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# VACUUM ACTIVATED DIFFUSION CHROMIUM PLATING OF 15Kh12VNMF AND 20Kh1M1F1TR STEELS

***Introduction.*** *15Kh12VNMF and 20Kh1M1F1TR steels are used in mechanical engineering as a material for turbine parts. To increase the operating temperature of such parts, it is necessary to improve the heat resistance of their surface.*

***Problem Statement.*** *Increasing the heat resistance of steel surface is possible by applying a protective layer to it. It is almost impossible to say unequivocally which coating and method of its formation on a particular steel provide a sufficient increase in the heat resistance of the surface of this material. Previously, 15Kh12VNMF and 20Kh1M1F1TR steels were not protected by vacuum chromium plating in sodium chloride vapor.*

***Purpose.*** *The purpose of this research is to study the process of vacuum activated chromium plating of 15Kh12VNMF and 20Kh1M1F1TR steels and its effect on the characteristics of the samples made of these materials.*

***Materials and Methods.*** *The samples for research are made of 15Kh12VNMF and 20Kh1M1F1TR steels. Tests for cavitation and abrasive wear have been made on stands. The heat resistance test has been carried out in a muffle furnace in the air. The metallographic methods and X-ray fluorescence analysis (XRF) have been used to study the sample surface.*

***Results.*** *The 15Kh12VNMF and 20Kh1M1F1TP steel samples have been plated with chromium by the vacuum saturation method in sodium chloride vapor at temperature T = 1070 °C and 1100 °C; the process duration is 4 and 10 hours. It has been found that the samples made of these steels and plated with chromium under cavitation*

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*and abrasive action slightly fall behind the original samples in terms of wear resistance. It has been established that when the samples are chromium plated, a diffusion layer with a thickness from 50 to 130 μm is formed on their surface, depending on the treatment conditions. The content of chromium in the surface layer of 15Kh12VNMF and 20Kh1M1F1TR steels varies, respectively, within 56—56 wt. % and 81—8 1 wt. %, depending on the saturation process parameters. The comparative tests of these samples for heat resistance have been carried out in the air, at a temperature of 900 °C. It has been found that the heat resistance of chrome-plated samples is much higher than that of the original ones.*

***Conclusions.*** *The studies of the process of vacuum activated chromium plating of samples made of 15Kh12VNMF and 20Kh1M1F1TR steels have shown that such treatment significantly increases the heat resistance of these materials in comparison with the original ones.*

*Keywords: vacuum chrome plating, steel 15Kh12VNMF, steel 20Kh1M1F1TR, heat resistance, and diffusion layer.*

Further increase in power, efficiency, and reliability of turbines for power plants involves the use of more durable materials in their manufacture or the application of protective coatings. The latter is preferable. This approach combines the strength of the base material, high hardness and heat resistance of the product surface. There are many methods for forming coatings on steel products. To create a protective coating, this may be a technology that forms a metal layer of heat-resistant components on the product surface. There are many protective coatings that strengthen the resistance of the steel surface to aggressive gases. Among the corrosion-resistant elements there are is chrome and materials based on it. When chromium is exposed to oxidizing media, there is formed a continuous protective film that prevents the penetration of gaseous media into the steel. Therefore, we used the method of vacuum activated diffusion chromium plating in sodium chloride vapor. This approach allows us to create a protective layer containing more than 80% chromium, on the steel surface. This coating has a high corrosion resistance.

The processes of chromium plating of metals and alloys have been studied in detail in monograph by Dubinin G.N. published in 1964 [1]. Many works have dealt with the process of chromium plating, but research in this direction is still ongoing. We have used the method of vacuum activated diffusion saturation of materials, which is protected by two patents [2, 3]. In this process, sodium chloride is used as an activator. This method and device for its implementation provide the formation of a uniform diffusion layer over the entire surface of the product, which has a complex shape and holes.

The purpose of this research is to develop coatings for the protection of steam turbine parts, which provide high physical and chemical properties of product surfaces. The protective layers on the surface of 15X12VNMF and 20X1M1F1TR steel samples at different process parameters have been created by the method of vacuum activated diffusion chromium plating. When the surface of the parts is saturated with chromium, a diffusion layer that protects the surface from the effects of steam-gas mix at a temperature of 650 °C is formed.

*Table 1.* **Composition of 15X12VNMF and 20X1M1F1TR According to DSTU**

| Steel grade | Mass fraction of elements, % according to DST 20072-74 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20X1M1F1TR (EP 182) | C | Si | Mn | S | P | Cr | Ni | Mo | V | Ti | Al | B | Cu |
| | 0.17—0.24 | < 0.37 | < 0.050 | < 0.030 | < 0.03 | 0.90—1.40 | < 0.30 | 0.80—1.00 | 0.7—1.0 | 0.05—0.12 | — | < 0.005 | < 0.2 |

| Steel grade | Mass fraction of elements, % according to DST 5632-72 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15X12VNMF (EP 802, EP 952) | C | Si | Mn | S | P | Cr | Ni | Mo | V | W | Cu |
| | 0.931 | 0.926 | 0.898 | 0.881 | 0.880 | 0.836 | 0.836 | 0.836 | 0.836 | 0.836 | 0.836 |

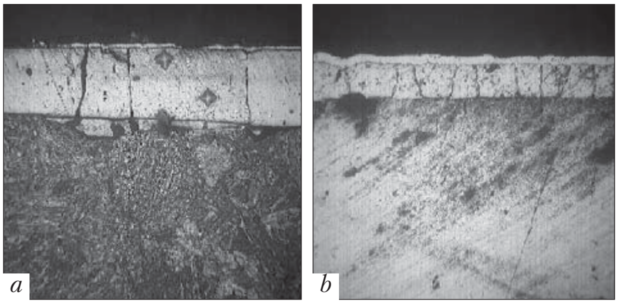

***Fig. 1.*** Photos of sample sections after chromium plating at a temperature of 1070 °C, for 4 hours: *a* — 15X12VNMF steel; *b* — 20X1M1F1TR steel

We have studied vacuum chroming samples made of 15X12VNMF and 20X1M1F1TR steels at a temperature T=1070 and 1100 °C; the process lasts for 4 and 10 hours. Pursuant to the Government Standard these steels shall the composition as specified in Table 1.

Table 2 shows the results of measurements of the chemical composition of sample surfaces made with the use of SPRUT (RFA).

The results of determining the composition of 15X12VNMF and 20X1M1F1TR steel samples surface, as presented in Table 2, have shown that chromium plating radically changes the surface composition. The changes in the concentration of chromium and iron have been established to depend on the temperature and duration of the saturation process. As the temperature and duration of chemical and heat treatment increase, so does the concentration of chromium in the surface layer increases, whereas the iron content decreases, with

*Table 2*. **The Results of Measurements of the Chemical Composition of Sample Surfaces Made with the Use of SPRUT (RFA)**

| Steel grade | Treatment | Mass fraction of elements, % | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20X1M1F1TR (EP 182) | Original steel | Si | Ti | V | Cr | Mn | Mo | Fe |
| | | 0.3 | 0.1 | 0.9 | 1.2 | 0.4 | 1.3 | 95.8 |
| 15X12VNMF | Original steel | Si | Cr | Mn | Ni | Cu | Mo | Fe |
| (ЭИ 802, ЭИ 952) | | 0.8 | 11.2 | 0.9 | 0.5 | 0.5 | 0.7 | 85.4 |
| 20X1M1F1TR (EP 182) | Steel nitrided at *Turboatom* | Si | Ti | V | Cr | Mn | Mo | Fe |
| | | 0.3 | 0.09 | 0.7 | 1.05 | — | 1.07 | 96.7 |
| 15X12VNMF (ЭИ 802, ЭИ 952) | Steel nitrided at *Turboatom* | Si | Cr | Mn | Ni | Cu | Mo | Fe |
| | | 0.2 | 9.9 | 0.5 | 0.2 | — | 0.7 | 88.5 |
| 20X1M1F1TR (EP 182) | Chromed steel: T = 1100 °C, 4 h | Si | Ti | V | Cr | Mn | Mo | Fe |
| | | 0.3 | 0.06 | — | 81.6 | — | 0.9 | 17.1 |
| 15X12VNMF (ЭИ 802, ЭИ 952) | Chromed steel: T = 1100 °C, 4 h | Si | Cr | Mn | Ni | Cu | Mo | Fe |
| | | — | 59 | — | — | — | — | 41 |
| 20X1M1F1TR (EP 182) | Chromed steel: T = 1070 °C, 6 h | Si | Ti | V | Cr | Mn | Mo | Fe |
| | | — | — | — | 87.5 | — | — | 12.5 |
| 15X12VNMF (ЭИ 802, ЭИ 952) | Chromed steel: T = 1070 °C, 6 h | Si | Cr | Mn | Ni | Cu | Mo | Fe |
| | | 0.1 | 64.3 | — | — | — | 0.8 | 34.7 |
| 20X1M1F1TR (EP 182) | Chromed steel: T = 1070 °C, 10 h | Si | Ti | V | Cr | Mn | Mo | Fe |
| | | 0.25 | | | 93.6 | | | 6.1 |
| 15X12VNMF (ЭИ 802, ЭИ 952) | Chromed steel: T = 1070 °C, 10 h | Si | Cr | Mn | Ni | Cu | Mo | Fe |
| | | — | 82.9 | — | — | 0.3 | 0.6 | 16.1 |
| 20X1M1F1TR (EP 182) | Chromed steel: T = 1100 °C, 10 h | Si | Ti | V | Cr | Mn | Mo | Fe |
| | | 0.2 | | | 93.1 | 2.2 | | 4.5 |
| 15X12VNMF (ЭИ 802, ЭИ 952) | Chromed steel: T = 1100 °C, 10 h | Si | Cr | Mn | Ni | Cu | Mo | Fe |
| | | 0.3 | 76.0 | — | — | — | 0.6 | 23.0 |

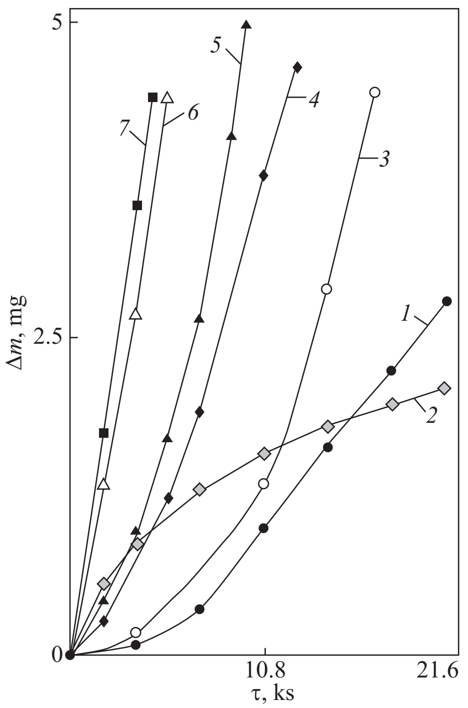


***Fig. 2.*** Kinetic curves of destruction of 15X12VNMF steel samples under the action of cavitation: *1* — without treatment; *2* — after furnace nitriding at the Turboatom enterprise; *3—7* — after chromium plating at different temperatures (*T*, K) and time (τ, ks); 3: *T* = 1343 K, τ = 14.4 ks; 4: *T* = 1373, τ = 14.4 ks; 5: *T* = 1373, τ = 21.6 ks; 6: *T* = 1343, τ = 36.0 ks; 7: *T* = 1373, τ = 36.0 ks

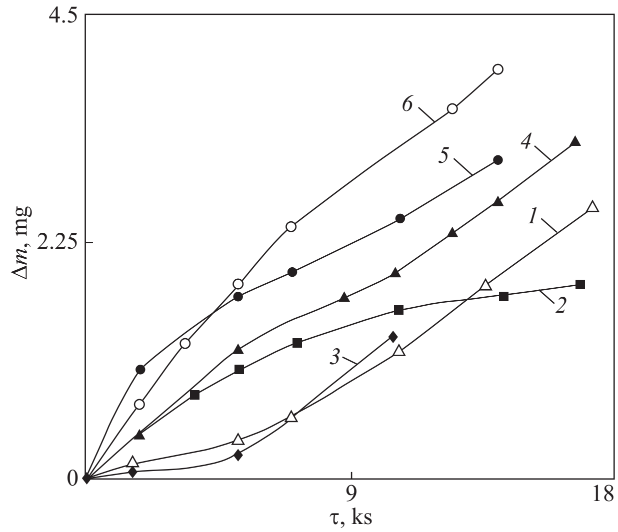


***Fig. 3.*** Kinetic curves of destruction of 20X1M1FTR steel samples under cavitation: *1* — without treatment; *2* — after furnace nitriding at the Turboatom enterprise; *3* — after chromium plating at *T* = 134 K, τ = 14.4 ks; *4* — *T* = 1373 K, τ = 14.4 ks; *5* — *T* = 1343 K, τ = 36.0 ks; *6* — *T* = 1373 K, τ = 13.6 ks

the alloying elements of the treated steels being practically invisible.

The metallographic studies have shown that with vacuum-activated chromium plating of samples made of 15X12VNMF and 20X1M1F1TR steel, the thickness of the diffusion layer reaches 130 μm, but the size of grains of the treated material grows.

To solve the problem of the stability of the studied materials under microshock load, NSC KhIPTI has developed a stand for creating cavitation with the use of the vibration method and the method statement for determining wear under such exposure [4, 5]. The ABI-1 device is used to study the abrasive wear of the samples. The kinematic scheme of the device includes an electric motor, a shaft, a system for fastening and loading the samples. The samples are worn in accordance with the plane — disk scheme. The flat samples are coated, and the disk is made of a material with rigidly fixed abrasive particles. The speed of the disk surface that contacts the sample surface is 4.38 m/s, and the load on the sample is 2.2 N. The wear rate is determined by measuring the loss of the sample mass for a fixed time of abrasion with an error of 0.015 mg.

Figures 2 and 3 show the experimental dependence of the loss of sample mass (mΔ) on the time of action (τ) of micro-shocks generated by cavitation. Figures 2 and 3 show that the kinetic curves (*1, 2*) have the same appearance, while others differ, depending on the parameters of the chromium deposition process, both for one and several different steels.

For 20H1M1FTR steel, kinetic curve *3* that corresponds to chromium plating at low process parameters, at the initial stage of cavitation (up to 10.8 ks), does not differ from that of the original sample, while curves *2*, *4—6* have higher rate of destruction. The kinetic curves characterizing the destruction of 15H12VNMF steel have a similar nature (*3—7*). As the nature of the kinetic curves changes, the sample destruction rates during the cavitation change accordingly. The

20X1M1FTR and 15X12VNMF steel sample destruction rates are calculated on the basis of the kinetic curves presented in Figs. 2 and 3, given the characteristics of steels, fracture zones, and

The results of studies of erosion of samples under the influence of abrasion and cavitation are presented below in Tables 3 and 4.

The data of Tables 3 and 4 have shown that additional chromium plating of the samples changes their resistance to cavitation and abrasion, with the rate of destruction depending on the process parameters (temperature and duration). The use of one of the options for chrome plating depends on the operating conditions of machine parts and mechanisms.

Given that the main purpose of the research is to increase the heat resistance of 15H12VNMF and 20H1M1F1TR steel surfaces, the samples have been tested for heat resistance in a muffle furnace in the air at a temperature *T* = 700, 900, and 1100 °C. Below, Table 5 presents the results of 15H12VNMF and 20H1M1F1TR steel sample heat resistance tests at a temperature of *T* = 900 °C in the air.

In the third column of Tables 5 and 6, $P_\tau$, is the sample weight, where τ is the test time.

Based on the data presented in Tables 5 and 6, certain conclusions may be drawn. The weight change for the original samples of 15H12VNMF steel is about 0.05 g, while the nitrided samples change their weight by 0.097 g. The weight change for the chrome-plated samples is much less, as it ranges from 0.00018 to 0.00145 g. This suggests that the heat resistance of chromium-plated samples is much higher than the stability of the original samples and the nitride ones. In the case of 20H1M1F1TR steel the weight change for the original samples is about 0.5 g, while the nitrided ones change their weight twice less. The weight change for the chromium-plated samples is much less, as it varies from 0.0002 to 0.00065 g. The tests for heat resistance at a temperature of 700 and 1100 °C have shown a significant increase in the corrosion resistance of 15H12VNMF and 20H1M1F1TR steel samples after chemical and heat treatment.

It has been found that during the chromium plating of samples made of 15X12VNMF and

*Table 3*. **Wear of 15X12VNMF Steel Samples as a Result of Abrasion and Cavitation Action**

| Sample number that corresponds to the curve number | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Number of treated sample | | 35 | 36 | 10 | 20-A1 | 20-A2 | 46 | 53 |
| Treatment parameters | Temperature, *T*, K | Untreated | Furnace nitriding | 1343 | 1373 | 1373 | 1343 | 1373 |
| | Duration τ, ks | — | — | 14.4 | 14.4 | 21.6 | 36.0 | 36.0 |
| The rate of destruction under the action of abrasion | mg/ks | 3.6 | 8.2 | 9.09 | 12.12 | 8.5 | 8.4 | 4.5 |
| The rate of destruction under the action of cavitation | μm/ks | 0.43 | 0.1 | 0.938 | 1.19 | 0.156 | 1.85 | 1.69 |

*Table 4*. **Wear of 20X1M1FTR Steel Samples as a Result of Abrasion and Cavitation Action**

| Sample number that corresponds to the curve number | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Number of treated sample | | 33 | 35 | 15 | 5 | 44 | 40 |
| Treatment parameters | Temperature, *T*, K | Untreated | Furnace nitriding | 1343 | 1373 | 1343 | 1373 |
| | Duration τ, ks | — | — | 14.4 | 14.4 | 36.0 | 36.0 |
| The rate of destruction under the action of abrasion | mg/ks | 2.6 | 2.0 | 4.42 | 4.58 | 5.0 | 5.8 |
| The rate of destruction under the action of cavitation | μm/ks | 0.52 | 0.37 | 0.709 | 0.715 | 0.729 | 1.014 |

20X1M1F1TR steels, on their surface, there is formed a diffusion layer with a thickness from 50 to 130 μm, depending on the conditions of chemical-heat treatment.

It has been established that after vacuum activated chromium plating, the chromium content in the surface layer of 15X12VNMF steel varies between 56—82 wt. %, and that in the surface layer of 20X1M1F1TR steel ranges within 81—93 wt. %, depending on the parameters of the saturation process.

The 15X12VNMF and 20X1M1F1TR steel samples have been tested for abrasive wear and cavitation, and the tests have shown that after the saturation of the steel surface with chromium, the surface stability is a little bit lesser than that of the original material.

As the tests for heat resistance in the air have shown, vacuum activated chromium plating significantly increases the heat resistance of samples of 15X12VNMF and 20X1M1F1TR steels.

*Table 5.* **Testing of 15H12VNMF Steel Samples for Heat Resistance in the Air, at a Temperature of $T$ = 900 °C, for 15.5 h**

| Treatment | Sample weight $P_\tau$, g | Change in the sample weight, g | Total change in the sample weight, g |
|---|---|---|---|
| Original sample | $P_0 = 4.50705$ | | 0.04995* |
| | $P_7 = 4.50965$ | $\Delta P_1 = 0.0026$ | |
| | $P_{5.5} = 4.54700$ | $\Delta P_2 = 0.03735$ | |
| | $P_3 = 4.51160$ | $\Delta P_3 = -0.03540$ | |
| Nitrided | $P_0 = 4.45360$ | | 0.09700* |
| | $P_7 = 4.49965$ | $\Delta P_1 = 0.04605$ | |
| | $P_{5.5} = 4.55060$ | $\Delta P_2 = 0.05095$ | |
| | $P_3 = 4.40180$ | $\Delta P_3 = -0.14880$ | |
| Chroming at $T$ = 1070 °C, for 4 h | $P_0 = 4.51880$ | | 0.00085 |
| | $P_{3.5} = 4.51910$ | $\Delta P_1 = 0.00030$ | |
| | $P_{3.5} = 4.51960$ | $\Delta P_2 = 0.00050$ | |
| | $P_{4.5} = 4.51965$ | $\Delta P_3 = 0.00005$ | |
| Chroming at $T$ = 1070 °C, for 10 h | $P_0 = 4.56900$ | | 0.00055 |
| | $P_{3.5} = 4.56920$ | $\Delta P_1 = 0.00020$ | |
| | $P_{3.5} = 4.56935$ | $\Delta P_2 = 0.00015$ | |
| | $P_{4.5} = 4.56940$ | $\Delta P_3 = 0.00005$ | |
| | $P_4 = 4.56955$ | $\Delta P_4 = 0.00005$ | |
| Chroming at $T$ = 1100 °C, for 4 h | $P_0 = 4.54020$ | | 0.00145 |
| | $P_{3.5} = 4.54085$ | $\Delta P_1 = 0.00065$ | |
| | $P_{3.5} = 4.54145$ | $\Delta P_2 = 0.00060$ | |
| | $P_{4.5} = 4.54165$ | $\Delta P_3 = 0.00020$ | |
| Chroming at $T$ = 1100°C, for 10 h | $P_0 = 4.60030$ | | 0.00018 |
| | $P_{3.5} = 4.60055$ | $\Delta P_1 = 0.00015$ | |
| | $P_{3.5} = 4.60080$ | $\Delta P_2 = 0.00025$ | |
| | $P_{4.5} = 4.60100$ | $\Delta P_3 = 0.00020$ | |
| | $P_4 = 4.600120$ | $\Delta P_4 = 0.00020$ | |

* in these cases, the total change in the sample weight is given for 12.5 h

*Table 6.* **Testing of 20H1M1F1TR Steel Samples for Heat Resistance in the Air, at a Temperature of $T$ = 900 °C, for 15.5 h**

| Treatment | Sample weight $P_\tau$, g | Change in the sample weight, g | Total change in the sample weight, g |
|---|---|---|---|
| Original sample | $P_0 = 9.51070$ | | 0.54570 |
| | $P_{6.5} = 9.82915$ | $\Delta P_1 = 0.31845$ | |
| | $P_5 = 9.92820$ | $\Delta P_2 = 0.11905$ | |
| | $P_4 = 10.05640$ | $\Delta P_3 = 0.10820$ | |
| Nitrided | $P_0 = 5.28515$ | | 0.27485 |
| | $P_{6.5} = 5.49810$ | $\Delta P_1 = 0.21295$ | |
| | $P_5 = 5.54435$ | $\Delta P_2 = 0.04625$ | |
| | $P_4 = 5. 56000$ | $\Delta P_3 = 0.05565$ | |
| Chroming at $T$ = 1070 °C, for 4 h | $P_0 = 5.06425$ | | 0.00020 |
| | $P_{6.5} = 5.06440$ | $\Delta P_1 = 0.00015$ | |
| | $P_5 = 5.06440$ | $\Delta P_2 = 0.000$ | |
| | $P_4 = 5.06445$ | $\Delta P_3 = 0.00005$ | |
| Chroming at $T$ = 1070 °C, for 10 h | $P_0 = 5.16915$ | | 0.00020 |
| | $P_{3.5} = 5.16915$ | $\Delta P_1 = 0.000$ | |
| | $P_{3.5} = 5.16920$ | $\Delta P_2 = 0.00005$ | |
| | $P_{4.5} = 5.16930$ | $\Delta P_3 = 0.00010$ | |
| | $P_4 = 5.16935$ | $\Delta P_4 = 0.00005$ | |
| Chroming at $T$ = 1100 °C, for 4 h | $P_0 = 5.20560$ | | 0.00040 |
| | $P_{3.5} = 5.20600$ | $\Delta P_1 = 0.00040$ | |
| | $P_{3.5} = 5.20600$ | $\Delta P_2 = 0.000$ | |
| | $P_{4.5} = 5. 20600$ | $\Delta P_3 = 0.000$ | |
| Chroming at $T$ = 1100°C, for 10 h | $P_0 = 5.21105$ | | 0.00065 |
| | $P_{3.5} = 5.21120$ | $\Delta P_1 = 0.00015$ | |
| | $P_{3.5} = 5.21120$ | $\Delta P_2 = 0.000$ | |
| | $P_{4.5} = 5.211 55$ | $\Delta P_3 = 0.00035$ | |
| | $P_4 = 5.21170$ | $\Delta P_4 = 0.00015$ | |

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ПРОЦЕС ВАКУУМНОГО АКТИВОВАНОГО ДИФУЗІЙНОГО
ХРОМУВАННЯ СТАЛЕЙ 15Х12ВНМФ і 20Х1М1Ф1ТР

**Вступ**. Сталі 15Х12ВНМФ і 20Х1М1Ф1ТР використовують в машинобудуванні як матеріал деталей турбін, для підвищення робочих температур яких необхідно поліпшити жаростійкість їхньої поверхні.

**Проблематика**. Підвищення корозійної стійкості поверхні сталей можливо через нанесення захисного шару. Однозначно сказати, яке покриття й метод його формування на конкретній сталі забезпечить достатнє підвищення жаростійкості поверхні цього матеріалу, практично неможливо. Раніше сталі 15Х12ВНМФ і 20Х1М1Ф1ТР не захищали методом вакуумного хромування в парах хлористого натрію.

**Мета.** Дослідити процес вакуумного активованого хромування сталей 15Х12ВНМФ і 20Х1М1Ф1ТР і його вплив на характеристики зразків з них.

**Матеріали й методи.** Зразки для досліджень виготовляли зі сталей 15Х12ВНМФ і 20Х1М1Ф1ТР. Випробування на кавітаційне й абразивне зношування провадили на стендах, а на жаростійкість — в муфельній печі на повітрі. Для досліджень поверхні зразків використовували металографічні методи й рентгенофлуоресцентний аналіз (РФА).

**Результати.** Зразки зі сталей15Х12ВНМФ і 20Х1М1Ф1ТР хромували методом вакуумного насичення в парах хлористого натрію при температурах 1070 і 1100 °С та тривалості процесу 4 і 10 год. Встановлено, що після хромування при кавітаційному і абразивному діянні зразки із цих сталей за зносостійкістю дещо поступаються вихідним зразкам. З'ясовано, що при хромуванні зразків на їхній поверхні утворюється дифузійний шар товщиною 50—130 мкм залежно від умов обробки. Вміст хрому в поверхневому шарі досліджуваних сталей змінюється, відповідно, в межах 56—82 ваг. % і 81—93 ваг. %, залежно від параметрів процесу насичення. Проведено порівняльні випробування цих зразків на жаростійкість на повітрі при температурі 900 °С. Встановлено, що жаростійкість хромованих зразків значно перевершує стійкість вихідних.

**Висновки.** Дослідження процесу вакуумного активованого хромування зразків зі сталей 15Х12ВНМФ і 20Х1М1Ф1ТР показали, що така обробка значно підвищує жаростійкість цих матеріалів порівняно з вихідними.

*Ключові слова*: вакуумне хромування, сталь 15Х12ВНМФ, сталь 20Х1М1Ф1ТР, жаростійкість, дифузійний шар.