УДК 622.279.23

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Increasing wear resistance steel parts in press-fit connections by new methods of fretting corrosion protection

Предложены новые методы повышения износостойкости стальных деталей, подвергающихся фреттинг-коррозии. Представлены результаты исследований качественных параметров поверхностных слоев, цементированных методом электроэрозионного легирования (ЦЭЭЛ) стальных деталей, а так же деталей, ЦЭЭЛ и покрытых мягкими антифрикционными металлами, после безабразивной ультразвуковой финишной обработки.

***Ключевые слова**: фреттинг-коррозия, поверхностный слой, усталость, прессовые посадки, микротвердость, шероховатость, глубина слоя.*

Запропоновано нові методи підвищення зносостійкості сталевих деталей, що піддаються фреттинг-корозії. Представлені результати досліджень якісних параметрів поверхневих шарів, цементованих методом електроерозійного легування (ЦЕЕЛ) сталевих деталей, а також деталей, ЦЕЕЛ і покритих м'якими антифрикційними металами, після безабразивної ультразвукової фінішної обробки.

***Ключові слова**: фреттинг-корозія, поверхневий шар, втома, пресові посадки, мікротвердість, шорсткість, глибина шару.*

The present paper suggests the new methods for improving wear resistance of steel parts that are exposed to fretting corrosion. The results of the investigations carried out to study qualitative parameters of surface layers of steel parts cemented using electroerosive alloying (EEAC), as well as the result of the investigations of the parts processed with EEAC and further coated with soft antifrictional metals after nonabrasive ultrasonic finishing are represented below.

***Keywords**: fretting corrosion, surface layer, fatigue, press-in fit, microhardness, roughness, layer depth.*

Introduction

Joint strength faults, fretting fatigue and fatigue failures are the most typical cases of faults for press-fit and press-key connections. Therefore, improvement of efficiency of these Joints is one of the most important tasks for ensuring reliability and durability of machine parts.

Fretting corrosion is viewed at various press-in fits on rotating shafts, within the seat places of impellers, in splined, key, bolted and riveted Joints.

Analysis of recent researches and publications

Wear caused by fretting corrosion occurs at slight oscillating, cyclic, reciprocative movements with small amplitudes.

As result of fretting corrosion fatigue strength of parts is reduced, that may cause serious damages.

It is possible to assemble fixed surfaces by pressing-in shaft into hole, when part with hole is heated, or when shaft is cooled [1].

Analysis of operation data of composite mill rolls of different dimension-types states that the sleeve is often improperly fixed on the roll axle during shrink-fit assembling [2]. Such imperfections stimulated development of a wide range of additional design and technological solutions as well as creation of other types of fastening means [3].

Damages due to fretting corrosion depend upon many following factors: amplitude of relative slippage, contact pressure, number of cycles, frequency of oscillations, material and environment.

For significant increase of load-carrying capacity of press-fit connections, the tendency connected with introduction of soft and hard interlayers into the contact zone has been widely developed recently [4–8].

Efficiency of each certain coating depends upon its thickness [5]. The conducted experiments showed that damage due to fretting increased when thickness of the electrodeposited silver layer was reduced from 125 μm to 12.5 μm. According to [9], most parts require coating with thickness 75–125 μm for practical application, although in individual cases thicknesses up to 300 μm were suggested.

The author of [10] in his book represents the results of A. Tum and F. Wunderlich, in which a significant improvement of fatigue limit of shafts with force-fitted parts by means of cementation is stated. It was found that fatigue limit of 12 *mm* in diameter samples with pressed-in bushings depended upon warpage during heat-treatment of the samples. After they took measures to prevent warpage, the fatigue limit increased from 137.3 *MPa* to 412.0 *MPa*. According to E. Ler fatigue limit of cemented samples having 60 *mm* in diameter increased more than twice when pressing-in.

Analysis of the literature sources shows that there is no universal mechanism of protection to prevent fretting corrosion. It is found that fretting corrosion of parts can be reduced or even utterly eliminated by changing qualitative parameters of their surface layers, for example, by applying corrosion-resistant protective coatings of required hardness, thickness and friction coefficient, at that the coatings should be properly combined with the substrate and should not reduce fatigue resistance of the surface layers.

The electroerosive alloying (EEA) method is one of the most promising technologies for forming surface layers with required properties for machine parts.

The EEA method has a number of characteristic features, and one of them allows alloying process without transferring anode material onto the cathode thus forming no material increment of material, for example, using the EEA method with a graphite electrode.

The EEA method with graphite electrode is based on diffusion process (saturation of surface layer of the part with carbon) and is quite similar to such kind of chemical heat treatment of surface as cementation.

As compared with the standard cementation, the EEA method of cementation of steel parts has not only all the advantages of the standard cementation i.e. hardening of the part surface preserves its original material properties, but also at the same time protects the part surface from warpage, and moreover small-size devices give possibility to carry out hardening on any available equipment. Processing speed at that is 1–5 min/cm^2.

When using the EEA method with graphite electrode, hardening of the surface of the machine part takes place thanks to diffusion-hardening processes, implying local saturation of the surface with carbon at reasonably high temperatures (up to 10000 ^0C), followed by rapid cooling of the part to almost environmental temperature.

Cementation of steel parts by EEAC may be studied as a certain technological branch, as the cementation method allows forming surface layers of increased wear resistance on the machine parts without changing the original dimensions of the part [11].

When using the EEAC method for steel parts, the thickness of hardened layer depends upon the discharge energy and the alloying time (processing speed). The more is discharge energy and the longer is alloying time, the deeper is the hardened layer. The surface roughness increases as well. Thus when using the EEA method for treatment of 40H (GOST) bisulfide alloyed steel (Ra = 0.5 μm) with carbon at processing speed equal to 5 min/cm^2 and discharge energy of 6.8 J, thickness of the hardened layer is more than 1.15 mm. The surface roughness at that amounts to Ra = 11.7–14.0 μm.

For the purpose of minimization of surface roughness after EEAC, as a rule methods of surface plastic deformation (SPD) are used.

Among the SPD methods the following ones are worth mentioning: plastic deformation with a ball and ultrasonic hardening, i.e. nonabrasive ultrasonic finishing method (NUFM).

It should be noticed that using of the SPD methods does not always have the intended effect. Thus, when one uses a ball for plastic deformation, a slight excess of the required specific effort causes microcracks in the surface layer which was preliminary treated using the EEA method with carbon [12]. Microcracks, which use to concentrate stresses, may cause damage of the parts, especially of those parts, which are exposed to alternating loads during operation.

Despite the fact that the subsequent NUFM processing significantly reduces the surface roughness, the obtained roughness is insufficient for many machine parts.

Grinding is not possible after EEAC, since in this case at least 50–100 μm of the surface layer is removed, and the very problem is that the layer to be removed by grinding has the highest hardness.

Thus the object of the research is to increase durability of the parts of press-fit connections by forming surface layers that reduce negative impact of fretting corrosion.

Quality of the layer formed using the EEAC method can be improved either by choosing the most efficient treating modes or by applying soft antifrictional material, for example, copper, silver, etc onto the cemented layer, and subsequent NUFM processing.

Improvement of quality of the cemented layer by choosing the most efficient EEA treating modes

To reduce surface roughness of the machine parts, while preserving quality of the surface layer (lack of microcracks, availability of layer with higher hardness, 100% uniformity, and etc.), and thus to expand area of application of these parts, it is suggested that the surface treated using EEA with carbon (graphite electrode) should be further alloyed with the same electrode, but here alloying should be done stage-by-stage. At each following stage one should use EEA mode applying the discharge energy, which would ensure two- or threefold decrease of the surface roughness of the same but unalloyed (original) material as comparing with the roughness at the previous stage. At that if the roughness is reduced by half, alloying should be carried out in 1 pass, and if it is reduced to a third, then alloying should be carried out in 2 passes. One pass means 100% treatment of the entire surface of the part at production speed that corresponds to the applied discharge energy.

Process speed of EEAC depending upon the alloying mode is shown in Table 1.

Table 1. ***Process speed of EEAC depending upon the alloying mode***

Discharge energy W_p [J]	0.1	0.31	0.53	0.9	2.83	3.4	6.8
EEAC speed min/cm^2	2.0	1.0	1.0	1.0	0.5	0.5	0.5

The procedure and the results of the carried out investigations are given below.

EEAC was carried out on the two EEA-treatment portable devices each equipped with a manual vibrator. The first one is "Elitron-22A" that provides the discharge energy within a range of 0.1–0.53 J; and the other one is "Elitron-52A" that has higher power and provides discharge energy up to 6.8 J.

EEAC process was carried out automatically on a special device in different modes within discharge energy range (W_p) from 0.1 J to 6.8 J.

The special samples were used for the research. The samples were made of 38HMYuA (GOST) and 40HN2MA (GOST) steels in the shape of a coil consisting of two 50 mm in diameter discs, each 10 mm wide, connected to each other with a spacer 15 mm in diameter and having two process sections of the same diameter (Fig. 1, a). Before being treated with EEAC the surfaces were polished up to Ra = 0.5 μm. The samples were fixed in the chuck of the turning machine, then EEAC (Fig. 2) and NUFM processing were carried out. Moreover, flat samples having dimensions 20 x 40 x 5 mm made of 20 (GOST) steel were used for the researches. The surface roughness was measured with a profilograph-profilometer mod. 201 manufactured by “Kalibr” factory. Next, the circular samples were cut so to obtain single discs (of 50 mm in diameter and 10 mm wide each) (Fig. 1, b). These discs in their turn were

a b

Fig. 1. Steel samples for investigation of result of EEAC

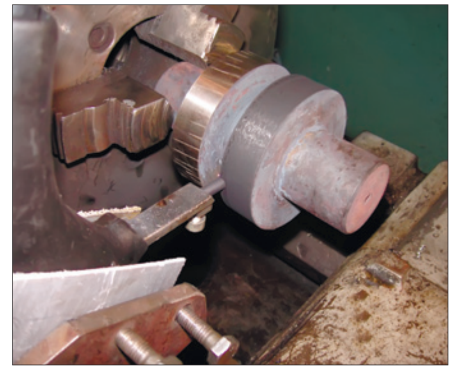
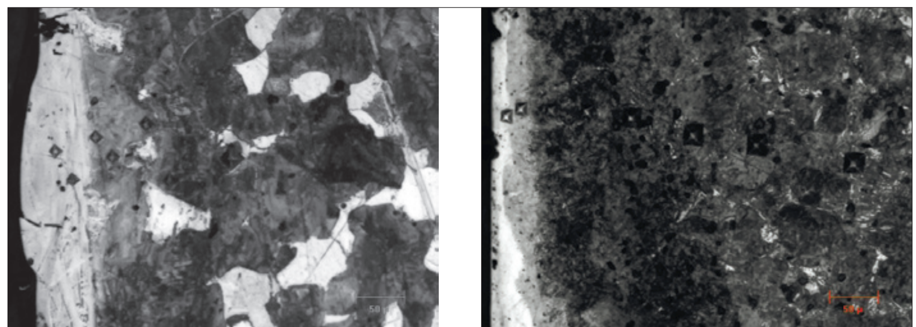


Fig. 2. EEAC-treatment using the turning machine



a b

Fig. 3. Microhardness distribution throughout the layer depth when using the EEA-treatment with carbon for 38HMYuA steel (W_p = 0.9 J)

EEAC-treatment was carried out using graphite electrodes (GE-4) with production speed of 5 min/cm^2.

When the circular samples made of 38HMYuA and 40HN2MYuA steels were treated using the EEAC method at the discharge energy W_p = 0.53 *J*, the surface roughness (Ra) increased from 0.5 *μm* to 1.4–1.7 *μm*. Finish machining using NUFM allows reducing the surface roughness to *Ra* = 0.6 *μm*. Thickness of the hardened layer, in this case, does not exceed 35 *μm* and microhardness does not exceed 950 HV and 800 HV respectively.

When the discharge energy of EEAC is increased to W_p = 0.9 *J*, depth of the hardened layer increases up to 150 *μm* – 170 *μm* (Figures 3 and 4). Microhardness on the surface of 38HMYuA and 40HN2MYuA steels amounts to 1350 *HV* and 760 *HV* respectively. The microhardness gradually decreases with deepening and smoothly becomes equal to hardness of the substrate, i. e. layer (total thickness of the layer with higher hardness; maximum microhardness on the surface, *HV*; roughness after treatments using EEAC and NUFM methods) for 38HMYuA and 40HN2MYuA steels are summarized in Table 2.

Table 3 represents the resulting values of maximum reduction of roughness for the samples after they were treated using the EEAC method at alloying modes with various discharge energy. Thus, for example, surface roughness of 38HMYuA steel amounts to *Ra* = 5.7 *μm* – 6.9 *μm* after treatment using the EEAC method at discharge energy of 2.83 *J*. After the surface was treated with a graph-

Table 2. ***Results of the investigation of steel samples after treatment using EEAC and NUFM methods***

Steel grade	Discharge energy, W_p [*J*]	Total layer thickness [*μm*]	Maximum mictohardness on the surface [*HV*]	Roughness, *Ra* [*μm*]	
				after EEAC	after NUFM
38HMYuA	0.1	10	900	0.8–0.9	0.2
	0.31	20	900	0.9–1.0	0.3
	0.53	35	950	1.4–1.7	0.6
	0.9	170	1350	1.6–2.0	0.8
	2.83	215	980	5.7–6.9	1.5
	3.4	230	960	8.3–8.5	2.3
	6.8	370	1010	11.9–14.0	3.2
40HN2MYuA	0.1	10	900	0.8–0.9	0.2
	0.31	20	900	0.9–1.0	0.3
	0.53	37	800	1.4–1.7	0.6
	0.9	163	760	1.7–2.0	0.9
	2.83	245	1002	5.7–6.7	1.5
	3.4	262	1006	8.6–8.9	2.3
	6.8	380	1070	11.9–14.1	3.2

ite electrode applying the EEA method at speed 2 min/ cm^2 (2 passes at speed 1 min/ cm^2) and using discharge energy of 0.9 *J*, the roughness of the surface amounts to *Ra* = 1.7 *μm* – 2.2 *μm*. Further increase of the production speed of alloying (number of passes) does not result in reducing of the surface roughness.

After 38HMYuA steel was treated using the EEA method with a graphite electrode at modes with discharge energies of 0.53 *J*; 0.31 *J* and 0.1 *J* and production speed of 3 min/ cm^2; 6 min/ cm^2 and 14 min/ cm^2 respectively, surface roughness amounts to *Ra* = 1.6 *μm* – 1.9 *μm*; 1.2 *μm* – 1.3 *μm* and 1.1 *μm* – 1.2 *μm* respectively. Further increase of the production speed of alloying (number of passes) does not result in reducing of the surface roughness.

Thus, in order to minimize surface roughness, for example the surface roughness of 38HMYuA steel that amounts to *Ra* = 11.9 *μm* – 14.0 *μm* after EEAC treatment of the surface at the discharge energy of 6.8 *J*, it is necessary to do the following:

At the first stage to carry out EEA treatment using graphite electrode at the discharge energy of W_p = 2.83 *J* (i.e. at the discharge energy that ensures reducing of surface roughness in ~ 2 times from 11.9 *μm* – 14.0 *μm* to 5.7 *μm* – 6.9 *μm*) at speed of 0.5 min/ cm^2. At the first stage the surface roughness after treatment with EEA amounts to *Ra* = 6.3 *μm* – 6.9 *μm*;

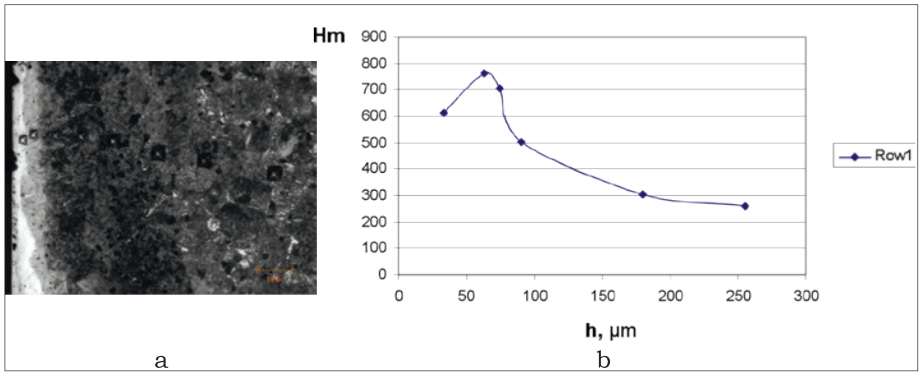


Fig. 4. Microhardness distribution throughout the layer depth when using the EEA-treatment with carbon for 40HN2MYuA steel (W_p = 0.9 J)

- at the second stage to carry out EEA treatment using graphite electrode at the discharge energy of W_p = 0.9 *J* (i.e. at the discharge energy that ensures reduction of surface roughness in ~ 3 times from 6.3 *μm* – 6.9 *μm* to 1.7 *μm* – 2.1 *μm*) at speed of 2 min/ cm^2. At the second stage the surface roughness after treatment with EEA amounts to *Ra* = 1.7 *μm* – 2.2 *μm*;

- at the third stage to carry out EEA treatment using graphite electrode at the discharge energy of W_p = 0.1 *J* (i.e. at the discharge energy that ensures reduction of surface roughness in ~ 2 times from 1.7 *μm* – 2.1 *μm* to 0.8 *μm* – 0.9 *μm*) at speed of 2 min/ cm^2. At the third stage the surface roughness after treatment with EEA amounts to *Ra* = 0.8 *μm* – 0.9 *μm*;

It should be noticed that it is impossible to achieve such results in reducing of surface hardness of the same steel that was pretreated with EEAC at the discharge energy of 0.6 *J*, when we use EEA treatment with graphite electrode in only one stage, irrespective of chosen EEA mode. Subsequent alloying, for example, at the discharge energy of W_p = 0.1 *J* at speed of 25 min/ cm^2 allows reducing surface roughness to *Ra* = 1.6 *μm* – 1.9 *μm*.

The results of stage-by-stage reduction of roughness for 40HN2MYuA and 12X18H10T steels, that both were treated using the EEAC method at the discharge energy of W_p = 2.83 *J*, are given in Table 3 for comparison.

Similar investigations were carried out on flat samples of 20 steel. The results of measurements of surface roughness of the samples before hardening are summarized in Table 4.

Sample number 1 was treated with EEAC at W_p = 2.83 *J*. The results

Table 3. ***Results of maximum reducing of surface roughness for the steel samples after treatment using the EEAC method***

Steel grade	Discharge energy, W_p [J]	Roughness, *Ra* [*μm*] Production speed [min/ cm^2]						
		After EEA	Discharge energy, *Wp* [*J*]					
			0.1	0.31	0.53	0.9	2.83	3.4
38HMYuA	0.1	0.8–0.9						
	0.31	0.9–1.0	0.8-0.9 2					
	0.53	1.4–1.7	0.8-0.9 2	0.9-1.0 1				
	0.9	1.7–2.1	0.9-1.0 2	1.0-1.1 1	1.4-1.7 1			
	2.83	5.7–6.9	1.1-1.2 14	1.2-1.3 6	1.6-1.9 3	1.7-2.2 2		
	3.4	8.3–8.9	1.3-1.6 18	1.4-1.7 7	2.0-2.3 4	2.3-2.7 3	5.7-6.7 0.5	
	6.8	11.9–14.0	1.6-1.9 25	1.8-2.1 13	2.4-2.6 8	2.6-3.1 5	6.3-6.9 0.5	8.5-9.0 0.5
40HN2MYuA	2.83	5.7–6.7	1.0-1.1 14	1.2-1.3 6	1.5-1.8 3	1.7-2.1 2		
12H18N10T	2.83	2.9–3.7	0.8-0.9 14	1.0-1.2 6	1.5-1.8 3	1.7-2.0 2		

of measurements of surface roughness are summarized in Table 5.

Sample number 2 was treated stage-by-stage using the EEAC method at W_p = 2.83 *J*; 0.9 *J* and 0.1 *J* at speed 0.5 $\min/cm^2$; 2.0 $\min/cm^2$ and 2.0 $\min/cm^2$ respectively. The results of measurements of surface roughness are summarized in Table 6.

Results of the investigations carried out on the scanning electron microscope with analyzer "REM-106I", which was used to evaluate of the surface layer quality and topography, are given below.

Fig. 5 shows the surface zones of the samples number 1 and number 2 under the similar magnification. The surfaces are represented in the mode that emphasizes the topography (the "Topo" mode). The yellow line corresponds to 0 of brightness, and the blue line corresponds to 1 of brightness. The green line shows distribution of contrast along the yellow (base) line. Since the picture is obtained in the mode, when contrast is formed mainly by surface microrelief, height of the teeth of the green line allows us to evaluate asperities of the microrelief.

Figures 6 and 7 below represent microslices and distribution of microhardness in the surface layer of 20 steel of the samples number 1 and number 2.

When we look at distribution of microhardness in samples number 1 (cementation with EEA at W_p = 2.83 *J*) and number 2 (stage-by-stage cementation with EEA at W_p = 2.83 *J*, 0.9 *J* and 0.1 *J*), we can say that in both cases the highest microhardness is detected in the near-surface layers. For the sample number 1 it amounts to 920 *HV* – 950 *HV* and spreads to the depth up to 60 *μm*, and for the sample number 2 it amounts to 690 *HV* – 720 *HV* and spreads to the depth up to 30 *μm*. The microhardness of both samples gradually decreases with deepening and at the depth of 130 *μm* and 100 *μm* it corresponds to the substrate microhardness – 180 *HV*.

Decrease of depth and microhardness of the hardened layer in the sample number 2 can be explained by the fact that during stage-by-stage treating with EEAC the discharge energy is reduced gradually, from W_p = 2.83 *J* to 0.9 *J* and 0.1 *J*, and the heat affected zone decreases gradually, so tempering, i.e. heating of the heat-treated alloy below phase change temperature, takes place in the already hardened layer.

Thus, the stage-by-stage cementation gives the following results:

- surface layer roughness reduces from *Ra* = 4.79 *μm* to *Ra* = 1.10 *μm* and from *Rz* = 13,62 *μm* to *Rz* = 3,14 *μm*;
- microhardness in the "white layer" (a subsurface layer with higher hardness) reduces from 920 *HV* – 950 *HV* to 690 *HV* – 720 *HV*;
- total depth of the zone of the surface layer with higher hardness reduces from 130 *μm* to 100 *μm*.

Improvement of quality of the cemented layer by applying soft antifrictional materials

EEAC was carried out on the two portable devices for EEA-treatment each equipped with a manual vibrator. The first one is "Elitron-22A" that provides the discharge energy over a range of 0.1–0.53 *J*; and the other one is "Elitron-52A" that has higher power and provides discharge energy up to 6.8 *J*.

EEAC process was carried out automatically on a special device in different modes within discharge energy range (W_p) from 0.1 *J* to 6.8 *J*.

The special samples were used for the research. The samples were made of 40H (GOST) steel in the shape of a coil consisting of two 50 *mm* in diameter discs, each 10 *mm* wide, connected to each other with a spacer 15 *mm* in diameter and having two process sections of the same diameter (Fig. 8). Before being treated with EEAC the surfaces were polished up to *Ra* = 0.5 *μm*. The samples were fixed in the chuck of the turning machine,

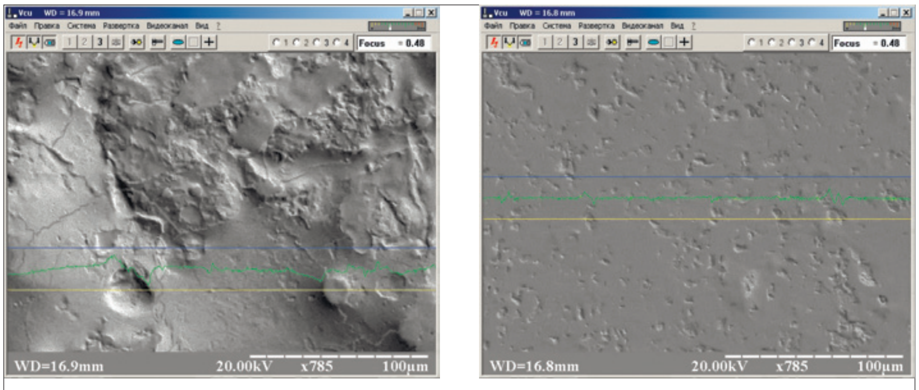


Fig. 5. Surface zones of the samples number 1 (a) and number 2 (b)

Table 4. ***Initial surface roughness of samples made of 20 steel***

Value of surface roughness in certain points [*μm*]						Roughness mean value [*μm*]	
Ra							
0.70	0.39	0.51	0.59	0.67	0.45		
Rz						*Ra*	*Rz*
2.00	1.11	1.46	1.58	1.96	1.35	0.55	1.58

Table 5. ***Surface roughness of samples made of 20 steel after EEAC treatment at the discharge energy of W_p = 2.83 J***

Value of surface roughness in certain points [*μm*]							Roughness mean value [*μm*]	
Ra								
5.10	5.00	4.64	4.43	4.49	5.20	4.70		
Rz							*Ra*	*Rz*
14.42	14.14	13.40	12.50	12.70	14.70	13.52	4.79	13.62

Table 6. ***Surface roughness of samples made of 20 steel after stage-by-stage cementation at the discharge energies of W_p = 2.83 J; 0.9 J and 0.1 J***

Value of surface roughness in certain points [*μm*]							Roughness mean value [*μm*]	
Ra								
1.10	1.14	0.98	1.21	0.90	1.29	1.11		
Rz							*Ra*	*Rz*
3.05	3.23	2.77	3.42	2.56	3.76	3.18	1.10	3.14

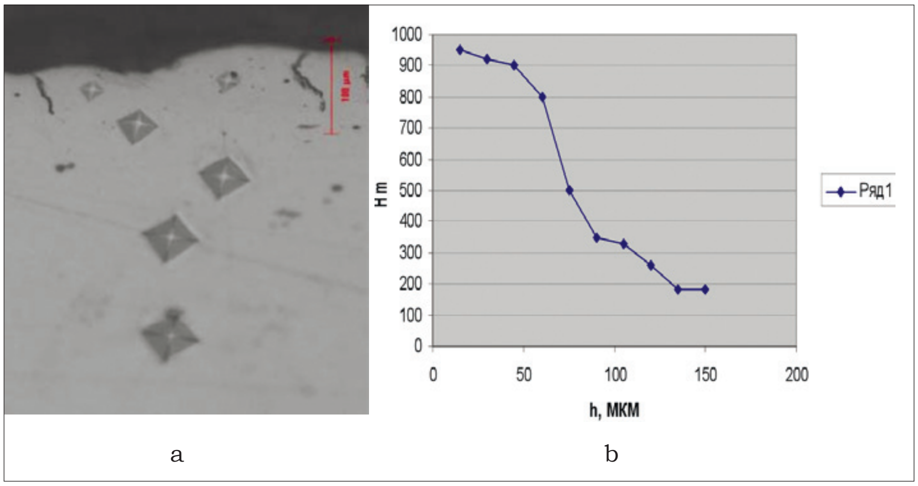


Fig. 6. Microslice (a) and distribution of microhardness in the surface layer of 20 steel of the sample number 1 (b)

then EEAC, alloying with silver and copper and NUFM processing were carried out. The surface roughness was measured with a profilograph-profilometer mod. 201 manufactured by "Kalibr" factory.

Results of the investigation of two series of 40X steel samples are represented below: 1 - cementation, alloying with silver, NUFM processing; 2 - cementation, alloying with copper, NUFM processing.

The results of the surface roughness measurements are represented in Table 7 and the results of durometric investigations are shown in Figures 9 and 10.

Fig. 9 shows the microslice and microhardness distribution in the sample of series 1. As can be seen from the Figure, on the surface of the sample there is a layer up to 35 *µm* deep with hardness of about 80–90 HV, which hardness is lower than the substrate microhardness (220 *HV*). The microhardness gradually increases with deepening and at the depth of ca. 60 *µm* it reaches its maximum value of 470 HV, and then it gradually decreases again and at a depth of 100 *µm* it corresponds to the substrate microhardness.

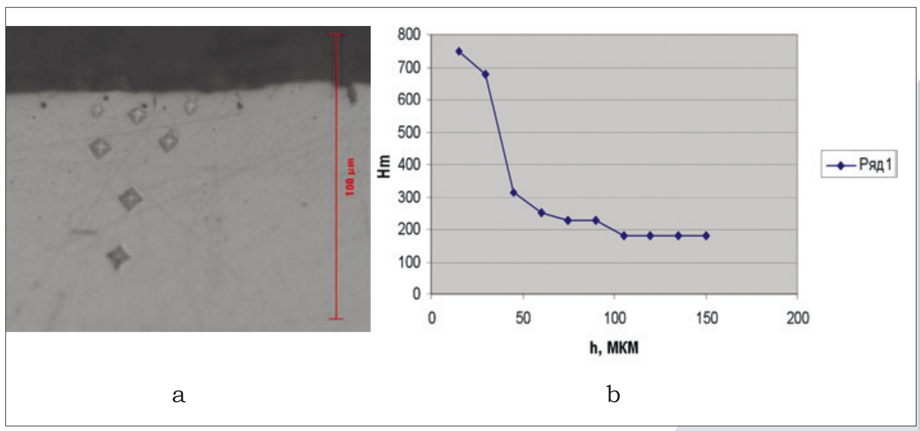


Fig. 7. Microslice (a) and distribution of microhardness in the surface layer of 20 steel of the sample number 2 (b)

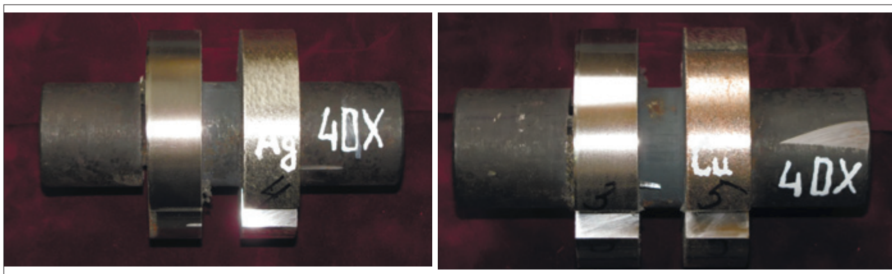
It should be noted that the sample diameter increased by 0.04 *mm* after EEA with silver and decreased by 0.02 *mm* after NUFM processing.

Fig. 10 shows the microslice and microhardness distribution in the sample of series 2. As can be seen from the Figure, on the surface of the sample there is a layer up to 40 *µm* deep with hardness of about 140–170 *HV*, which hardness is lower than the substrate microhardness (220 *HV*). The microhardness gradually increases with deepening and at the depth of ca. 75 *µm* it reaches its maximum value of 510 *HV*, and then it gradually decreases again and at a depth of 120 *µm* it corresponds to the substrate microhardness.

When assembling the hub and the shaft, soft antifrictional material, which lies between the hard hub surface and the hard EEAC-generated shaft sublayer, undergoes deforming and penetrates into all holes eliminating asperities and imperfections of the surfaces of the mating parts. As a result the area of the mating surfaces of the hub and the shaft increases considerably (up to 100 %), thus causing increase of the Joint tightness as well as increase of the friction force at moving and torsional loads, which finally increases reliability and durability of the Joint.

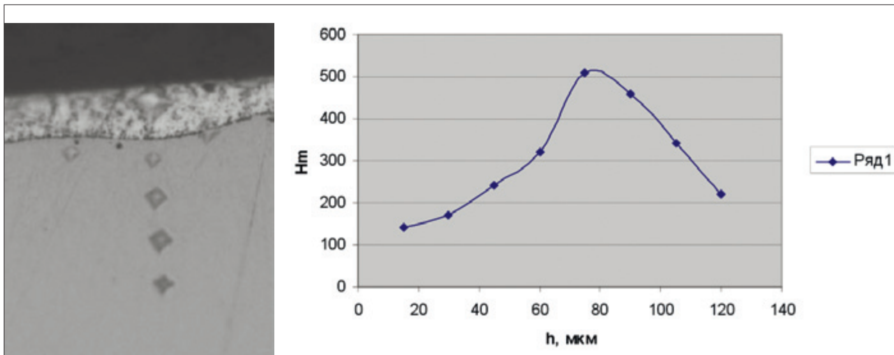
Table 7. ***Surface roughness of two series of samples***

EEA with silver								
Value of surface roughness in certain points [*µm*]							Roughness mean value [*µm*]	
Ra								
0.59	0.86	1.27	0.47	1.33	0.76	0.59		
Rz							*Ra*	*Rz*
1.68	2.44	3.59	1.33	3.76	2.14	1.68	0. 88	2.49
EEA with copper								
Value of surface roughness in certain points [*µm*]							Roughness mean value [*µm*]	
Ra								
0.55	0.65	0.91	0.62	0.87	0.71	0.51		
Rz							*Ra*	*Rz*
3.05	2.40	2.35	2.64	2.48	3.01	3.25	0. 80	3.19



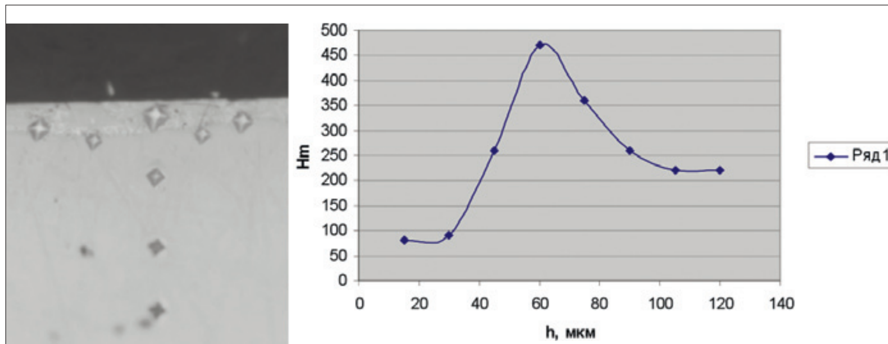
a b

Fig. 8. Steel samples for investigation of result of EEAC and EEA:
a – with silver and b – with coppe



a b

Fig. 9. Microslice (a) and microhardness distribution in the 40H steel surface layer after EEAC, EEA with silver and NUFM processing (b)



a b

Fig. 10. Microslice (a) and microhardness distribution in the 40H steel surface layer after EEAC, EEA with copper and NUFM processing (b)

Conclusions

1. EEA cementation of the press-fit connections followed with NUFM processing can be an effective method for improvement of fatigue strength and for fretting corrosion prevention. Such treatment allows forming a surface layer with microhardness of 900–1350 *HV*, which gradually decreases to the hardness of the substrate metal, the depth of 10 μm to 380 μm, which depends on the discharge energy and production speed, and surface roughness Ra 0.2 μm to 3.2 μm.

2. Roughness of the surface layer that was cemented using EEA can be reduced by applying stage-by-stage cementation, but at that the surface microhardness and depth of the hardened layer are reduced as well.

3. Applying soft antifrictional materials onto surface of the EEAC layer with subsequent NUFM treatment allows improving quality of the press-fit connection and thus increasing area of contact surfaces, as in this case resistance of the surface layer deformation when press-fitting is reduced.

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