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TECHNOLOGICAL METHODS OF ENSURING THE RELIABILITY AT REPAIR AND RENOVATION OF THE SCREW COMPRESSOR ROTORS

UDC 621.9.048

The article presents a new combined technology for use in the renovation of the rotors of screw compressors that increases their reliability and useful life through a combination of different methods of increasing the quality of the surfaces of parts, including: electroerosion alloying, ion nitriding, carburizing by means of electroerosion alloying, non-abrasive finishing, coating with polymer materials, and sulphurizing.

Key words: *screw compressor, rotor, wear, surface layer, electroerosion alloying, microhardness.*

Introduction. Screw compressors are used in the metallurgical, mining, chemical, and other branches of industry. If the necessary conditions of use are observed, the useful life of a screw compressor reaches 40000 h and more. The life of a screw compressor is limited by the life of the bearings, in which drive and driven screws (rotors) are mounted. Failure of roller bearings may be induced by an accident associated with seizure of the rotors and failure of their helical profile sur-faces (belts). Repair of such a compressor is performed only under factory conditions and in individual cases the compressor block must be entirely replaced. There is, thus, a very critical need for studies that can improve the technology used in renovation of screw compressors.

The mounting faces beneath the bearings and the surfaces of the belts experience wear in the course of use of the rotors (Fig. 1). Wear of the belts generally does not exceed 0.3 mm in diameter, though it may nevertheless lead to a significant reduction in the productive capacity of the compressor.

Analysis of Main Achievements and Publications. Electroerosion alloying is one of the technologically simplest methods of surface hardening, restoration of parts, and application of protective coats. Among the principal advantages of electroerosion alloying, we may cite local treatment of the surface; high coupling strength between the deposited material and the base; the fact that pure metals as well as alloys may be used as the treating materials; and diffusion enrichment of the surface of the cathode (part) by the component elements of the anode (electrode) without altering the dimensions of the part [1].

However, electroerosion alloying of heat-treated elements does not always produce the desired result, since a tempered zone, i.e., zone of reduced hardness, forms beneath the layer of elevated hardness following electroerosion alloying. This causes the hardened layer to force through and, as a consequence, leads to rapid wear of the part.

Application of a process of ion nitriding before or after electroerosion alloying makes it possible to eliminate zones of reduced hardness with the use of electrodes made of solid wear-resistant metals [2]. Moreover, a gradual variation of the hardness of the strain-hardened layer and an increase in the overall depth of the zone of elevated hardness are observed.

A method of carburization of steel parts by means of electroerosion alloying is also known [3] with graphite (carbon) serving as the material of the electrode. To reduce the roughness of the surface of parts, electroerosion carburizing alloying is per-formed in a series of stages, with the magnitude of the discharge energy falling on each successive stage [4].

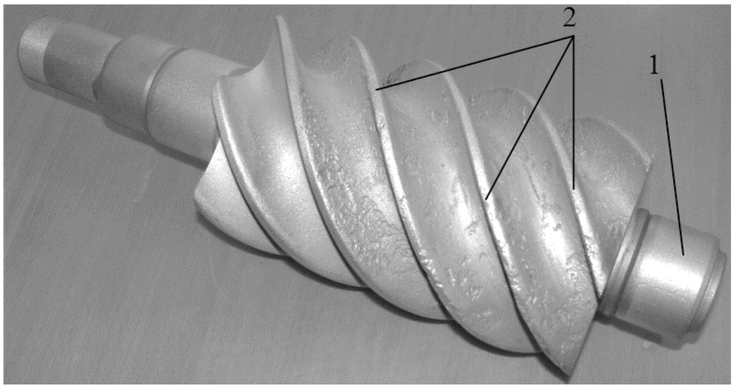


Fig. 1 – Characteristic regions of wear of the rotors of a screw compressor:
1 - mounting sites of bearing; 2 - working surfaces of belts

Repair to the rotors of a screw compressors used at Zasyad'ko Mine has also been described [5]. An axial displacement of the driven screw (material of screw, steel 40, hardness ~150 HB) of the compressor block occurred as a result of an accident to the compressor plant, which produced scratching of the surface of the belts along the outer diameter of the mount-ing face of the bearing viewed from the suction direction.

Wear of the surface of the edges of the teeth reached 2.5 mm on either side. The belts of the teeth were restored at the Elitron-52A plant, with O10Ts1.5N bronze used as the material of the electrodes. Following "dimensional" grinding of the bearing journals and the outer surface of the belt, the compressor block was assembled, tested, and shipped to the customer.

Specially adapted coats may be applied to the contacting surfaces in order to reduce wear, bonding, seizure, etc. [6]. New technologies for repairing equipment that utilize metal-polymer materials have been increasingly employed in recent years in view of their excellent adhesion to metal, deformation characteristics that are close to those of the metal, and minimum shrinkage in the course of hardening [7].

The objective of the present study is to increase the reliability and useful life of screw compressors by improving the technology used in renovating rotors through the use of new combined technologies, such as ion nitriding, electroerosion alloying, electroerosion carburizing alloying, nonabrasive ultrasonic finishing, sulphurizing, and the application of metal-polymer materials.

Technique of investigations. Specimens (steel 40Kh heat treated to a hardness of 3000–3100 MPa) in the form of coils consisting of two disks (diameter 50 mm and width 10 mm) connected by a spacer 15 mm in diameter with two process segments each 15 mm in diameter were used to study the different methods employed in restoration of the mounting journals of the rotors of the screw compressors of bearings. The surfaces of the disks were polished to Ra = 0.5 μm.

The process of electroerosion carburizing alloying (EECA) was applied using an EG-4 graphite electrode (OST 229–83) on a EIL-8A plant with discharge energies of 0.42 and 0.10 J and productive capacity 2 and 5 min/cm2, respectively. Ion nitriding (IN) of the specimens was performed at a temperature of 520°C for 12 h on an NGV-6.6/6-I1 plant. The samples were hardened in four different sequences: ion nitriding; electroerosion carburizing alloying; electroerosion carburizing alloying + ion nitriding; ion nitriding + electroerosion carburizing alloying. Following ion nitriding, some of the specimens were polished to different depths and electroerosion carburizing alloying performed in accordance with the regimes specified in Table 1. Nonabrasive ultrasonic finishing was employed following electroerosion carburizing alloying to reduce the roughness of the surface.

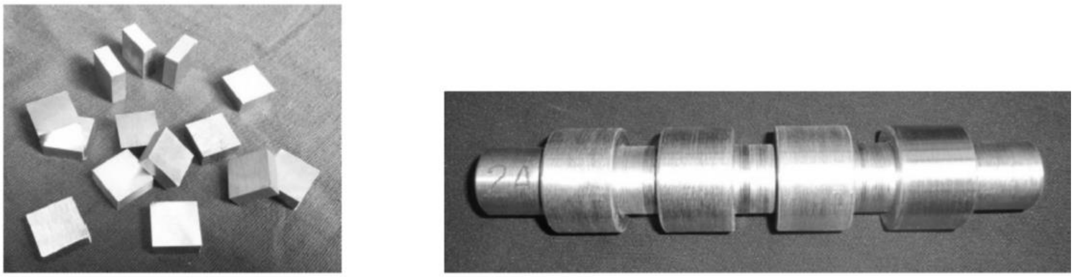
Table 1

Regimes of Electroerosion Carburizing Alloying of Specimens of Steel 40Kh Accompanying Removal of the Surface Layer

Depth of removed layer, mm	Discharge energy, J		Productive capacity, min/cm^2	
	Stage 1	Stage 2	Stage 1	Stage 2
0,05	0,42	0,10	2	5
0,10	0,42	0,10	2	5
0,15	0,60	0,10	1	5
0,20	0,60	0,10	1	5

Segments were cut out of the hardened samples, microsections were fabricated, and metallographic and hardness testing investigation were conducted. The roughness of the surface was measured with the use of a Model 201 combined surface roughness recorder and roughness indicator from the Kalibr factory.

The following specimens were fabricated from steel 40 in order to conduct studies designed to develop a technology for restoration of the worn surfaces of the belts of rotors: flat specimens (15 × 15 × 6 mm) and cylindrical specimens (diameter38 mm and length 25 mm) connected by spacers (diameter 25 mm and length 15 mm) (Fig. 2). The surfaces of the specimens were polished to Ra = 0.5 μm.



a b

Fig. 2 – Flat (a) and round (b) specimens produced from steel 40

Electroerosion carburizing alloying of flat specimens was performed on an Elitron-52A plant, while the cylindrical specimens were treated on a EIL-9 mechanized plant mounted on screw-cutting lathes. Wire made of bronze (BrO10F1), babbit (B88), and graphite (EG-4) were used as the material of the electrodes.

The uniformity of the coating was estimated visually with the use of a magnifying glass (magnification ×6).

Results of studies. Restoration of mounting journal of the rotors of the screw compressors of bearings. Figure 3 illustrates the microstructure and distribution of the microhardness Hμ by depth of the surface layer h of specimens of steel 40Kh following different types of treatment.

A "white" layer that is not amenable to etching by means of ordinary reagents is clearly seen in all the microscopic photographs; the microhardness of the layer oscillates from 7010 MPa with ion nitriding and electroerosion carburizing alloying to 8250 and 11190 MPa with ion nitriding + electroerosion carburizing alloying and electroerosion carburizing alloying + ion nitriding, respectively (Table 2).

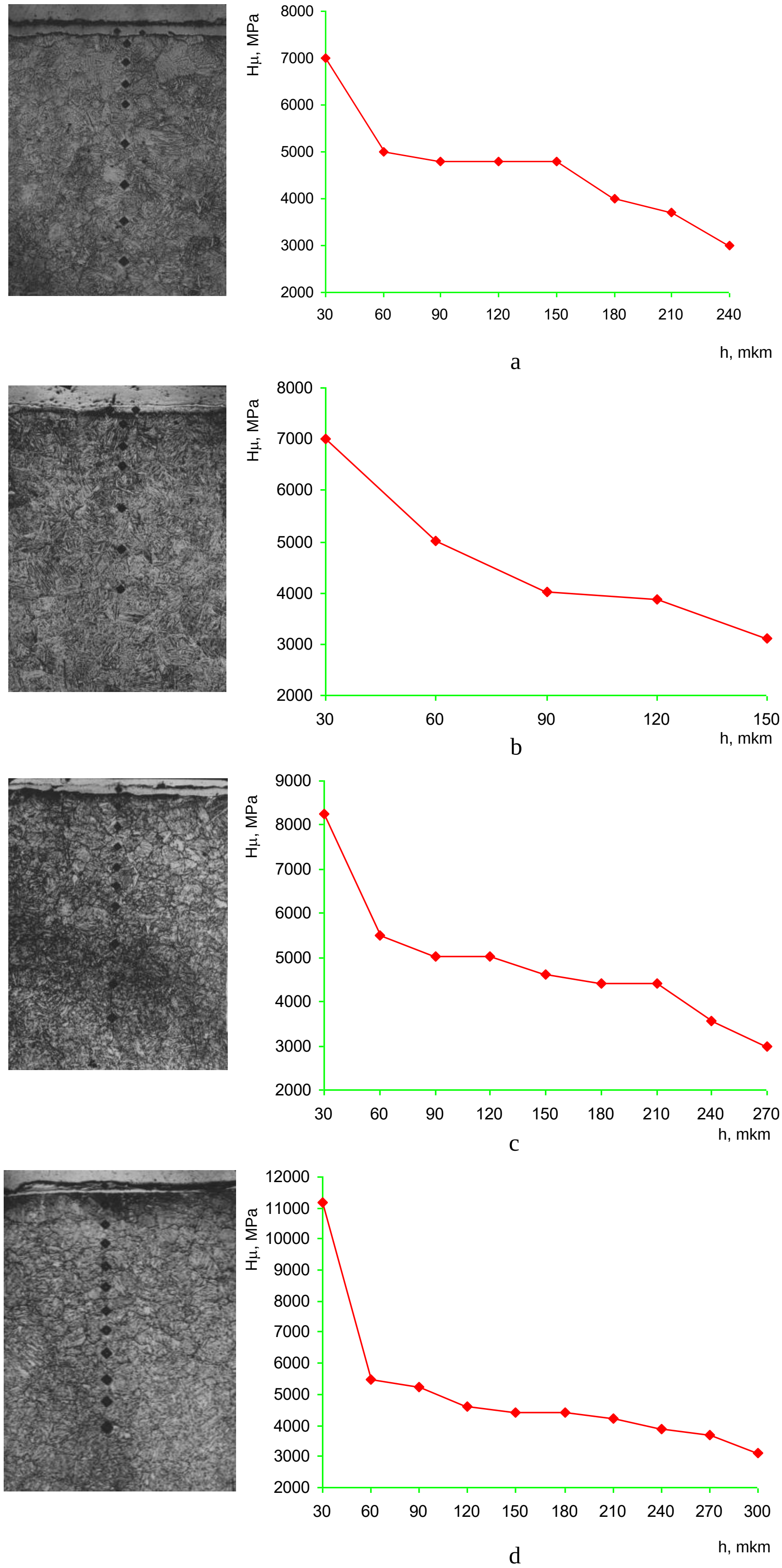


Fig. 3 – Microstructure and distribution of microhardness of surface layer of specimens of steel 40Kh following treatment: a – IN; b – EECA; c – EECA + IN; d – IN + EECA.

A transitional diffusion zone with gradually de-creasing microhardness that reaches the microhardness of the base (3000–3100 MPa) is situated lower down.

The depth of the zone of elevated hardness reaches 60–70, up to 190, 220, and 250 μm in the case of electroerosion carburizing alloying (EECA), ion nitriding (IN), electroerosion carburizing alloying + ion nitriding, and ion nitriding + electroerosion carburizing alloying, respectively.

Table 2

Distribution of Microhardness by Depth of Surface Layer of Steel 40Kh Following Hardening

Method of harde-ning	Microhardness, MPa (measurement step ~30 μm)										Ra, μm
	1	2	3	4	5	6	7	8	9	10	
IN	7010	5010	4800	4800	4800	4010	3700	3000			0,5
EECA	7010	5010	4010	3860	3100						0,8
EECA + IN	8250	5490	5010	5010	4600	4410	4410	3580	3000		0,8
IN + EECA	11190	5490	5220	4600	4410	4410	4230	3860	3700	3100	0,8

*Microhardness of base 3000–3100 MPa.

The greatest depth (250 μm) and maximum microhardness of the hardened layer (11190 MPa) is found in specimens following IN + EECA. The roughness parameter of the surface Ra = 0.8 μm, which is lower than that found with the use of metallic electrodes (3–5 μm).

The results of a study of the microstructure and microhardness of the surface layer of specimens of steel 40Kh hardened by means of ion nitriding and subjected to polishing (nona-brasive ultrasonic finishing (NUF)) and electroerosion carburizing alloying are presented in Table 3 and Fig. 4.

Table 3

Distribution of Microhardness in Surface Layer of Steel 40Kh following Ion Nitriding (IN), Nonabrasive Ultrasonic Finishing (NUF), and Electroerosion Carburizing Alloying (EECA)

Depth of polishing, mm	Microhardness, MPa (measurement step ~30 μm)							Ra, μm, following	
								EECA	NUF
	1	2	3	4	5	6	7		
0,05	8200	6300	4800	4800	4800	4010	3000	0,8	0,5
0,10	7650	5200	4800	4000	3700	3200	3100	0,8	0,5
0,15	7250	4700	4200	4000	3400	3000		1, 2	0,5
0,20	7200	5490	4220	3800	3100			1,6	0,6

The thickness of the zone of elevated microhardness produced following electroerosion carburizing alloying de-creases with increasing depth of the layer removed following ion ni-triding.

Combined technology for restoration of surface belts of rotors of screw compressors. Coatings made of tin bronze BrOF10-1 and babbit B88 (to prevent the formation of scratches) were deposited on the specimens by means of electroerosion alloying.

The maximum degree of uniformity (100%) and minimum roughness were achieved by stepwise alloying of the flat samples at Wp = 0.13 and 0.05 J. At the same time, the roughness parameter Ra of the surface decreased from 30.2 to 7.3 μm (Fig. 5a). This may be attributed to the fact that in the course of application of bronze, the electrical discharges occur on the pro-jections of the irregularities of the previously deposited layer on stage 2 (with the use of a lower alloying regime), as a result of which the projections partially crumble and are deformed, which leads to a decrease in the surface roughness and an increase in its uniformity.

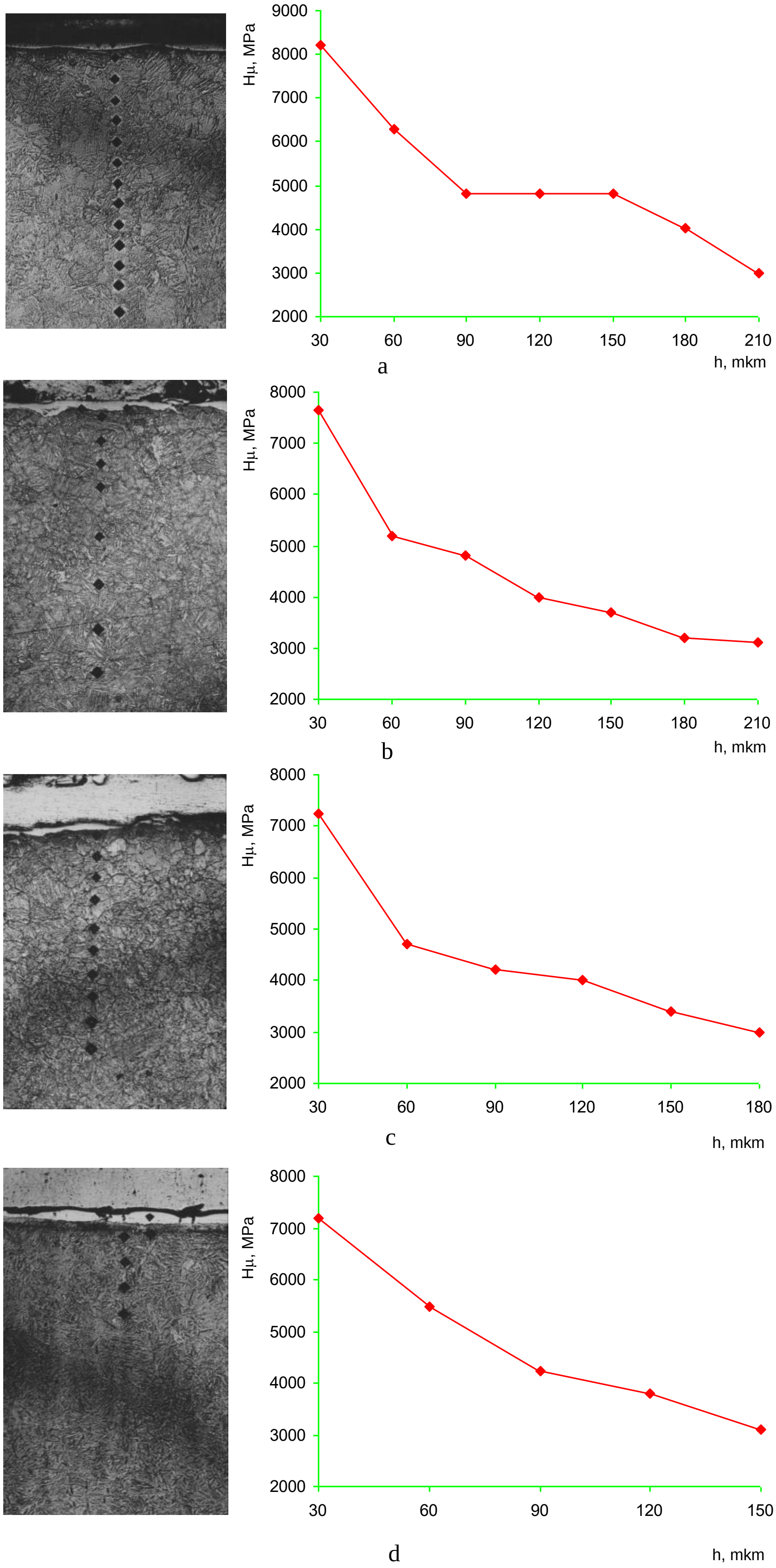
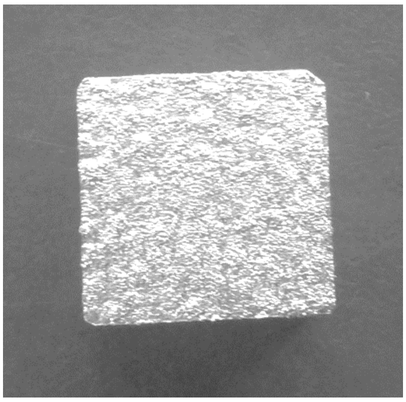


Fig. 4 – Microstructure and distribution of microhardness of surface layer of specimens of steel 40Kh following treatment by IN + EECA with partial removal of the hardened surface layer following ion nitriding to a depth of: a – 0.05 mm; b – 1.0 mm; c – 0.15 mm; d – 0.20 mm.

Babbit B88 was deposited next on the bronze coating at Wp = 0.27 J, after which electroerosion alloying was per-formed using a graphite electrode (first at Wp = 0.39 J and then at Wp = 0.27 J). Treatment with a metallic brush was performed after each stage of electroerosion alloying.

The thickness of the coat following alloying with bronze and babbit and with the use of a graphite electrode reached 0.25 mm, Ra = 8 μm (cf. Fig. 5b).



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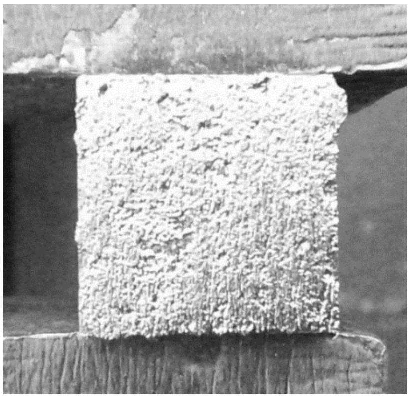

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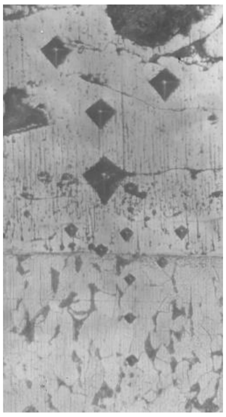
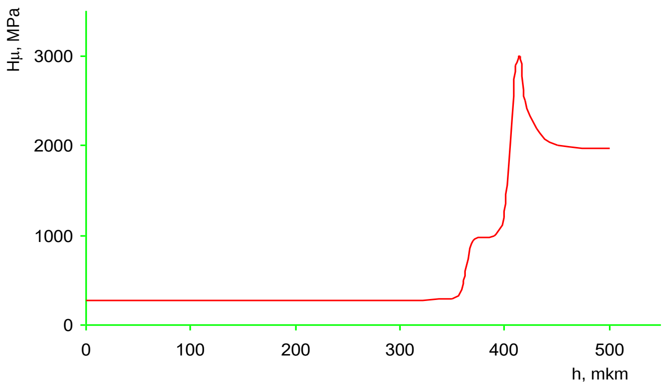


X 200

c



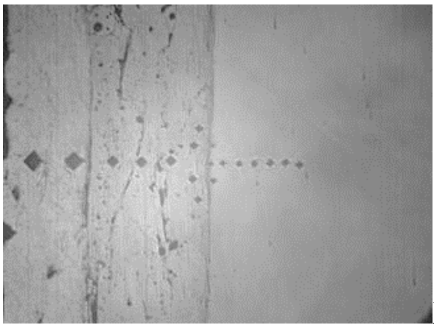
d

Fig. 5 – Sample of steel 40 following treatment by electroerosion alloying of bronze (a), bronze and babbit B88 (b), structure of the coating (c), and distribution of microhardness by depth of layer (d).

An analysis of the structure of the babbit coat with a sub-layer of tin bronze showed that the resulting layer consists of four zones. The upper layer is up to 350 μm thick with microhardness Hμ = 240–360 MPa of the babbit, with a layer of tin bronze situated next at a depth of 50–80 μm and microhardness Hμ = 790–900 MPa. A transitional zone with depth down to 10 μm in which the microhardness increases gradually by depth to the microhardness of the zone of thermal influence (2500– 3000 MPa) is even lower down (between the layer of tin bronze and the steel layer) and then, decreasing, falls down to the level of the microhardness of the base metal Hm = 1750–1800 MPa.

Treatment by an electrode made of tin babbit and subsequent treatment by a graphite electrode repeated several times (beginning with a discharge energy of 0.27 J) is used to obtain a thicker layer. After three-fold treatment, the total thickness of the coat reaches 1 mm.

The structure of the surface layer of steel 40 following electroerosion alloying on a EIL-9 mechanized plant with bronze (BrO10F1) and babbit (B88) is shown in Fig. 6a. Both bronze and babbit were deposited at a short-circuit current Is.c = 15 A. Electroerosion alloying was performed in two passes. After deposition of bronze in the first pass, the thickness of the layer reached 0.17–0.18 mm and in the case of babbit, 0.12–0.13 mm.



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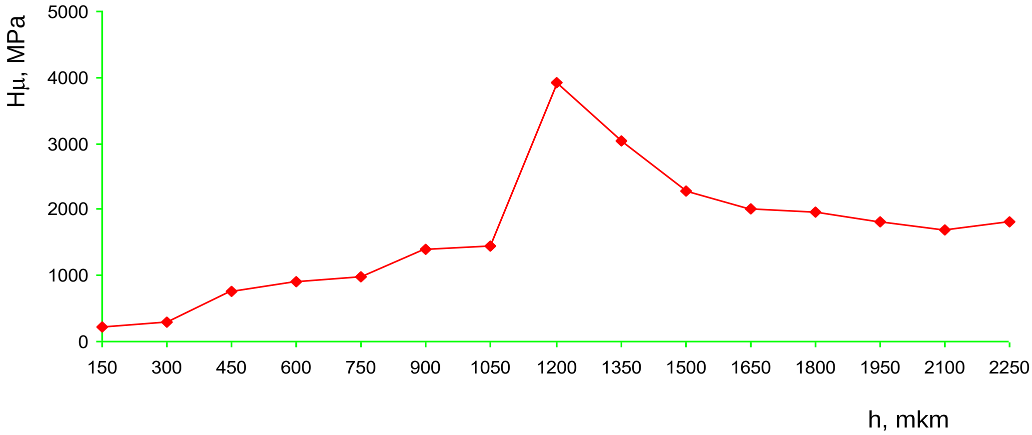

b

Fig. 6 – Structure (a) and distribution of microhardness by depth of layer (b) following treatment by electroerosion alloying of steel 40 on a EIL-9 plant with bronze and babbit B88.

An analysis of the distribution of the microhardness by depth of the layer (cf. Fig. 6b) showed that the hardness of babbit reaches 230–290 MPa and that the microhardness gradually grows with increasing depth, increasing in the segment with a bronze coat from 750 to 900 MPa. Below, in the transition zone between bronze and steel 40 the hardness increases from 1400 to 1450 MPa, grows to 3920 MPa in the zone of thermal influence and then gradually falls to 1700–1800 MPa. The zone of elevated hardness is at a depth of 90–100 μm.

The combination of a soft material with another soft material as well as the formation of pairs of materials of the same type is not recommended [10], hence belts of one of the rotors may be restored using tin bronze as the material of the electrodes and babbit as the antifriction material. Electrodes made of corrosion-resistant steel should be used to restore the worn surfaces of the belts of the second rotor, which makes it possible to create coats of higher quality than that achieved with the use of electrodes made of ordinary steels.

A coat 0.6 mm thick in diameter with uniformity up to 70 and 60% may be applied in a single pass on the Elitron-347 and EIL-9 mechanized plants with the use of steels 12Kh18N10T and VNS-2 (08Kh15N5D2T), respectively, as the materials of the electrodes. In this case, the roughness of the surface reaches Rz = 300 μm. After five passes, the thickness of the layer may reach 2.8 mm in diameter but the uniformity falls to 50–60%. The roughness parameter of the surface Rz for steels 08Kh15N5D2T and 12Kh18N10T grows and amounts to 1250 and 800 μm, respectively. With the use of electroerosion al-loying, steel 08Kh15N5D2T is strengthened (microhardness 4780 MPa), while the microhardness of steel 12Kh18N10T re-mains at the previous level (1500–1600 MPa).

Thus, the use of a combined technology that incorporates electroerosion alloying produced using electrodes made of steel 12Kh18N10T and deposition of coats of metal-polymer material is recommended for restoration of the worn surfaces of the belts of rotors [8].

Sulphur may be introduced into the coat (sulphurizing) to prevent the development of scratches on the steel surface of the restored rotor belt [11]. For this purpose, the restored segment of the surface must be periodically treated with sulfur or sulfur added to the composition of electrodes made of steel 12Kh18N10T.

Following mechanical treatment (polishing or treatment with a knife) across the width, the surface of the belt will consist of individual metallic segments and segments of metal-polymer materials. With increasing depth of the treatment, the area of sections of the surface made of metal-polymer material will decrease, while the area of sections formed by means of electroerosion alloying will correspondingly increase

Conclusions:

1. A new combined technology is proposed for the repair of the bearing shafts of screw compressors (SC) shafts, which consists of pressing on the worn surface of the bushing shaft, which was previously strengthened by ion nitriding, and after grooving and grinding in size, subjected to carburizing by electro-erosion alloying (EEA) and nonabrasive ultrasonic finishing methods.

2. When restoring the worn working surfaces of the ribbon of rotors, it is advisable to use a combined technology (CT) consisting in the formation of a coating of tin bronze and run-in coating from Babbitt by the EEA method on a more worn rotor, and on the second combined coating consisting of 12X18H10T stainless steel sections and zones of metal-polymer materials (MPM). In this case, separately taken technologies of EEA and deposition of MPM do not in any way diminish the dignity of each other, but complement them, and eliminate the disadvantages inherent in each technology separately.

3. The EEA method can be varied by the thickness of the deposited layer and the height of the microroughness, and by subsequent blade treatment it is possible to provide a certain ratio of the areas of deposited metal and MPM.

4. The combination of the sulphurizing process with the restoration of the surfaces of the SC rotor ribbons by the EEA method significantly reduces the occurrence of emergency situations associated with grasping the surfaces of the rotors and forming scuffs.

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Аннотация

Тарельник В.Б., Марцинковский В.С., Коноплянченко Е.В. Технологические методы обеспечения надежности при ремонте и восстановлении роторов винтовых компрессоров

Описана новая комбинированная технология реновации роторов винтовых компрессоров, повышающая их надежность и долговечность за счет целенаправленного сочетания отдельных способов повышения качества поверхностей деталей комбинированными технологиями, включающими: электроэрозионное легирование (ЭЭЛ), ионное азотирование, цементацию методом ЭЭЛ, метод безабразивной финишной обработки, нанесение полимерных материалов и сульфидирование.

Ключевые слова: *винтовой компрессор, ротор, износ, поверхностный слой, электроэрозионное легирование, микротвердость.*