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New Method of Friction Assemblies Reliability and Endurance Improvement

Viacheslav Tarelnyk[1,a], Vasyl Martsynkovskyy[2,b], Aleksandr Dziuba[1,c*]

[1]Sumy NAU, Kirova Str. 160, Sumy, 40021, Ukraine

[2]TRIZ Ltd, Mashynobudivnykiv Str.1, Sumy, 40020, Ukraine

[a]tarelnik@i.ua, [b]mbc@triz.sumy.ua, [c]brp@triz.sumy.ua

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Abstract. Thus a new method of shaft necks processing is suggested for practical application, including application of soft antifriction metal coating, chosen from group: indium, tin, copper, silver, which differs that the coating is applied by electroerosion alloying on the shaft neck surface with discharge energy 0.01-0.03 J in the final operation, or the coating of copper or silver is applied with discharge energy 0.04-0.4 J and subject to post-processing, for example nonabrasive ultrasonic finishing. In such cases the surface layer with the microhardness less that the microhardness of the backing is formed. That promotes the fall of friction assembly normal operation and reduces the possibility of babbit microfractures formation in cubic crystals SnSb, which subsequently become the center of fractions formation in bulk of the layer.

Introduction

The majority of essential parts and assemblies of centrifugal compressors, pipes, turbines and other machines operate under high speed, load and temperature, and under conditions of corrosive, abrasive effect and other effects of working environment.

The solution of problem, related to increase of machine service life, directly depends on assemblies wear-resistance and reliability improvement. Under various conditions of parts operation the most loaded is the surface layer. Thus the actual operational life directly depends on the carrying capacity of the parts surface, which is defined by the quality of their surface layer.

As a result, formation of surface layers with special properties for sliding friction assemblies, for example, journal bearings (JB), is the critical task at present.

Analysis of the Last Researches and Publications

The proposed method relates to electrophysical and electrochemical machining, in particular, electroerosion alloying, and can be used for bearing journal necks processing, contacting with babbit bearing shells.

The bearing materials of soft metals Sn, Pb, Cd, Sb, Zn are characterized by solid structural constituents in plastic perform, called babbit. They are lined at the warmed brasses (250 ºC) under the temperature 450-480 ºC. Centrifuging is used more often. It is lined into the mold even under pressure; lining thickness is 1-3 mm.

The substantial defect of babbit is low fatigue resistance, especially under temperature increase up to more than 100 ºC. Under lining thickness decrease the fatigue resistance increases. The minimal babbit lining thickness shall be 0.25-0.4 mm [1].

It is known that fretting and damage development of the wearing surfaces in postbreaking period depends on irreparable micro- and sometimes macrodamages on the friction surface, existing in the break-in process. Local destruction of the structural constituents as a result of overload relates to such damages. As a result of low-cycle fatigue the damages exist in metal, moreover the most weak structural constituents are damaged. As a result of using babbit <Б83 in cubic crystals SnSb in thin-layer bearing, the microfractures exist, which become the source of fracture widening in the bulk of layer [2].

The well-known method of electroerosion alloying is the process of material transfer onto the work surface by spark discharge. This method has a range of specific peculiarities:

- anode material (doping material) may form on the cathode surface (alloyed surface) the tightly applied coating layer. In that case not only the boundary line between the applied material and basic metal is missing but even anode and cathode diffusion exists;
- alloying may be performed in strictly indicated places, not protecting the rest of the workpiece surface;
- electroerosion alloying technology of the metal surfaces is very simple, and the necessary equipment is small-sized and transportable [3].

The method of bearing shells processing is quite similar to the suggested one, and it consists in the following that indium or tin are faced on the babbit coating surface by electroerosion alloying under discharge energy 0.01-0.03 joule. Herewith the surface layer is formed with the microhardness less than the backing microhardness, and the shots (SnSb) of square form [4] are missing.

It should be noted that under application of soft antifriction metals indium or tin on the babbit surface peculiar difficulties exist:

- alloying electrode fritting;
- low capacity;
- electroerosion process is difficult to mechanize;
- difficult coating soundness.

Formulation of the Article Object (Terms of Reference)

Thus the work objective is reliability and endurance improvement of babbit bearings by means of running-in coatings application improvement.

In order to achieve the objective it is necessary to solve the problem of running-in coatings formation of the soft antifriction metals at the journal neck with the required tribotechnical characteristics.

The Basic Research Material

Because of the mentioned above defaults, connected with running-in coatings on the babbit shells, the problem is suggested to solve in the following way. The layer of soft antifriction material, chosen of indium, tin, brass and silver group, is usually applied by electroerosion alloying not on the babbit shell surface, but on the contact surface of the journal neck. In the case of surface layer formation with the surface roughness $R_a > 1$ micron the following processing should be performed by means of surface plastic deformation, for example nonabrasive ultrasonic finishing.

In the modern engineering the choice of the material and thermal processing of shafts and axes can be defined by their performance criterion, including the criterion of supported journals performance. The importance of the last criterion of sliding supports can be crucial.

The main materials for shafts are carbon and alloy steel due to their high mechanical characteristics, work-hardenability and easiness of cylindrical works rolling.

Heat-treated medium-carbon and alloy steel C 45 (DIN), 41 Cr 4 is applied for most of shafts. For high-stress shafts of the major machines the alloy steel (DIN) is used: 40Ni Cr 6, 36 CrNiMo 4 etc. The shafts of these types of steel are usually subjected to improvement, high temper hardening and surface hardening with high frequency heating.

High speed shafts, rotating in journal bearings, require quite high journal hardness; they are manufactured of carburizing steel 16 MnCr 5 or nitrided steel.

In order to manufacture profile shafts- crankshafts with large flanges and hollows and heavy shafts along with steel high-strength cast iron (with spherical graphite) and modified cast iron are applied.

Surface roughness for journal bearing subject to service conditions is Ra=1.0-0.16 micrometers [5].

Research Methods

The materials, applied for research, are divided into materials for cathode (machine parts) and anode (of the alloyed electrode).

The applied materials of anode and cathode, and their some physical and mechanical properties are mentioned in the Tables 1, 2.

Table 1. Physical and mechanical properties of the materials, applied during electroerosion alloying as cathode (sample)

Material grade (DIN)	Crystal lattice	Tensile strength under tension [Kg/mm]	Yield point, [kg/mm$^{2]}$	Hardness, [HB]
C 45	CBL (cement bond log)	96.8	84.6	280
41 Cr 4	CBL (cement bond log)	98	86	220

The majority of factors have impact on the quality characteristics during electroerosion alloying, of the list of which the alloying modes should be marked out.

The impact of the sample material, modes of electroerosion alloying on the quality characteristics of the coatings was defined at the unit with manual vibrator “EIL-8A” (Fig.1). The main operation modes are mentioned in the Table 3.

Table 2. Physical and mechanical properties of materials applied during electroerosion alloying as anode (alloying electrode)

Material grade	Melting temperature, [ºC]	Hardness	Thermal conductivity, [W/m K]	Coefficient of thermal expansion 10^{-6}, [grad $^{-1}$]
copper	1084	88HB	401	16.5
silver	817	25HB	453	14.2
tin	232	5HB	59.8	22
indium	157	0.9HB	87	60.5

Fig. 1. “EIL-8A”

Table 3. Operation modes of “EIL-8A”

Mode No.	Open-circuit voltage $U_{x.x}$, [V]	Operating current I_p, [A]		Discharge energy W_u, [J]	
		C= 150 mfd	C= 300 mfd	C=150 mfd	C=300 mfd
1	16	0.2-0.4	1.0-1.4	0.01	0.02
2	23	0.3-0.5	1.4-1.6	0.02	0.05
3	30	0.5-0.6	1.6-2.0	0.04	0.08
4	37	0.6-0.7	1.8-2.0	0.06	0.12
5	47	0.7-0.8	2.0-2.2	0.10	0.20
6	57	0.8-0.9	2.2-2.4	0.15	0.30
7	67	0.9-1.0	2.4-2.7	0.20	0.40
8	77	1.0-1.2	2.6-2.8	0.27	0.55
9	87	1.1-1.3	2.6-3.5	0.34	0.68

Coating layer thickness was measured with micrometer, and the surface roughness- with profilograph-profilometer 201 “Kalibr” by means of profilograms reading and processing. Coating soundness was estimated visually.

The most part of the experiments was carried out with the use of steel C 45 as cathode (sample), where the quality of the formed coatings (thickness and roughness) after electroerosion alloying was estimated. Right-angled samples 10x10x8 mm with the roughness of the initial surface Ra= 0.5 micron were used for research.

Samples of 41 Cr 4 steel were subjected to cementation by electroerosion alloying [6]. Afterwards the coatings of copper and silver were applied and subjected to nonabrasive ultrasonic finishing. Layer roughness, soundness, thickness and microhardness distribution were tested on these samples while deepening out of the surface.

Cementation with electroerosion alloying was performed at the portable unit with the manual vibrator “Elitron - 22A”, providing discharge energy over the range 0.1 to 0.53 J and high power unit of electroerosion alloying – “Elitron - 52 A” with discharge energy up to 6.8 J.

The process of cementation by electroerosion alloying was performed with the help of special tool at different modes over the range of discharge energy (W_p) from 0.1 to 6.8 J (Fig.2).

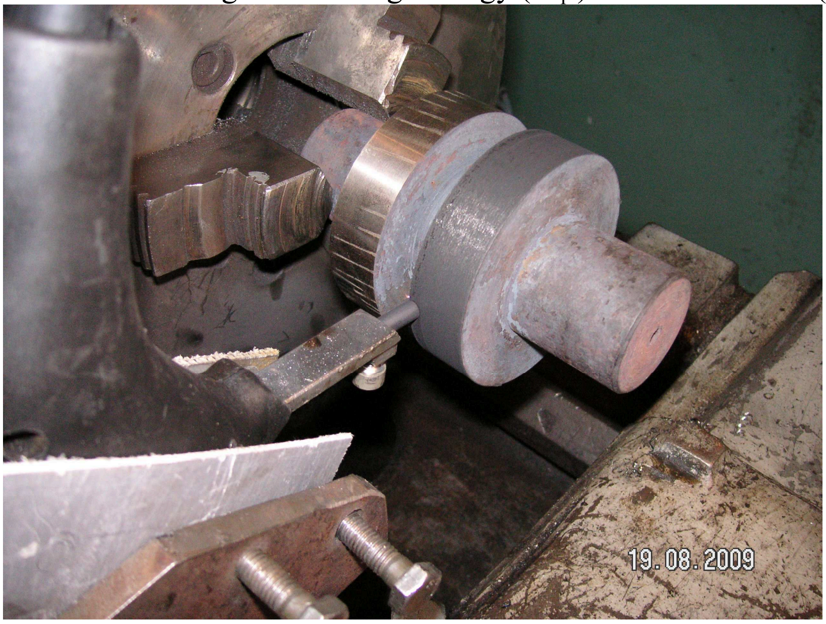
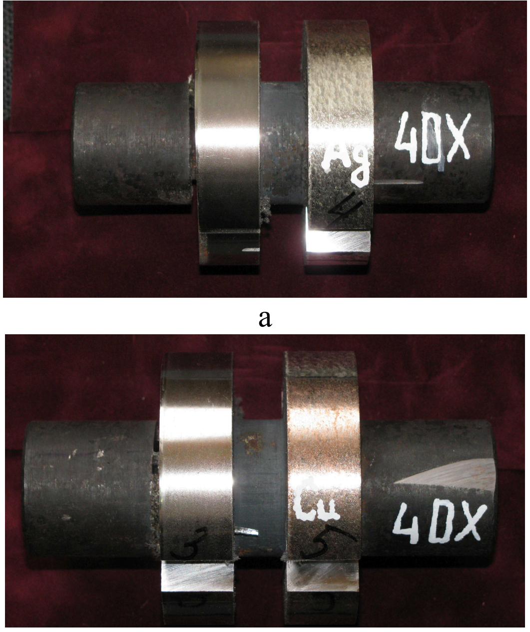


Fig. 2. Cementation with electroerosion alloying using turning lathe

While researches the bobbin-shaped samples of 41 Cr 4 steel, consisting of two plates, with the diameter 50 mm and width 10 mm, connected by spacer with diameter of 15 mm, and having two process sections with the same diameter (Fig.3). Plate surfaces before cementation by electroerosion alloying were grinded up to Ra= 0.5 micron. The samples were fixed in the chuck, cementation with electroerosion alloying was performed, alloying with silver and copper and nonabrasive ultrasonic finishing. Surface roughness was measured by profilograph at the all processing stages- profilometer 201 “Kalibr”. Particular segments were cut out of the plates in order to manufacture sections for metallographical and durometric tests (Fig.4).



a

b

Fig. 3. Steel samples for cementation analysis by electroerosion alloying and electroerosion alloying: a- silver and b- copper

Fig. 4. Sections for metallographic and durometric tests

After manufacturing the sections were tested at the optical microscope “Neofot-2”, where the layer quality, its soundness, thickness and sublayer zones were estimated- diffusion zones and heat-affected zones. The durometric analysis of micro-hardness distribution in the surface layer and in section depth was performed. Micro-hardness measurement was carried out with the help of diamond-pyramid microhardness tester PMT-3.

During cementation by electroerosion alloying graphite electrodes EG-4 OST 229-83 were used.

The process of electroerosion alloying was carried out with the capacity of 5 min/cm^2.

The results of analysis of the following sets of samples of 41 Cr 4 steel are listed below:

- step cementation (W_p= 2. 83 and 0.9 J; with capacity 5 and 2.0 min/cm^2); processing with nonabrasive ultrasonic finishing (sample No.3);
- cementation (W_p= 2. 83 J; with capacity 5 min/cm^2); silver alloying (W_p= 0.4 J; with capacity 1 min/cm^2); processing with nonabrasive ultrasonic finishing (sample No.4);
- cementation (W_p= 2. 83 J; with capacity 5 min/cm^2); copper alloying (W_p= 0.4 J; with capacity 1 min/cm^2); processing with nonabrasive ultrasonic finishing (sample No.5).

Research Results

On the basis of the research conducted we received the qualitative features of coatings made of soft metals (copper, indium, tin and silver), applied by electroerosion alloying on 45 steel, and the recommended rational time of the 1st alloying of the surface T_{rat} (Table 4).

Table 4. Qualitative features of coatings made of soft metals (copper, indium, tin and silver), applied by electroerosion alloying on 41 Cr 4 steel

Mode W_u, J	T_{rat}, min	Roughness, Rz, [micron]				Incrementation, Δh, [mm]			
		Cu	In	Sn	Ag	Cu	In	Sn	Ag
0.01	4.0	0.6	0.6	0.6	0.6	0.01	0.01	0.01	0.01
0.02	3.5	0.7	0.7	0.7	0.6	0.01	0.02	0.01	0.02
0.04	3.0	0.1	0.8	1.0	0.7	0.02	0.02	0.03	0.02
0.05	2.7	1.2	-	1.5	0.8	0.03	-	0.05	0.02
0.08	2.0	1.3	-	4.5	1.0	0.03	-	0.10	0.03
0.10	2.0	1.4	-	5.6	1.0	0.04	-	0.12	0.035
0.20	1.2	1.5	-	-	1.2	0.05	-	0.13	-
0.34	1.0	1.6	-	-	1.4	0.09	-	0.13	-
0.40	1.1	2.0	-	-	-	0.09	-	-	-
0.68	0.75	27	-	-	-	0.14	-	-	-

When changing the material of the supporting plate 41 Cr 4 steel into cast iron the coating formation mechanism remains quietly the same.

The next nonabrasive ultrasonic finishing leads to surface roughness reduction up to Ra=0.5 micron.

The results of roughness measurement of the sample No.3 are included in the Tables 5, 6.

Table 5. Surface roughness of sample No.3 after phased cementation with discharge energy W_p= 2. 83 J and 0.9 J.

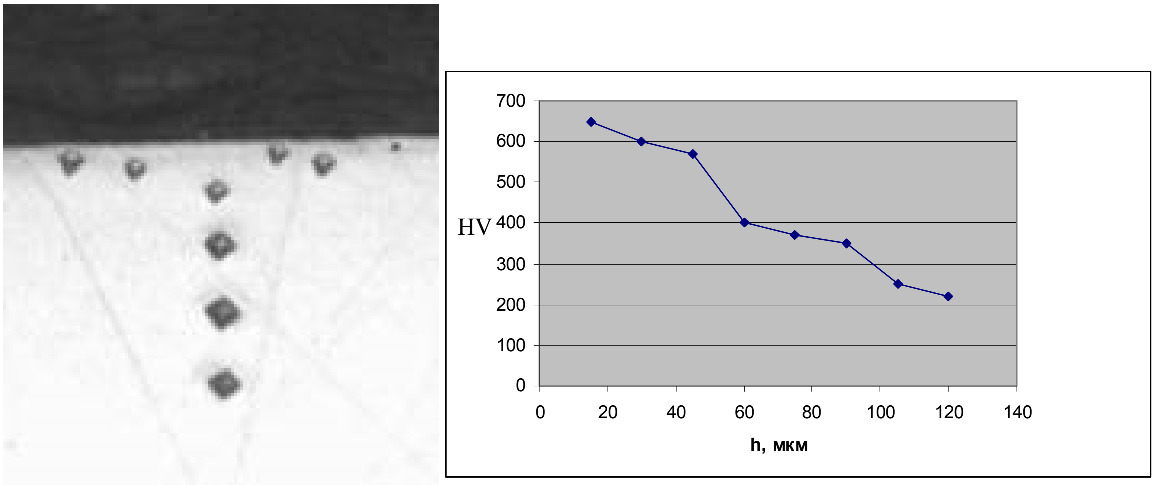
The value of the surface roughness at particular points, [micron]						Mean value of the roughness parameter, [micron]	
R_a							
3.09	2.73	2.19	3.41	2.31	2.24		
R_z						R_a	R_z
10.27	8.19	13.21	10.20	14.70	12.57	2.3	11.5

Table 6. Surface roughness of the sample No.3 after phased cementation with discharge energy W_p= 2. 83 J and 0.9 J, and nonabrasive ultrasonic finishing

The value of the surface roughness at particular points, [micron]							Mean value of the roughness parameter, [micron]	
R_a								
0.7	0.47	0.52	0.64	0.59	0.45	0.7		
R_z							R_a	R_z
1.93	1.31	1.49	1.81	1.67	1.29	1.93	0.56	1.58

Figure 5 illustrates the microsection and hardness distribution in sample No.3. As shown, the maximum sample microhardness (up to 650 HV) occurs on its surface and softly goes down to the microhardness of the backing, which is 220 HV. The depth of the hardened region extends to 100 micron.

Then upon phased cementation with discharge energy W_p= 2. 83 J and 0.9 J, and nonabrasive ultrasonic finishing, the surface roughness (R_a) of round bar of steel 41 Cr 4 comprises 0.56 micron, herewith the depth of the hardened region extends to 100 micron.



a) b)

Fig. 5. Microsection (a) and microhardness distribution in the surface layer of 41 Cr 4 steel, sample No.3 (b)

The results of surface roughness measurement of the sample No.4 after phased cementation and silver electroerosion alloying are illustrated in the Table 7 with further nonabrasive ultrasonic finishing in the Table 8.

It is important to note that while silver electroerosion alloying the diameter of sample No.4 has increased to 0.03 mm.

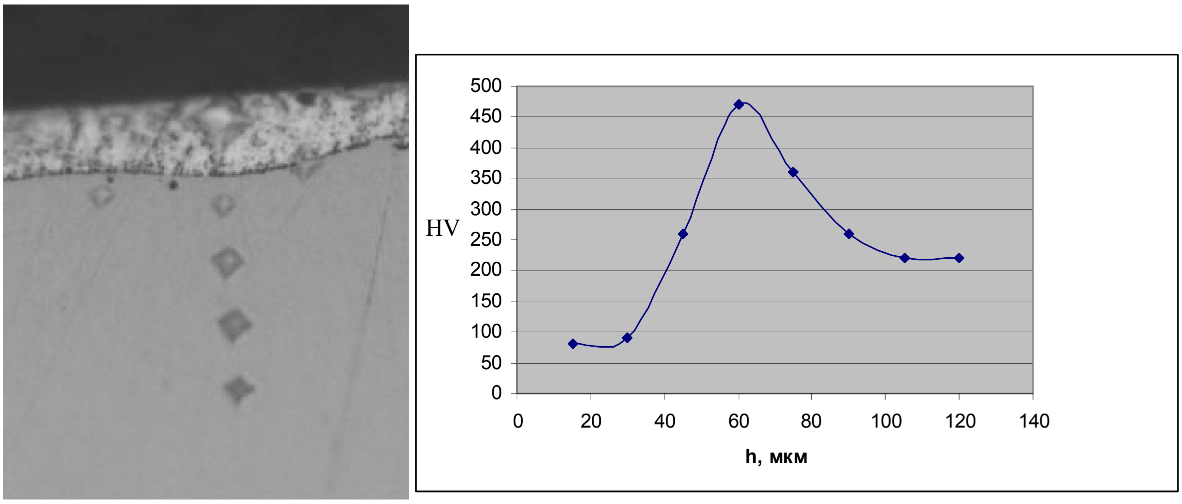
Table 7. Surface roughness of sample No.4 after phased cementation and silver electroerosion alloying

The value of the surface roughness at particular points, [micron]						Mean value of the roughness parameter, [micron]	
R_a							
1.92	3.3	1.55	2.57	2.15	2.04		
R_z						R_a	R_z
5.43	9.37	4.38	7.26	6.17	5.76	2.26	6.40

Figure 6 illustrates microsection and microhardness distribution in sample No.4. As shown, there is a layer with microhardness 80-90 HV on the sample surface, which is less than the microhardness of backing (220 HV), and 35 micron of the depth. Further, the microhardness increases, and in the depth of ~ 60 micron has a maximum 470 HV, whereafter goes down again to the depth 100 micron and corresponds the microhardness of backing.

Table 8. Surface roughness of the sample No.4 after phased cementation, silver electroerosion alloying and nonabrasive ultrasonic finishing

The value of the surface roughness at particular points, [micron]							Mean value of the roughness parameter, [micron]	
R_a								
0.59	0.86	1.27	0.47	1.33	0.76	0.59		
R_z							R_a	R_z
1.68	2.44	3.59	1.33	3.76	2.14	1.68	0. 88	2.49



a) b)

Fig. 6. Microsection (a) and microhardness distribution in the surface layer of 41 Cr 4 steel, sample No.4(b)

The results of surface roughness measurement of the sample No.5 after phased cementation and silver electroerosion alloying are illustrated in the Table 9 with further nonabrasive ultrasonic finishing in the Table 10.

Table 9. Surface roughness of the sample No.5 after phased cementation, copper electroerosion alloying

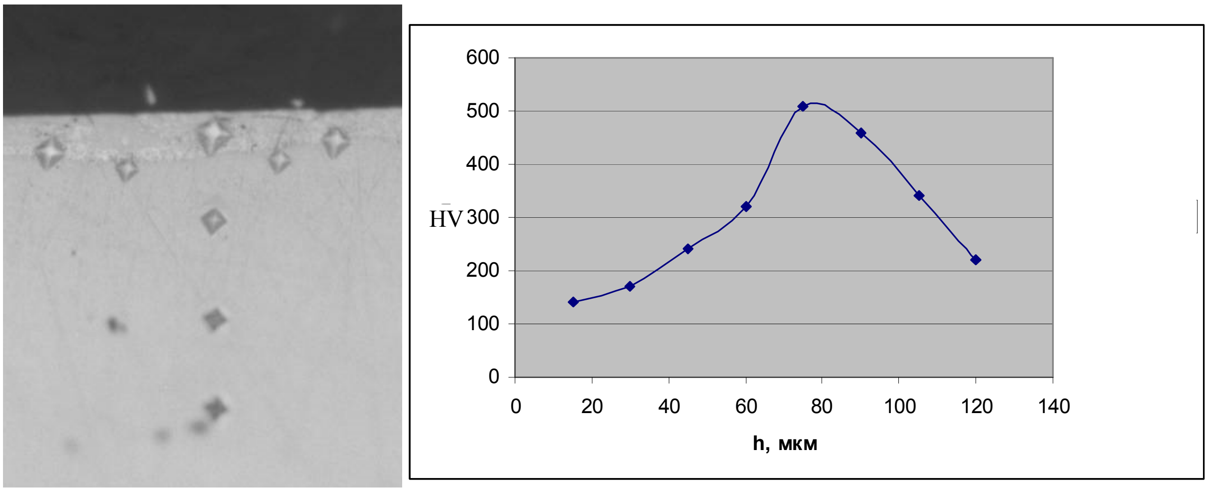
The value of the surface roughness at particular points, [micron]						Mean value of the roughness parameter, [micron]	
R_a							
3.02	4.46	2.5	3.38	2.14	3.41		
R_z						R_a	R_z
8.54	12.63	7.07	9.67	6.06	10.2	3.15	9.03

Table 10. Surface roughness of the sample No.5 after phased cementation, copper electroerosion alloying and nonabrasive ultrasonic finishing

The value of the surface roughness at particular points, [micron]							Mean value of the roughness parameter, [micron]	
R_a								
0.55	0.65	0.91	0.62	0.87	0.71	0.51		
R_z							R_a	R_z
3.05	2.40	2.35	2.64	2.48	3.01	3.25	0. 80	3.19

It should be noted that while copper electroerosion alloying the diameter of the sample No.5 has increased to 0.04 mm, and after nonabrasive ultrasonic finishing has reduced to 0.02 mm.

Figure 7 illustrates microsection and microhardness distribution in sample No.5. As shown, there is a layer with microhardness 140-170 HV on the sample surface, which is less than the microhardness of the backing (220 HV), and 40 micron of the depth. Further, the microhardness increases, and in the depth of ~ 75 micron has a maximum 510HV, whereafter goes down again to the depth of 120 micron and corresponds the microhardness of the backing.



a) b)

Fig. 7. Microsection (a) and microhardness distribution in the surface layer of 41 Cr 4 steel, sample No.5(b)

Analyzing the performed researches it should be noted that while soft antifriction metals application, for example copper or silver, on the regions, cemented with electroerosion alloying, the surface of the machine part is formed of two layers:

- layer of soft antifriction metal from outside
- layer of solid wear-resisting metal below.

Soft antifriction metal application while nonabrasive ultrasonic finishing allows to get high-quality wear-resisting layer with the required roughness.

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