. 1 – Microstructure of titanium aluminum chromium plated U8A steel (a, c), of titanium aluminum chromium plated with TiN (b) layer; a – optical microscope; b, c – electron microscope; etchant 3 % solution of HNO₃ in alcohol, $T = 1050\text{ }^{\circ}\text{C}$; $t = 4\text{ h}$; b – saturated mixture: Ti (25 %); Al (15 %); Cr (25 %); Al₂O₃ (35 %); NH₄Cl (5 %), c – saturating mixture: Ti (15 %); Cr (25 %); Al (15 %); NH₄Cl (5 %); Al₂O₃ (40 %)

Table 1 – Phase composition and properties of multi-component coatings on U8A steel (titanium aluminum chromium plating, 1050 °C, 4 h)

Sample No*	Coating phase composition**	Crystal lattice period, nm	Thickness, μm	Microhardness, GPa
1	Fe(Ti,Al,Cr)	$a = 0.2990$	6.5	–
	TiC	$a = 0.4320$	11.5	32.1
	Fe _α (Al,Cr)	$a = 0.2864$	50.0-55.0	2.2-1.2
2	σ-phase	$a = 0.8812$ $c = 0.5446$	2.0-2.5	–
	TiAlCr	$a = 0.1218$	4.5-5.0	–
	Fe(Ti,Al,Cr)	$a = 0.1218$	5.0	9.1
	TiC	$a = 0.2991$	2.5-3.0	33.0
	TiNO	$a = 0.4324$	–	–
	TiN	$a = 0.4242$	5.0	24.5
3	σ-phase	$a = 0.8812$ $c = 0.5446$	2.0	–
	TiAlCr	$a = 0.1211$	5.5	–
	Fe(Ti,Al,Cr)	$a = 0.2986$	5.0	9.8
	TiC	$a = 0.4329$	3.5-4.0	35.5
	TiN	$a = 0.4246$	4.5	22.9
4	Fe ₂ Ti ₄ O	$a = 1.1354$	2.0-3.0	7.6
	TiC	$a = 0.4330$	25.0-28.5	35.0
5	Cr ₇ C ₃	$a = 1.4050$ $c = 0.4510$	2.5-4.0	17.9
	TiC	$a = 0.4318$	12.5-13.0	35.6
	TiN	$a = 0.4251$	5.0-6.0	23.5
6	Cr ₇ C ₃	$a = 1.4052$ $c = 0.4508$	2.0-3.0	8.2
	TiC	$a = 0.4320$	14.0	35.0
	TiN	$a = 0.4259$	5.0	29.5

* Sample No:

- 1 – Ti(15); Al(15); Cr(25); Al₂O₃(40); NH₄Cl(5);
- 2 – Ti(15); Al(15); Cr(25); Al₂O₃(40); NH₄Cl (5); steel with TiN layer;
- 3 – Ti(15); Al(15); Cr(25); Al₂O₃(40); NH₄Cl (5); previously nitrated steel;
- 4 – Ti(25); Al(10); Cr(25); Al₂O₃(35); NH₄Cl (5);
- 5 – Ti(25); Al(10); Cr(25); Al₂O₃(35); NH₄Cl (5); steel with TiN layer;
- 6 – Ti(25); Al(10); Cr(25); Al₂O₃(35); NH₄Cl (5); previously nitrated steel.

** On the surface of samples 1-5 there is Al₂O₃ compound, of samples 1, 4 – compound Fe₂(Al,Ti)C14: $a = 0.4909\text{ nm}$; $c = 0.8010\text{ nm}$; of sample 2 – AlTi₃ compound: $a = 0.5740\text{ nm}$; $c = 0.4638\text{ nm}$

The analysis of the research results of crystalline lattice parameters of TiN, TiC layers on samples of U8A steel (No 5, Table 1) showed a dependence on the saturation time (Fig. 3). A small growth during saturation of the parameter of TiN lattice is established in the work, the maximum of the parameter of the TiC compound at the time of metallization of 2 h may be due to various factors. Firstly, there is a change in the concentration of compounds in carbon and nitrogen, as well as elements of the metal sub-lattice. A decrease in the lattice periods of penetration phases when the composition is rejected from the stoichiometric occurs for both ordinary massive samples and for films [11]. It should be pointed out that the experimentally established value of periods of film lattices is more than that for massive ones. It is due to the influence of residual stresses, the size of grains, and the presence of penetration and substitution impurities on the lattice period of coating compounds [11].

The coatings are detected on cross section slabs in light and electron microscopes in the form of light, light gray bars with a well-defined weakly developed boundary with the base (Fig. 1). Previously mentioned, the titanium-aluminum chromium coating on U8A steel consists of layers of Cr_7C_3 , TiC, TiN compounds. The layer of Cr_7C_3 compounds, which is located on the outer side of the diffusion zone, has a bright color on the gray background of the TiC layer. In some areas of the TiC coating, individual inclusions of the Cr_7C_3 phase were detected in the range of 0.5-2.5 microns.

Spherical inclusions with a diameter of 12.0-15.0 μm were found in the structure of the $\text{Fe}_x(\text{Al})$ layer of titanium aluminum chrome plating (Fig. 1c). The spheres consist of rails that are packed in. The rails were oriented one to the other at an angle close to 45° . The thickness of individual rails is 0.5-1.0 μm . The microhardness of the formed structure reaches 9.5-10.1 GPa, which makes it possible to identify the formed structure as martensitic or intermetallic.

In general, the coatings obtained in the work are practically free of pores, chips, cracks, are well-bonded to the base. Analyzing by a light microscope, the TiN layer after diffusion metallization remained with a characteristic light-golden color. It indicates the proximity of TiN composition to stoichiometric.

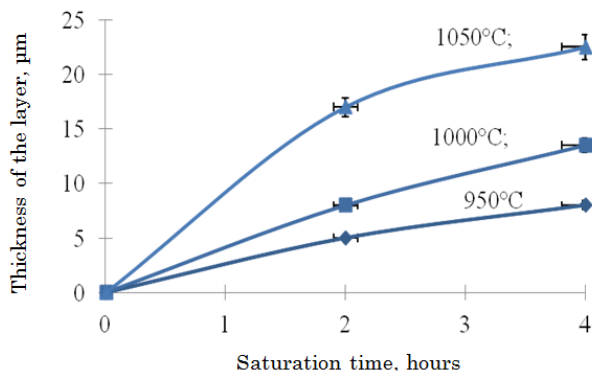


Fig. 2 – Dependence of the thickness of the TiC layer on U8A steel on the saturation time. Sample No 4 (Table 1): titanium aluminum chromium plating, % by mass: Ti (25); Al (10); Cr (25); Al_2O_3 (35); NH_4Cl (5)

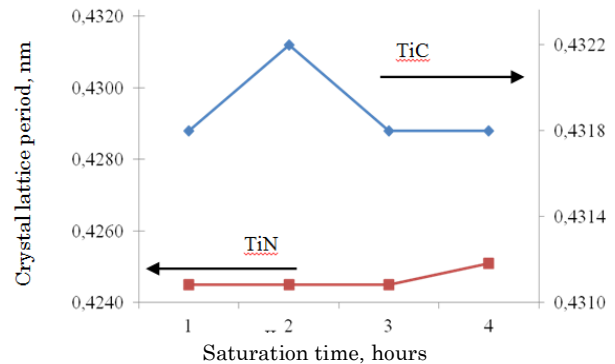


Fig. 3 – Influence of saturation time on the lattice of TiC, TiN coatings. Sample No 5 (Table 1): titanium aluminum chromium plating, % by mass: Ti (25); Al (10); Cr (25); Al_2O_3 (35); NH_4Cl (5). U8A steel with a layer of TiN

In the analysis of the formation mechanism of titanium aluminum chromium plating coatings on the U8A steel, the results of theoretical and experimental studies of multicomponent saturation processes were taken into account. A common feature of the formation of the coatings studied in the work (samples 1-6, Table 1) is that the TiC, TiN compounds, intermetallics consist of elements extracted from the base. The TiN layer on the U8A steel obtained by the method of physical precipitation, or in the nitrogenous steel formed by the process of titanium aluminum chromium plating performs barrier functions – predominantly diffusion penetration of aluminum (samples 3, 4, Table 1), chromium (samples 5, 6, Table 1) in the basis. In the last case, there is a layer of Cr_7C_3 carbides on the outer side.

The discussed in the work mechanism of coating formation with the participation of chemical transport reactions works well with adsorption-shock perceptions concerning crystallization (Fig. 4) [12]. With the crystal growth, the surface migration of individual atoms is [4] $\lambda_2 = D_s \tau$, where D_s is the coefficient of diffusion; τ is the time until the atom is re-vaporized or attached. For diffusion layers, time τ corresponds to the time until the next layer is deposited. For the given saturation method, the growth rate of the coating is 1-4 nm/s, and the time to attachment is 10^{-2} - 10^{-3} s. For the time of re-evaporation 10^{-2} , calculations have shown that the temperature, at which the crystal growth of coatings practically does not depend on the diffusion of metals, corresponds to the temperatures of the chemical heat-treatment of this work – 900-1050 °C.

At temperatures of the chemical heat-treatment preset in this work, the carbide and nitride phases of the nucleus are largely determined by the diffusion of carbon or nitrogen to adsorbed titanium atoms (Fig. 4a-c). The nuclei grow on the surface and height, become three-dimensional, link up, and develop a coating. The process speed is significant – it does not allow aluminum to penetrate the base. The growth rate is due to two mechanisms: on the outer side of the diffusion zone or simultaneously on the outer and inner sides (Fig. 4a).

The mechanism shown in Fig. 4 can be used for coatings 1-6, Table 1. A small amount of aluminum and significant of chromium in the reaction medium is accompanied by the formation on the outside of the coating of a layer of Cr_7C_3 carbide (coatings 5, 6, Table 1).

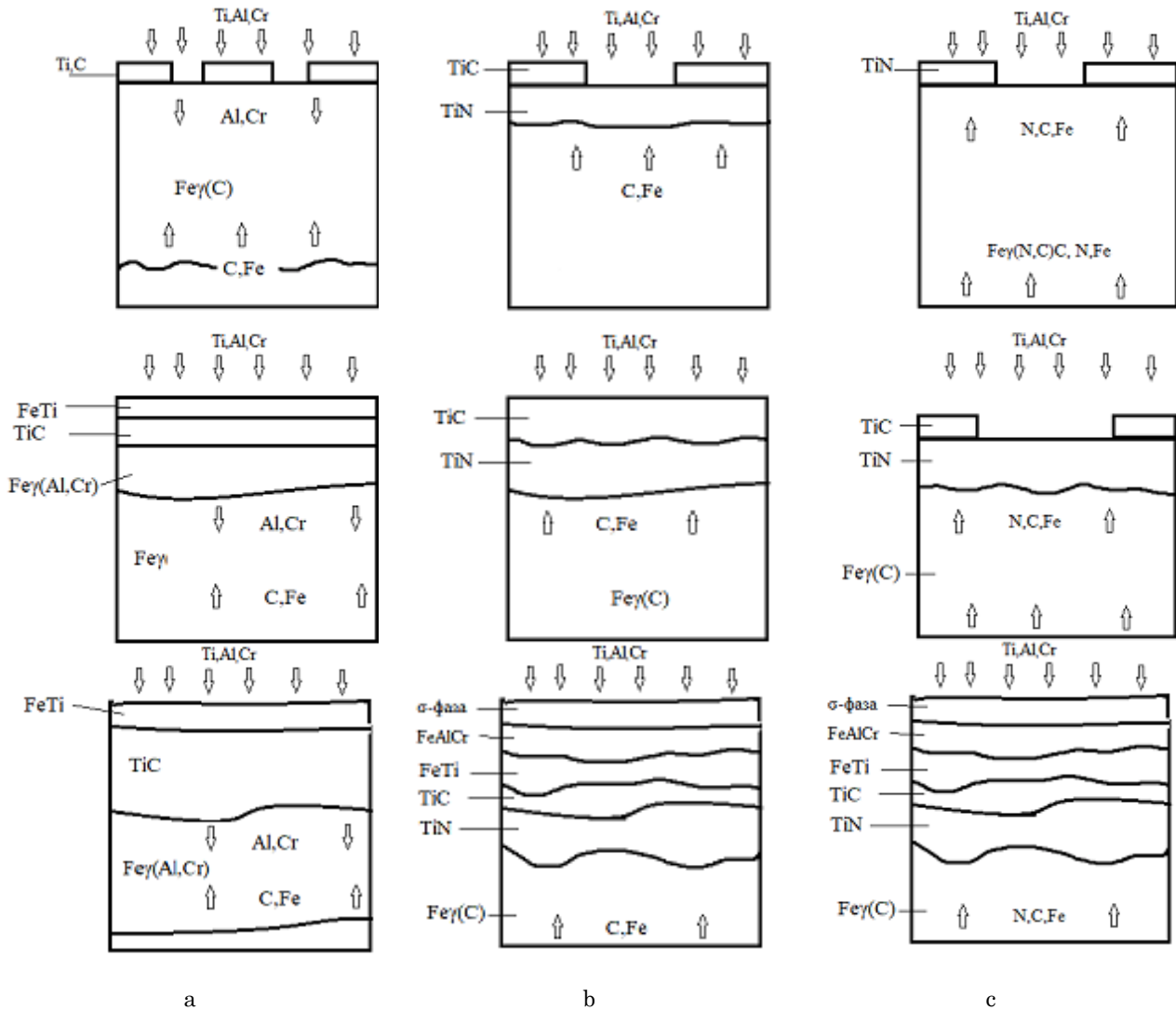


Fig. 4 – The mechanism of titanium-aluminum-chrome coating formation on U8A steel from the gas phase at saturation temperature: the initial U8A steel (a); U8A steel with a layer of TiN (b); nitrated U8A steel (c)

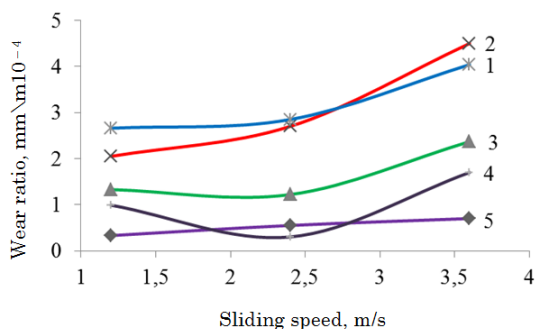


Fig. 5 – Dependence of the wear intensity in conditions of sliding friction; load 50 N, time 120 s; 1 – U8A steel after quenching and low tempering, hardness 61 HRC; 2 – sample No 1; 3 – sample No 2; 4 – sample No 5; 5 – sample No 4 (Table 1)

The ability to act as a barrier to aluminum TiN phase, the lack of such ability of the TiC phase, can be explained by the analysis of the TiN, TiC, Al electronic structure [4]. In the TiN phase, oppose to TiC, the conduction band is occupied by weakly coupled conduction electrons and electrons that occupy anti-binding states. In contact with aluminum, the electrons of anti-binding states can pass

into 3p states with spin opposite to the spin of electrons of Al atoms. The formation of singlet states can lead to a limited number of Ti - N - Al bonds, since the number of electrons in the anti-binding states is limited. As a result, formation of TiN films of a small thickness, separating the TiN layer of Ti - N - Al compound with an adsorbed layer of aluminum and inhibiting the penetration of aluminum into the steel base, becomes possible.

In [3, 4], it was shown that the titanizing of the U8A nitrogenized steel leads to the formation of multi-layer coatings, in which the composition of the TiC, TiN layers is present. The TiN layer has high barrier properties, which are realized during the metallization of nitrated steels, steels with a previously applied layer of TiN and service.

Results of measurements of microhardness of investigated coatings on U8A steel are given in Table 1. The analysis of the data showed that the layers based on TiC titanium carbide have the highest microhardness among the studied layers: 32.1-32.6 GPa. Sufficiently high hardness of the FeTi layer (samples 2, 3, Table 1) is due to high nitrogen content, which is confirmed by micro-ray spectral analysis.

The TiN layer microhardness obtained by the method of physical deposition of the phase (samples 2, 5, Table 1) is 20.4 GPa. After titanium aluminum chromium plating, the microhardness of this layer increased and became equal to 23.5-24.5 GPa (samples 2, 5, Table 1). The growth of microhardness is due to the alloying of the TiN layer in titanium aluminum chromium plating, primarily C, Fe, Cr, Al. The scheme of alloying of the TiN layer is comprehensible during the metallization of the U8A nitrogenized steel. The probability of the TiN layer formation is higher than the probability of the TiC layer formation, which determines the layers studied in the work: sample 6, Table 1: TiN, TiC, Cr₇C₃; sample 3, Table 1: TiC, TiN, FeTi, TiAlCr, σ -phase.

In the work, the wear resistance was determined in conditions of slip friction without lubrication. The wear intensity was evaluated by using the expression $I = (h/v)\tau \cdot 10^{-4}$, where I is wear ratio; h are the dimensions of the well; v is the sliding speed; τ is the test time (see Fig. 5).

The characteristic dependence of the wear ratio of coated steels on the test speed is the growth of wear with increasing speed, as well as the presence of a minimum on curve 5.

It is considered [13] that there may be a slip rate for which wear will be minimal. The reason for the presence of a fixed speed is a coating with a range of properties. The presence of such properties influences the contact interaction: reduces the coefficient of friction, the temperature in the contact area of the coating – counter body, inhibits the diffusion interaction between the base and the counter body.

In order to protect alloys from oxidation in the active medium, the ability of the coating to retain its properties and chemical composition at high temperatures is important. It is reasonable to create multi-component coatings with a barrier layer on the boundary of the coating section – the basis. The obtained coatings showed high heat resistance due to the formation of complex oxides on the surface with the participation of Al, Cr, Ti. The highest heat resistance at a temperature of 1000 °C for 80 h was established for

coatings with a barrier layer of TiN specimens No 3 (Table 1). The coatings were obtained by titanium aluminum chromium plating of U8A steel.

High heat resistance makes it possible to perform heat treatment of U8A steel products with coatings under natural aeration conditions. Heating up to the temperatures of quenching (760-800 °C), the ageing at these temperatures practically does not affect the phase composition and properties of the coatings. The subsequent quenching through water into oil and tempering leads to the formation of cracks, detachment of coatings, indicating high adhesion of the coating with the base.

The results of the research obtained in the work allowed to conclude that it is possible to obtain on the U8A steel surface multilayer coatings involving Ti, Cr, Al with a barrier component of TiN. The coatings have high microhardness, wear resistance, heat resistance, which allows them to be recommended as U8A steel protectors.

4. CONCLUSIONS

1. The diffusion coatings are formed on steel U8A as a result of a combination of processes of titanium aluminum chromium plating with the prior nitriding or with a previously applied layer of TiN.

2. The dependence of the phase composition of the coatings on the composition of the saturated mixture is established: Ti(25); Al(10); Cr(25); Al₂O₃(35); NH₄Cl(5% by mass): phase composition of TiN, TiC, Cr₇C₃; Ti(15); Al(15); Cr(25); Al₂O₃(40); NH₄Cl (5 % by mass): phase composition of TiN; TiC; FeTi; TiAlCr; σ -phase.

3. Maximum microhardness set for the layers of compounds is: TiC – 32.1-35.6 GPa; TiN – 20.5-24.5 GPa.

4. U8A steel wear resistance with coatings in conditions of sliding friction without lubrication increases compared with the original (61HRC) in 3.1-13.3 times. The maximum durability showed the multilayer coatings of phase composition: TiN, TiC, Cr₇C₃.

5. The highest heat resistance at 1000 °C during 80 h of testing was demonstrated by the coatings of phase composition: TiN, TiC, FeTi, TiAlCr, σ -phase (layers listed from the base to the surface).

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Дифузійне насичення сталі У8А в суміші порошоків металів за участю хлористого амонію

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Встановлено вплив складу насичуючої суміші з порошоків титану, алюмінію, хрому та хлористого амонію; попереднього азотування в середовищі дисоційованого аміаку, шару нітриду титану, насиченого перед титаноалюмохромуванням методом фізичного осадження з газової фази на фазовий, хімічний склад та властивості покриттів. Основні відмінності фазового складу одержаних покриттів від традиційних зумовлені наявністю бар'єрного шару, в якості якого було використано нітрид титану TiN. Встановлено, що бар'єрні властивості шару нітриду титану полягають в гальмуванні дифузійного проникнення в основу алюмінію, що перешкоджає формуванню шару Fe₃(Al), і, таким чином, позитивно впливають на властивості покриттів. В роботі було досліджено дві групи покриттів: перша – TiN, TiC, FeTi, TiAlCr, σ – фаза; друга – TiN, TiC, Cr₇C₃. Серед досліджених в роботі сама висока мікротвердість виявлена для шарів карбіду титану – 32.1-35.6 ГПа, а також нітриду титану – 20.5-24.5 ГПа. Отримані покриття сприяють зростанню зносостійкості сталі У8А в умовах тертя ковзання без змачування в 3.1-13.3 рази. Найкращі результати показали покриття TiN, TiC, Cr₇C₃. Отримані в роботі покриття показали високу жаростійкість, що зумовлено формуванням на поверхні оксидів складного складу за участю алюмінію, хрому, титану. Найвища жаростійкість при температурі 1000 °С впродовж 100 годин було виявлено для сталі У8А з покриттям TiN, TiC, FeTi, TiAlCr, σ – фаза (шари, перераховані від основи до поверхні) з концентрацією хрому та алюмінію на поверхні відповідно 50.0 та 14.5% мас. Отримані покриття можуть бути використані для підвищення терміну експлуатації інструментів із сталі У8А.

Ключові слова: Дифузійні покриття, Титан, Алюміній, Хром, Фазовий склад, Мікроструктура, Зносостійкість, Мікротвердість.