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THE CHOICE OF MATERIAL FOR STRENGTHENING OF LEADING EDGES OF WORKING BLADES OF STEAM TURBINES

D.B. Hlushkova, O.D. Hrinchenko, L.L. Kostina, A.P. Cholodov
Kharkiv National Automobile and Highway University, Kharkov, Ukraine
E-mail: diana@khadi.kharkov.ua

Research on the state of strengthened layer of working blades of steam turbines made by electrospark doping with T15K6 alloy and 15Х11МФ-Ш steel is commissioned. Microstructure, microhardness and thickness of weld pad are studied. The possibility of 15Х11МФ-Ш steel using for hardening of leading edges of working blades of steam turbines is substantiated.

INTRODUCTION

Modern issues of creation and modernization of power equipment put forward high demands for improving the indicators of economy and reliability of turbines. Erosion destruction of the working blades leading edges of low-pressure aft stages of heavy steam turbines becomes one of the main factors determining the functional ability and efficiency of a blade system and a turbine as a whole (Fig. 1). A blade system, especially blading of low-pressure rotors, as the most complex and highly loaded part of a turbine, largely determines the entire unit reliability. An additional point is that the blade of the aft stage of low-pressure cylinder determines the threshold for maximum turbine power. Creation of a blade system represents a complex task in the field of strength, gas dynamics, vibration, anti-erosion protection with obligatory blades optimization in bench conditions [1].

One of the most important issues is development of effective methods to protect blade systems from erosion with simultaneous reducing of mechanical losses caused by humidity.

Presence of a liquid phase in the working medium of steam turbines causes additional energy losses in stages and erosive wear of the flow range elements. Different density of the components of working medium leads to a significant mismatch between the liquid and vapor phases velocities and, as a consequence, to a complex pattern of motion of many drop flows, in some cases resulting in a sharp concentration of coarse moisture in various locations of the steam part.

Effectiveness of currently developed methods of the stages erosion protection is mainly determined by a particular manufacturer's own experience of implementing anti-erosion measures [2].

Despite the wide experience of creating various active and passive methods of anti-erosion protection gathered to the present days all over the world, cases of serious damage to the working blades of the aft stages of steam turbines due to the erosion-hazardous dropping moisture in the steam part occurrence can be observed.

In order to increase the blades service lifetime, the blades leading edges are protected in various ways, among which are: high-frequency current hardening, electrospark alloying with solid alloys based on W, Ti carbides, welding of stellite plates, ion implantation with TiN formation on the coating surface, subsonic and supersonic plasma spraying of wear-resistant coatings etc.

Fig. 1. Erosive wear of К 220-44 turbine blade leading edge (17520 hours running)

Each method application has its limitations: it is technically difficult to harden the radius transition from a blade airfoil to a desk-type bandage by high-frequency currents; utilization of the widely used T15K6 alloy as a strengthening electrode for blades operating in primary circuit turbines is unacceptable because of the presence of cobalt element, which in result of activation forms long-lived isotopes [3]; the method of ion implantation involves usage of expensive vacuum equipment [4].

Resulting from topicality of the issue of increasing the erosion resistance of steam turbine blades, works to improve the available technologies for protecting the leading edges of working blades of the low pressure aft stages were executed.

OBJECTIVE

The subject of consideration in the present academic paper constitutes investigation of the possibility of using 15Х11МФ-Ш steel as a material for a strengthening electrode while performing the electrospark alloying of a leading edge of steam turbine working blade in order to protect it against the impact of water droplet erosion during operation in phase transition zone.

The comparative results of conducted experiments on hardening of 15Х11МФ-Ш steel for blades of steam turbines with electrospark alloying with T15K6 alloy and 15Х11МФ-Ш steel are given herein.

STATEMENT OF BASIC MATERIALS

Special requirements constitute subject to the coatings designed for aft stages working blades of heavy steam turbines, among which are: droplet erosion resistance, continuity and adhesion under the operational loads action, absence of a negative effect of the coating formation parameters on the blade material mechanical properties, high corrosion properties, linear expansion coefficient close to the one that the main blade metal has.

In order to perform the test, the samples from working blades of 15Х11МФ-Ш steel were strengthened by the method of electric spark alloying (ESA) with two materials: the traditional T15K6 alloy and pioneer used to harden the leading edges of blades 15Х11МФ-Ш steel identical to the blade material (Fig. 2, 3).

The method of electrospark alloying is based on the phenomenon of electrical erosion of materials during a spark discharge in a gaseous medium, polar transit of erosion products onto a layer of altered structure and an alloy. As a result of electrical breakdown of the interelectrode spacing arises a spark discharge in which the electron flux leads to a local heating of the electrode (anode). Mixing of cathode and anode material under the influence of significant thermal loads occurs on the cathode surface, which promotes the formation of high adhesion between the substrate and generated layers.

The works on hardening of the samples were executed on ЭИЛ8А model of electrospark installation in mode No. 7 (pulse current amplitude value $I = (175\pm10)$ A, pulse energy $E_{\text{pulse}} = 3.15$ J, pulse duration time $t_{\text{pulse}} = 1000$ ms, frequency at 600 Hz).

The study was carried out on samples from blade blank parts of 15Х11МФ-Ш steel, manufactured by forged method and heat-treated to a hardness of 271 HB. The samples material has the following mechanical properties (Tabl. 1).

Fig. 2. The sample of blade strengthened with T15K6 alloy by the method of electrospark alloying

Fig. 3. A sample of a blade strengthened with 15Х11МФ-Ш steel by the method of electrospark alloying

Table 1

Mechanical properties of the blade

	$\sigma_{0,2}$, MPa	σ_m, MPa	δ_5, %	Ψ, %	KCU, J/cm^2	HB, MPa
Testing results	669	827	20	58	116	2710
108.020.03-82 Industrial Standard requirements	666.4…813.4	≥814	≥13	≥40	≥39.2	2480…2850

Microstructure of the samples parent metal constitutes a sorbitol with preservation of martensitic planes orientation. Microstructure of the samples features uniformity, grains of different etch ability can be observed within the structure, size of needles corresponds to 7…8 points of State Standard of Ukraine 8233-56 (Fig. 4). Hardened layers' surface is studied. Figs. 5 and 6 show SEM images of the samples' surface at magnifications at x50 and x1000. Appears that the shown surface is very heterogeneous; strengthening is performed unevenly due to the hardening pulse discreteness. Undulation of the sample's surface of hardened layer performed by T15K6 alloy is in 2.8 times coarser than the one performed by 15Х11МФ-Ш steel (43.9 and 15.3 μm respectively).

Fig. 4. Microstructure of the blade sample parent metal, x100

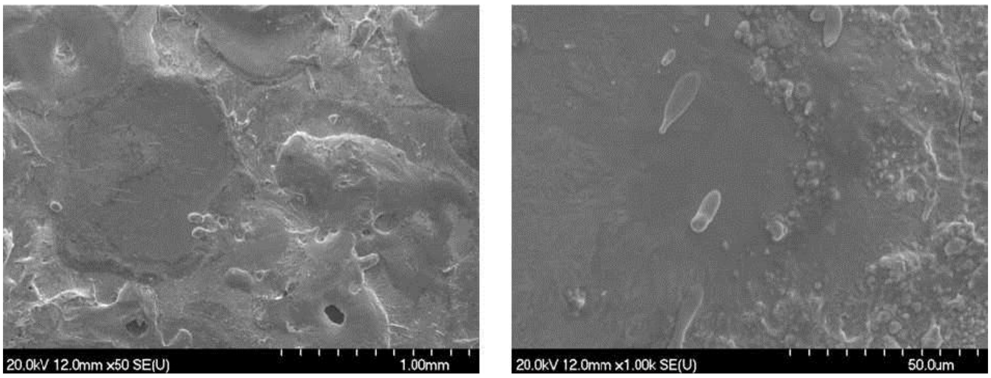


Fig. 5. Surface topography of hardened layer performed by T15K6 alloy, x50

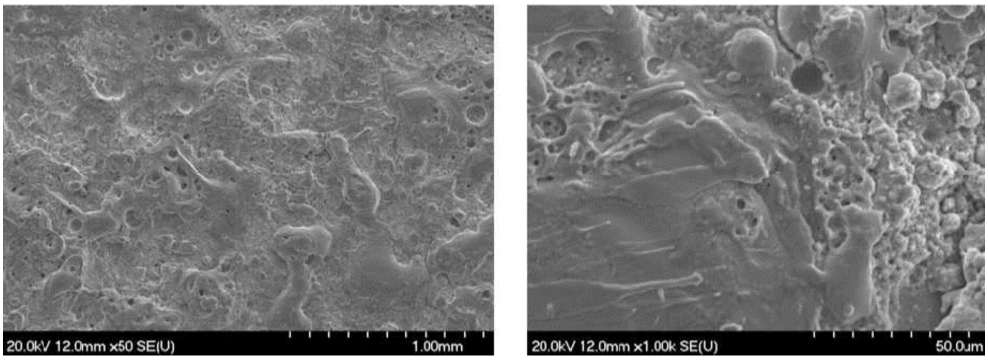


Fig. 6. Surface topography of hardened layer performed by 15Х11МФ-Ш, x1000

Determination of chemical elements on the surface of the layers is executed by XPS spectroscopy method. Figs. 7, 8, and Tabl. 2 show data for layer performed by T15K6 alloy.

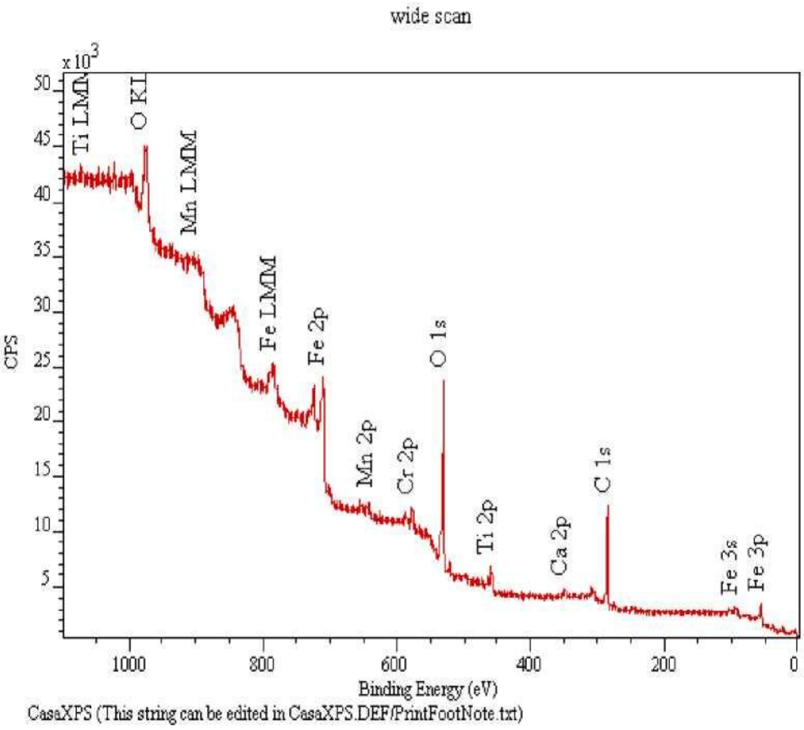


Fig. 7. Speculative analysis of elements in the layer hardened by T15K6.
XP spectrum of 2 keV Ar^+ observed in 5 min after etching

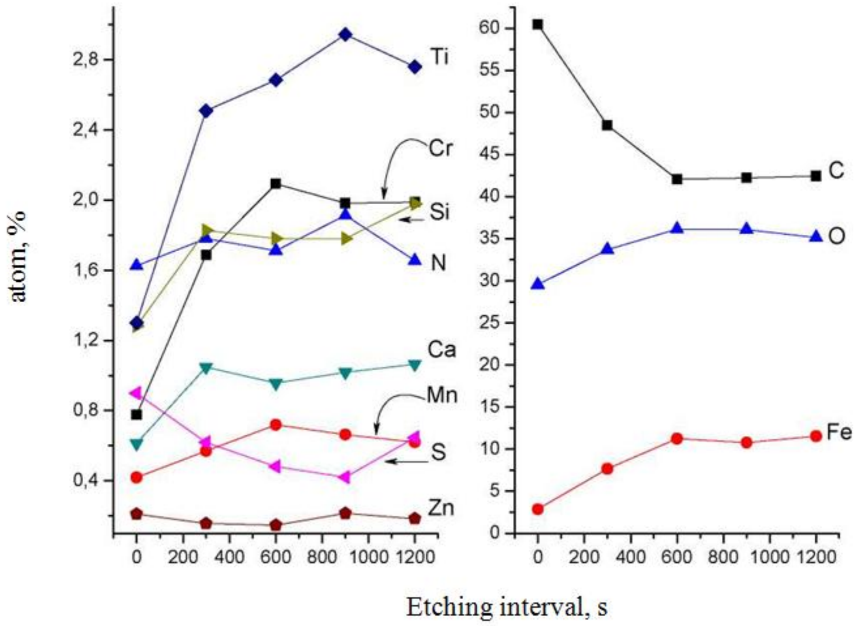


Fig. 8. Dispensing of elements in the layer hardened by T15K6

Table 2

Content of elements in the sample hardened by T15K6

Element	Series	Mass, %	Weight, %	Inaccuracy, %
Ti	K	8.30	10.75	0.77
Cr	K	11.87	14.16	1.01
Fe	K	62.24	69.15	4.17
W	L	17.60	5.94	5.80

Fe, Cr, W, Si, S, and N are revealed; in XP spectrum a carbon peak is expressed and the manganese peak is clearly defined. Each metal element is in an oxidized state. Manganese and zinc are found exclusively as traces.

Figs. 9–11 and Tabl. 3 show data for layer hardened by 15Х11МФ-Ш steel.

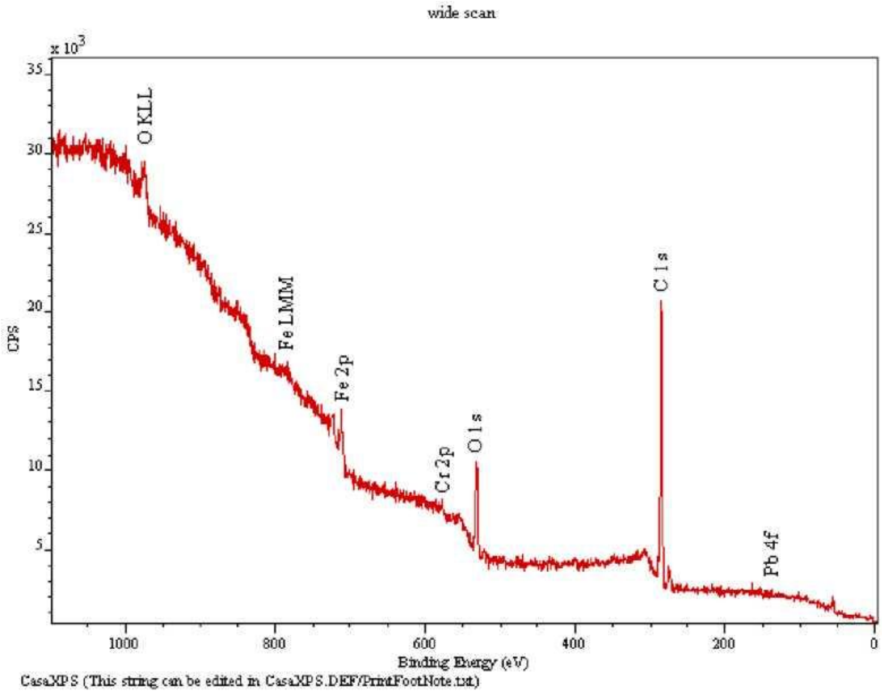


Fig. 9. Speculative analysis of elements in the layer hardened by 15Х11МФ-Ш steel. XP spectrum of 2 keV Ar^+ observed in 5 min after etching

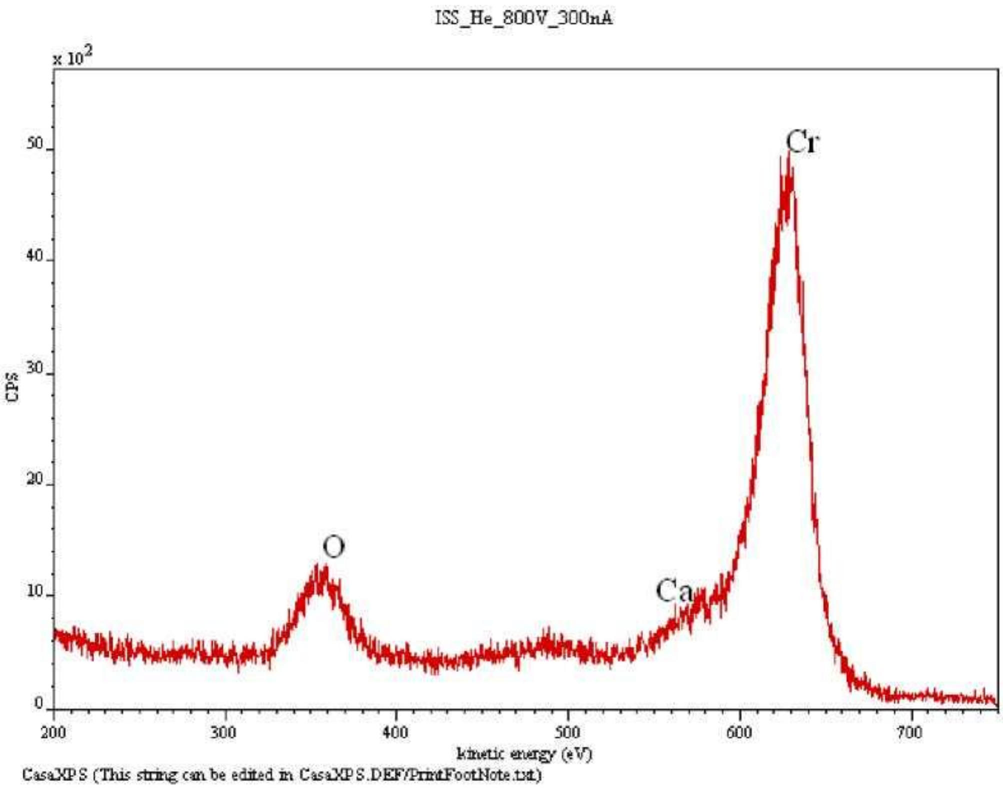


Fig. 10. Speculative analysis of elements in the layer hardened by 15Х11МФ-Ш steel. ISS spectrum data on the sample was collected by He^{+} ions of 800 eV without etching

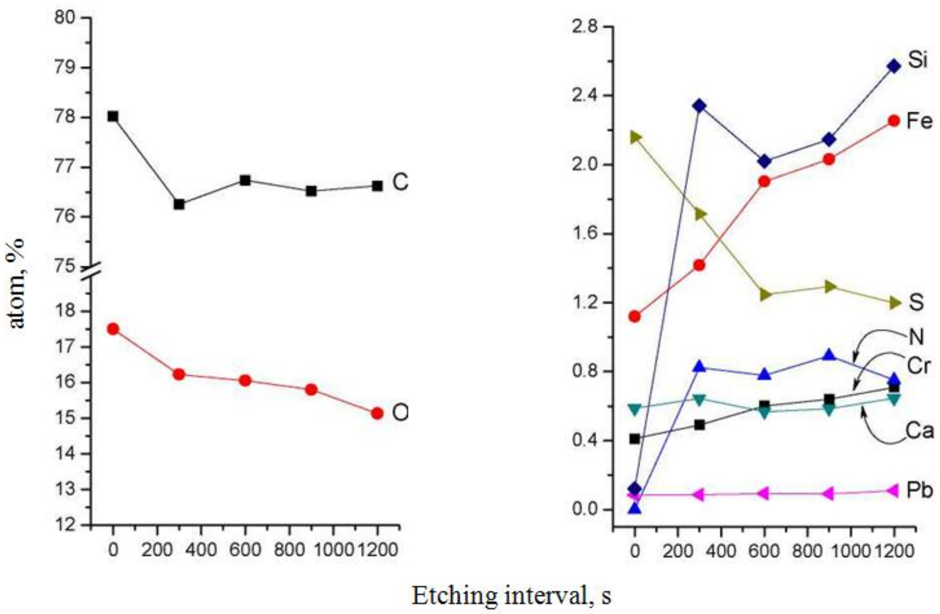


Fig. 11. Dispensing of elements in the layer hardened by 15Х11МФ-Ш steel

Table 3

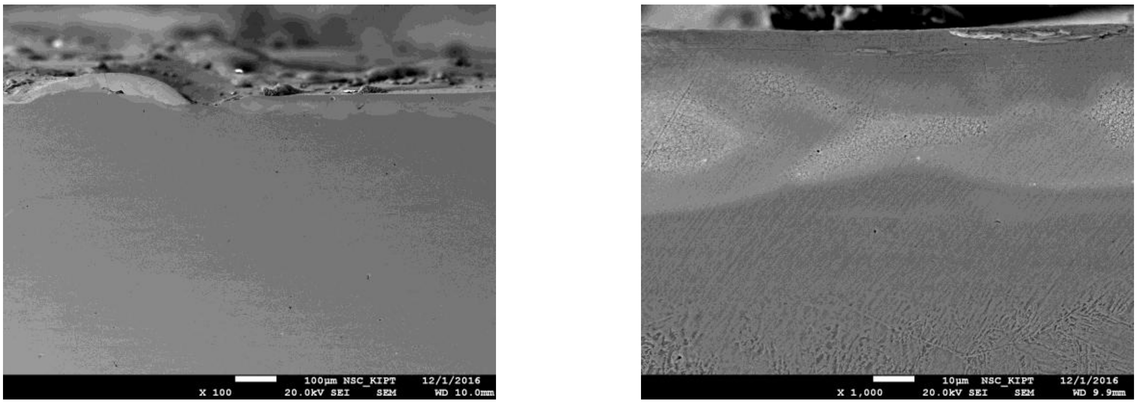
Content of elements in the sample hardened by 15Х11МФ-Ш steel

Element	Series	Mass, %	Weight, %	Inaccuracy, %
Si	K	2.67	5.09	0.26
Cr	K	20.09	20.69	1.29
V	K	1.19	1.25	0.31
Mn	K	3.49	3.40	0.58
Fe	K	72.55	69.56	4.47

The surface layer showed a high content of chromium, namely up to 20%.

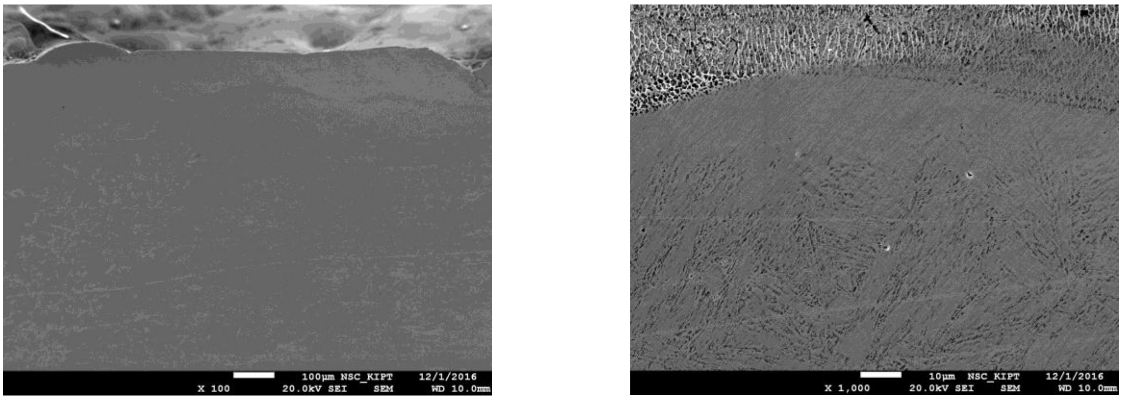
Metallographic examination of the layers was executed. The surface hardened layer on both samples has an explicit dendritic structure. XDR states that a significant amount of the α-phase and the austenite phase are present in the layer hardened by T15K6; the composition includes tungsten carbide, titanium and cobalt. α-phase, austenite phase, insignificant amount of titanium carbide are observed in the layer strengthened by 15Х11МФ-Ш.

Figs. 12 and 13 show photo illustrations of the layers at 50- and 1000-fold magnifications. The surface of the samples is rough, inhomogeneous.



a *b*

Fig. 12. Electrospark alloying layer performed by T15K6: a – x100; b – x1000



a *b*

Fig. 13. Electrospark alloying layer performed by 15Х11МФ-Ш: a – x100; b – x1000

Measurement of the hardened layer thickness was conducted in sections made according to the specimens' cross-sectional plane.

The surface hardened layer features heterogeneity through the layer's thickness, but in cases of hardening by T15K6 alloy and 15Х11МФ-Ш steel the average thickness values practically coincide (Fig. 14).

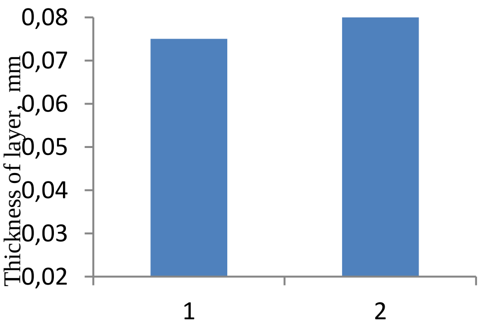


Fig. 14. Histograms of the average values of the hardened layer thickness: 1 – T15K6 alloy, 2 – 15Х11МФ-Ш steel

Investigation of the strengthened layer microstructure has showed that the structure is homogeneous, practically non-etching. In some places, single pores are found. In the surface layer of the parent metal a light-etching diffusion zone of the electrode material through the sample depth ward and a dark-etching zone of sub-hardening are observed under the influence of high temperatures. In some places, pores are found.

Fig. 15 shows histograms of the microhardness measurements of the test samples.

As follows from the histograms presented above, the microhardness for hardening by T15K6 alloy and 15Х11МФ-Ш steel is practically the same in all zones.

A full-scale experiment on K220-44 turbine was conducted. Operation of the blades hardened at the leading edge by 15Х11МФ-Ш steel for 2 years in a slightly alkaline medium at pH 9.8 has shown satisfactory results, as demonstrated in Figs. 16 and 17.

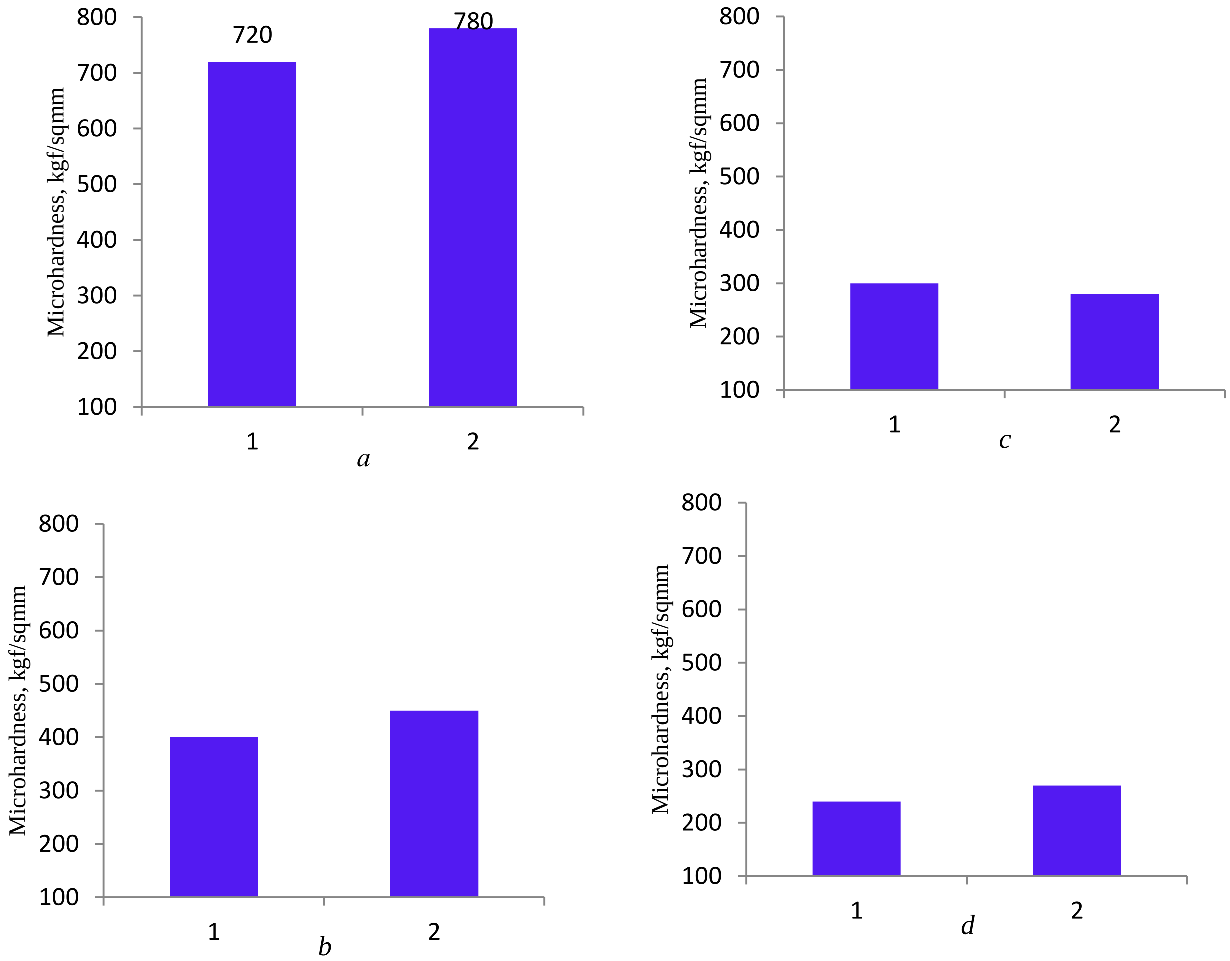


Fig. 15. Histograms of the microhardness measurements of the test samples strengthened with T15K6 alloy (1) and 15Х11МФ-Ш steel (2): a – hardened layer; b – transition (diffusion) zone; c – heat-affected zone (~ 0.05 mm from the "parent metal – hardened layer" edge); d – heat-affected zone (~ 0.1 mm from the "parent metal – hardened layer" edge)

Fig. 16. Blades hardened with T15K6 alloy by electrospark alloying method

Fig. 17. Blades hardened with 15Х11МФ-Ш steel by electrospark alloying method

CONCLUSIONS

15Х11МФ-Ш material identical to steel of which the working blades of steam turbines are manufactured is advantageous for the erosion-resistant protection formation, which results in cost avoidance in electrospark alloying electrodes material purchasing.

The roughness of the layer made by 15Х11МФ-Ш steel is lower, than of the one performed with T15K6 hard alloy metal.

The average thickness of the surface layers performed in the same modes, both with the T15K6 alloy and with 15Х11МФ-Ш steel, practically coincides.

Microhardness on the surface of the hardened layer is higher while using 15Х11МФ-Ш-Ш steel than when using Т15К6 hard alloy metal; microhardness of the transition zone, the heat-affected zone at different distances from the "parent metal – hardened layer" edge practically do not differ.

On the basis of conducted researches it is possible to recommend replacement of the applied strengthening electrode from Т15К6 alloy on 15Х11МФ-Ш-Ш steel for protection from water droplet erosion of leading edges of steam turbines working blades.

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ВЫБОР МАТЕРИАЛА ДЛЯ УПРОЧНЕНИЯ ВХОДНЫХ КРОМОК РАБОЧИХ ЛОПАТОК ПАРОВЫХ ТУРБИН

Д.Б. Глушкова, Е.Д. Гринченко, Л.Л. Костина, А.П. Холодов

Исследовано состояние упрочненного слоя рабочих лопаток паровых турбин, выполненного электроискровым легированием сплавом Т15К6 и сталью 15Х11МФ-Ш. Исследовались микроструктура, микротвердость и толщина наплавленного слоя. Обоснована возможность применения стали 15Х11МФ-Ш для упрочнения входных кромок рабочих лопаток паровых турбин.

ВИБІР МАТЕРІАЛУ ДЛЯ ЗМІЦНЕННЯ ВХІДНИХ КРОМОК РОБОЧИХ ЛОПАТОК ПАРОВИХ ТУРБІН

Д.Б. Глушкова, О.Д. Грінченко, Л.Л. Костіна, А.П. Холодов

Досліджено вплив матеріалу електроду на стан зміцненого шару робочих лопаток парових турбін. Зміцнений шар формувався електроіскровим легуванням сплавом Т15К6 і сталлю 15Х11МФ-Ш. Досліджувались мікроструктура, мікротвердість і товщина наплавленого шару. Обґрунтовано можливість застосування сталі 15Х11МФ-Ш для зміцнення вхідних кромок робочих лопаток парових турбін.