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METALLOGRAPHIC STUDIES OF SAMPLES MADE OF 65G STEEL SUBJECTED TO COMPLEX TREATMENT BY ELECTROSPARK AND VIBRATION ARC DISCHARGES USING CERMET POWDERS

Research article

Abstract

In this paper, some physical and mechanical properties of the surface layer of widely used steel 65G in mechanical engineering and agriculture, subjected to plasma treatment. The research is aimed at increasing the service life of parts and friction units of machinery and equipment. It is shown that vibroplasma surface treatment with the use of metal-ceramic powders allows to increase the hardness of the surface layer by more than 3 times. The elemental composition and microstructure of the sample surface were studied. The microstructure of the base material of the coated samples corresponds to the structure of the reference sample. The microstructure of the reference sample corresponds to the microstructure of low-carbon (pre-eutectoid) steel after annealing. Grained ferrite-pearlite structure with a predominance of ferrite. In the process of vibro plasma treatment in the surface layer of the sample is formed of 3 zones: the zone of deposited metal-ceramic material, a hardened area of the surface layer mixed with elements of the base and filler material and heat affected zone.

Keywords: resource, wear resistance, plasma.

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МЕТАЛЛОГРАФИЧЕСКИЕ ИССЛЕДОВАНИЯ ОБРАЗЦОВ ИЗ СТАЛИ 65Г, ПОДВЕРГНУТОЙ КОМПЛЕКСНОЙ ОБРАБОТКЕ ЭЛЕКТРОИСКРОВОЙ И ВИБРОДУГОВОЙ РАЗРЯДАМИ С ПРИМЕНЕНИЕМ МЕТАЛЛОКЕРАМИЧЕСКИХ ПОРОШКОВ

Научная статья

Аннотация

В данной работе исследованы некоторые физико-механические свойства поверхностного слоя широко применяемой стали 65Г в машиностроении и сельском хозяйстве, подвергнутой плазменной обработке. Исследования направлены на повышение ресурса работы деталей и узлов трения машин и оборудования. Показано, что виброплазменная обработка поверхностей с применением металлокерамических порошков позволяет увеличить твердость поверхностного слоя более чем в 3 раза. Исследованы элементный состав и микроструктура поверхности образцов. Микроструктура основного материала образцов с покрытиями соответствует структуре эталонного образца. Микроструктура эталонного образца соответствует микроструктуре малоуглеродистой (доэвтектоидной) стали после отжига. Зернистая феррито-перлитная структура с преобладанием феррита. В процессе виброплазменной обработки в поверхностном слое образца образуется 3 зоны: зона наплавленного металлокерамического материала, упрочненная зона поверхностного слоя с перемешанными элементами основного и присадочного материала и зона термического влияния.

Ключевые слова: ресурс, износостойкость, плазма.

1. Introduction

Today all over the world there is a tough struggle for competitive and popular products. The same applies to mechanical engineering and agricultural production. Many parts and assemblies of machines and mechanisms operate in aggressive environments and environments with abrasive particles. As a result, they quickly lose their efficiency. There is a need to replace them with new parts and components, leading to unplanned downtime, financial costs and loss of production cycle time. There is an increase in the cost of production and a decrease in profits. Products are losing their demand.

The use of materials such as heat-strengthened steel 65G with a hardness of HRC 50 for the manufacture of parts also does not solve the problem. Restoration of worn parts by traditional repair technologies does not ensure the competitiveness of products. There is only one way out - the use of technologies for hardening the surfaces of machine parts and mechanisms with the use of concentrated energy flows. Among them, the most simple and affordable are plasma technologies for strengthening worn surfaces by vibration methods [1], [2], [3], [4], [5]. The analysis shows that, despite the practical applicability of plasma technologies, there are unlimited opportunities for their improvement. The fact is that today the physical-mechanical and physical-chemical processes under the influence of concentrated energy flows on the surface of the processed products have been studied only partially. There is no optimization and simulation of the process. Plasma chemical processes occurring in the plasma medium itself have not been studied. There are no full-fledged studies of the interaction of the plasma itself with sprayed materials, alloyed elements and the environment. Therefore, any research of plasma technologies, which have an applied nature, are relevant.

In this paper, the energy of electric spark and vibroarc discharges with the use of cermet powders in the process of hardening are selected as a concentrated energy flow. This technology will allow the introduction into the structure of the surface layer a list of alloying elements of carbide materials, carburization of this layer and the creation of a hardened layer consisting of oxides, carbides, borides and nitrides [6]. The difference between the energy of electric spark and vibro-arc discharge installations from the energy of other sources: laser, plasma (plasma torches) and electron beam installations is that it allows for complex surface treatment. When this occurs, the thermal diffusion hardening of the substrate by the depth of detail doping in the surface layer of the component elements of the carbide electrode material, and a hardened layer is a plasma-chemical reaction products the elements of the electrode material as with the base surface, and with the environment. A hardened layer appears with a melted base, mixed electrode material and products of carbide compounds of various oxides, nitrides and carbides. The next difference is that the cost of electric spark and vibroarc discharge installations is much lower than the cost of the above installations. Therefore, such an indicator as the ratio of price and quality of the products obtained for this work is also important.

Methods of hardening of surfaces of products by electric spark and vibroarc discharges have certain advantages in comparison with other plasma methods. They do not overheat the base of the product, but only allow you to change the physical-mechanical and physical-chemical properties of the surface layer of the material. In this case, it is possible to harden the surface layer with alloying elements of carbide materials. As a result of plasma chemical reactions, a new structure of the surface layer of the part material is formed not only with the alloying of the electrode elements, but also with the appearance of various compounds. At the same time, not only the elements of the electrode and the material of the part participate in the process. The plasmochemical process takes place in the atmosphere of the environment, which is usually not only air. It can be dust particles of products of a particular production, and various gases. In addition, any environment has a certain humidity. It should also be taken into account that the plasma-chemical process in the vibration method is intermittent. In the interval between discharges, the process of structural changes in the material continues, the formation of new compounds and, possibly, new chemical elements appear. The next discharge interacts with this" ensemble " of chemical elements and various compounds. Then this process is repeated again. Therefore, in recent years, scientists have been paying more and more attention to the study of plasma technologies by vibration methods [7], [8].

2. Methods and materials

The studies were carried out on samples of 65G steel 40x40 mm in size with a thickness of 4 mm. Samples for research are cut from the plow share of the tillage equipment. The ploughshare is made of 65G steel with a hardness of 50 HRC. Number of samples 7 pcs. Sample No. 1 - the initial sample, sample No. 2 - the sample with vibration-arc treatment in the presence of PG-10N-01 carbide powder, sample No. 3 - the sample with vibration-arc and electric-spark treatment in the presence of 70% PG-10N-01 carbide powder and 30% boron carbide , sample No. 4 - with electric spark and vibration arc treatment in the presence of carbide powder PG-10N-01, sample No. 5 - a sample with a vibratory arc and electric spark treatment, sample No. 6 - with an electric spark treatment and sample No. 7 - a sample with a vibratory arc treatment. Electrodes for electric spark processing were VK6 tungsten-cobalt rods with a diameter of 6 mm. During vibratory arc treatment, the electrodes were copper-graphite rods with a diameter of 8 mm. Ceramic-metal powders were selected carbide powders PG-10N-01 and boron carbide. Cermet powders were introduced into the discharge zone separately and as a mixture.

- For metallographic studies, metallographic plates were prepared in advance. Preparation of the cuts included cutting the sample, fixing it, surface preparation and chemical etching.

- Cutting of the sample of the required size was carried out on a manual cutting machine "Labotom-3 Struerus" with water cooling, which prevents changes in the structure in the process of sample preparation.

- Fixing of the sample was carried out on an automatic electrohydraulic press "CitoPress-1 Struerus" by pressing into a cylindrical washer made of polymer resin with a dimeter of 40 mm.

- Preparation of the surface of the fixed sample consisted in its mechanical processing in order to obtain a flat surface of the required quality. Machining included grinding and polishing on a grinding and polishing machine "LaboPol-5 Struerus".

- Surface quality control was carried out visually and using a microscope. The prepared metallographic microsection has reached the mirror-like surface free of scratches and foreign debris.

- Chemical etching to reveal the structure of steel samples and coatings was carried out with 4% alcohol solution of nitric acid (HNO3), samples and coatings of non – ferrous metals-with concentrated alcohol solution of nitric acid.

- Determination and photographing of the microstructure was performed using an inverted metallographic microscope Olympus GX51 with magnification from 50x to 1000x.

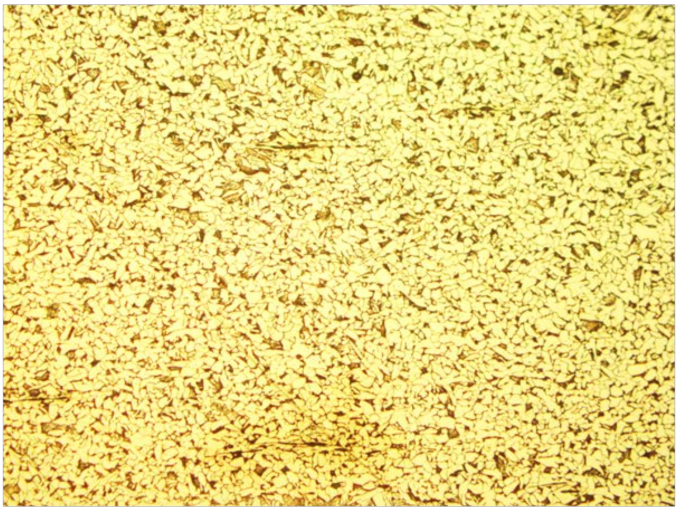
- Microhardness was measured on a KMT-1 computerized microhardness tester according to the Vickers scale in accordance with GOST R ISO 6507-1-2007. Measurements of microhardness were made by the depth of section of the samples. The measurement step was selected individually for each sample in such a way as to obtain the most accurate distribution of microhardness over the depth of section. The microhardness value was averaged over three prints. The method of metallographic studies is more fully described in [9].

-The elemental composition of the samples was studied using a scanning electron microscope
(SAM) “EVO 50 XVP” company “Zeiss "with elemental analyzers" INCA Energy-350 " and "INCA Wave-500".

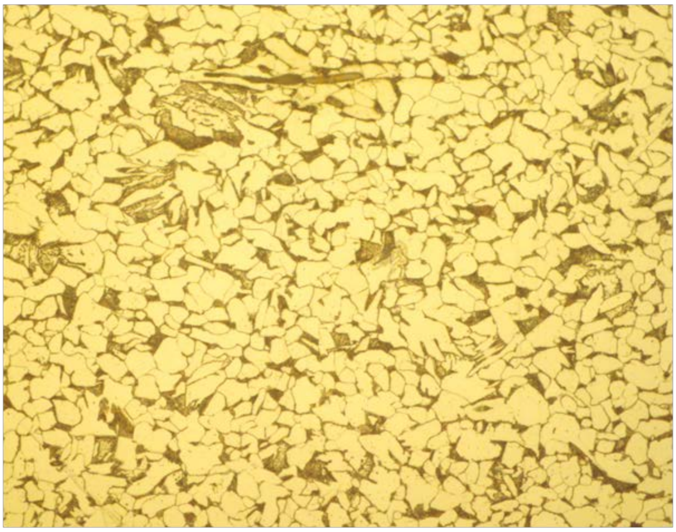
3. Results

Figure 1 shows photographs of the microstructures of the initial sample at various magnifications. The microstructure of the reference (initial) sample corresponds to the low-carbon microstructure (pre-eutectoid) steel after annealing. Granular ferrite-pearlite structure with a predominance of ferrite. A comparison of the microstructures of the reference sample and the basic material of the samples with coatings showed the correspondence of their structures.

The microstructure of the initial sample was investigated and showed that it does not correspond to the structure of the claimed steel grade 65G in the section "Methods and materials" (further research on microhardness will confirm this). Steel 65G, especially at a hardness of 50 HRC, should have a troostite structure, and the hardness (microhardness), even according to the most approximate estimates, should be at least 400-500 HV. It appears that, despite the manufacturer's declared steel grade, ploughshares are made of steel of a much worse grade, which often happens with domestic (Russian) manufacturers.



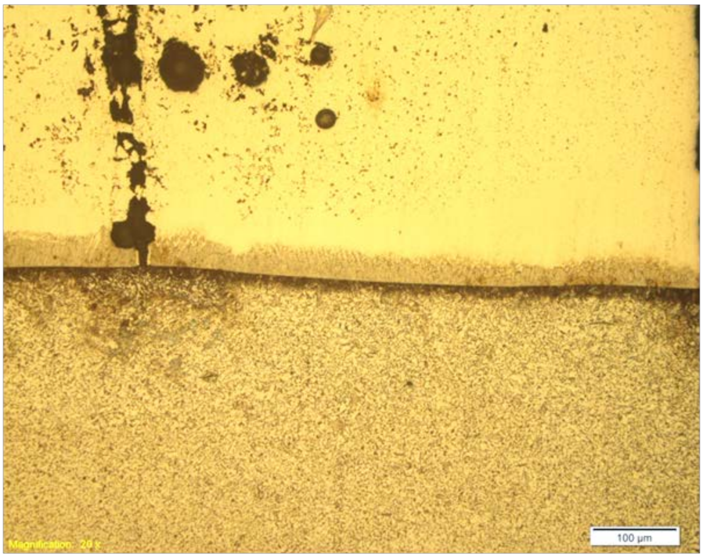
Microstructure of the original sample (x200)



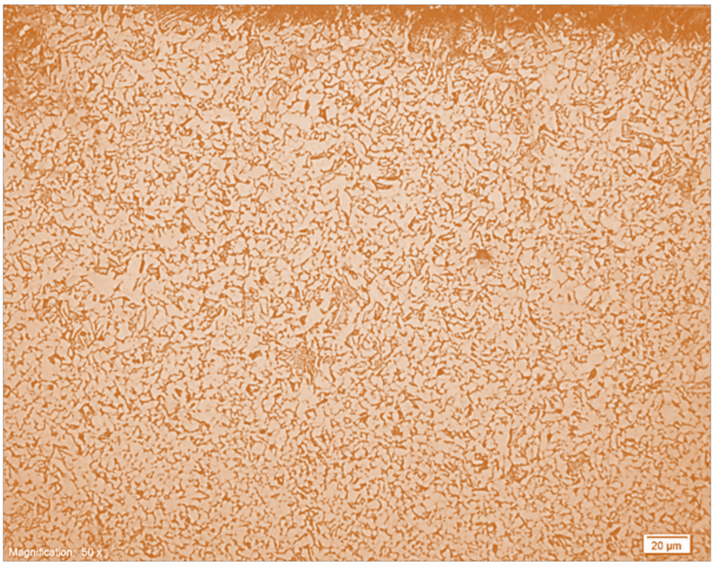
Microstructure of the original sample (x500)

Figure 1 – Photos of microstructures of the initial sample at different magnifications

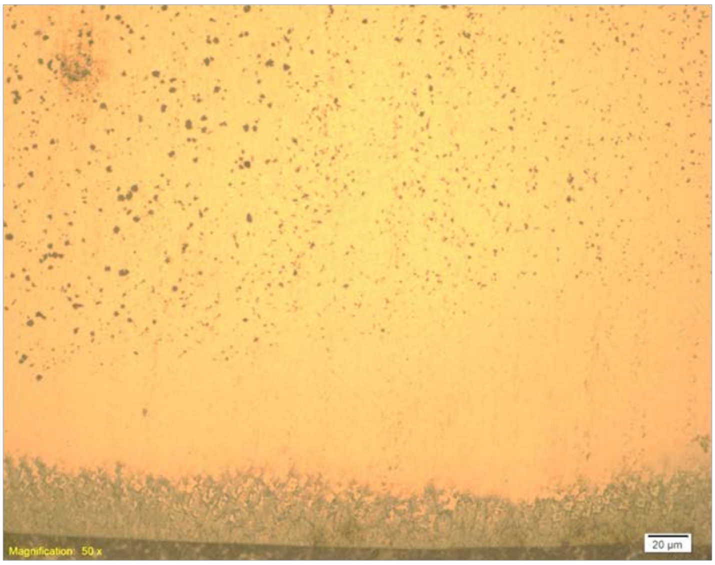
Photos of microstructures of sample No. 2 are shown in figure 2. In the sample there is no pronounced zone of thermal influence (ZTI). This is due to the fact that all the energy of the vibro-arc discharge was spent on plasma-chemical treatment of the metal-ceramic powder and hardening of the surface layer of the material.



Microstructure of the deposited layer and the base of sample No. 2 (x200)



Microstructure of the base and the zone of thermal influence of sample No. 2 (x500)

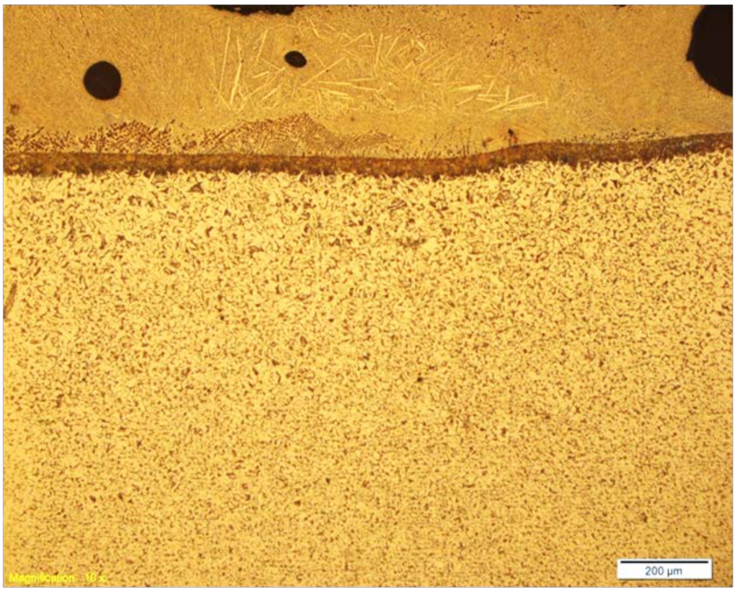


Microstructure of the deposited layer of sample No. 2 (x500)

Figure 2 – Photos of microstructures of sample No. 2 with vibro-arc treatment in the presence of PG-10N-01 carbide powder at various magnifications

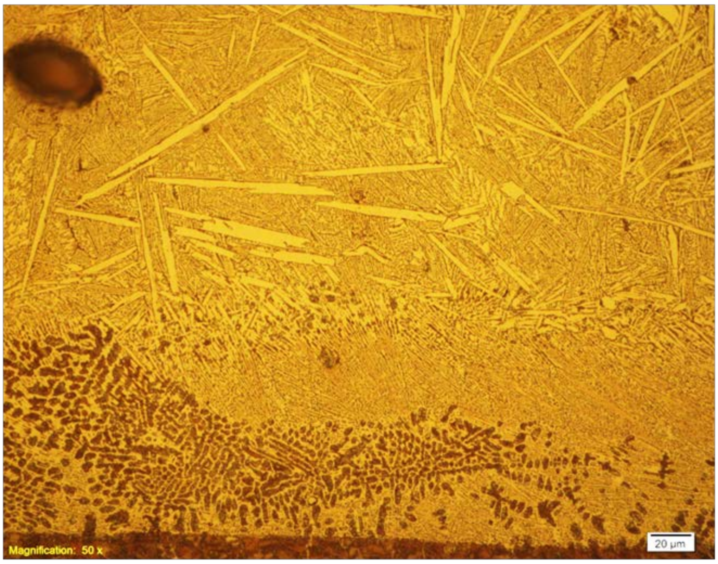
In the sample there is no pronounced zone of thermal influence (ZTI). Changes in the structure are noticeable only in the layer immediately adjacent to the surfacing with a depth of not more than 20 microns. It can be seen that this is a hardened surface layer. The structure of the coating is not revealed. Only the layer directly in contact with the base material and formed as a result of mixing of the base and filler material can be etched. The presence of dark specks and grains in the deposited layer means that during processing, atomized particles of the copper graphite electrode were introduced into the deposited layer.

Figure 3 shows photos of microstructures of sample No. 3 with vibro-arc and electric spark treatment in the presence of 70% of PG-10N-01 carbide powder and 30% of boron carbide. In the heat affected zone, finely dispersed quenching structures are observed. The thickness of the heat affected zone, visually determined by the change in structure, is 0.05 mm. For a more accurate determination of the structure and properties of the heat-affected zone, it is recommended to study the microhardness not only of the coating, but also of both the heat-affected zone and the base material zone. In the structure of the coating, 3 components can be distinguished. The dark grains that are observed near the base material are doped perlite. White needles and eutectic are structural components of filler material. It must be assumed that this effect is introduced into the discharge zone mixture of carbide powder PG-10N-01 and boron carbide. It is seen that in the deposited layer there are also particles of a copper graphite electrode. When studying microhardness, it is recommended to pay attention to the zone in which hardness is determined: in the zone containing perlite, or only in the zone of the structure of the deposited material.



Microstructure of the deposited layer and the base of sample No. 3 (x100)

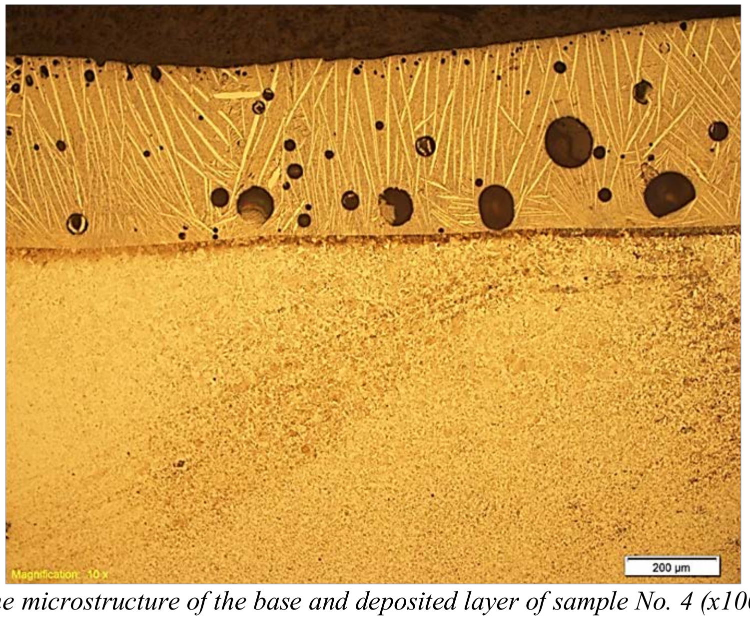
Microstructure of the zone of thermal influence of sample No. 3 (x500)



Microstructure of the deposited layer of sample No. 3 (x500)

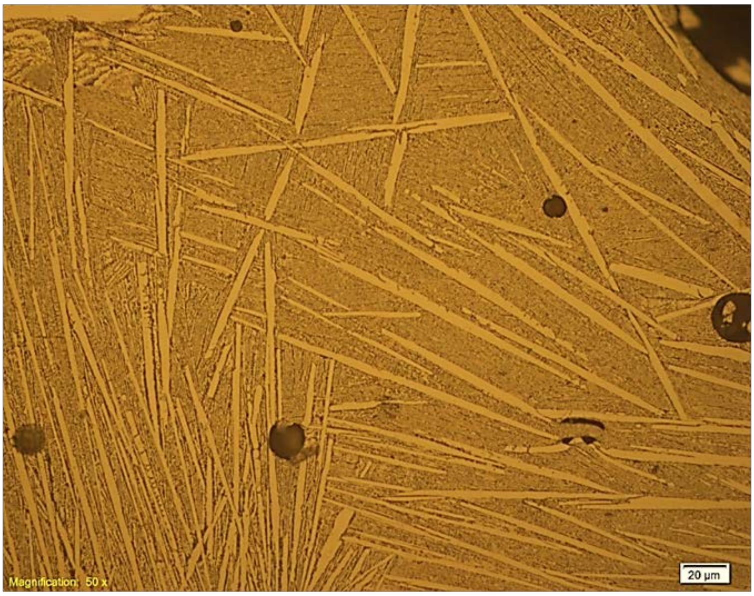
Figure 3 – Photos of microstructures of sample No. 3 with vibro-arc and electric spark treatment in the presence of 70% of PG-10N-01 carbide powder and 30% of boron carbide at various magnifications

Figure 4 shows photographs of the microstructures of sample No. 3 with electric spark and vibratory arc treatment in the presence of PG-10N-01 carbide powder. The depth of the ZTI, visually determined by the change in structure, is 0.4 mm. The microstructure of the ZTI is large white grains of ferrite and dark areas of perlite. Large grains indicate heating to a high temperature close to the Ac3 point (1000 - 1100 ° C) and slow cooling. For a more accurate determination of the structure and properties of ZTI, it is recommended to study the microhardness of not only the coating, but the microhardness of both ZTI and the base material. White needles and eutectics, the structural components of the filler material, are observed in the coating structure. By the predominant direction of the needles, one can judge the direction of heat removal into the body of the part. Long needles, stretching across almost the entire deposited layer, indicate slow cooling.



The microstructure of the base and deposited layer of sample No. 4 (x100)

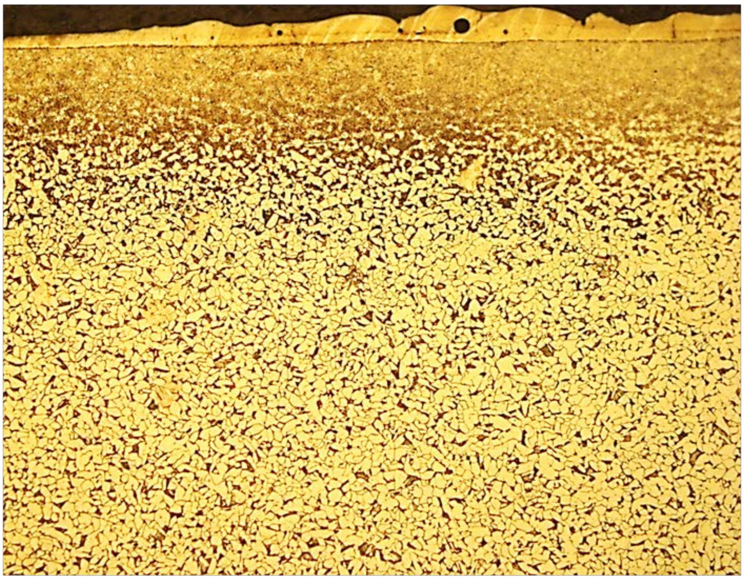
The microstructure of the heat-affected zone of sample No. 4 (x500)



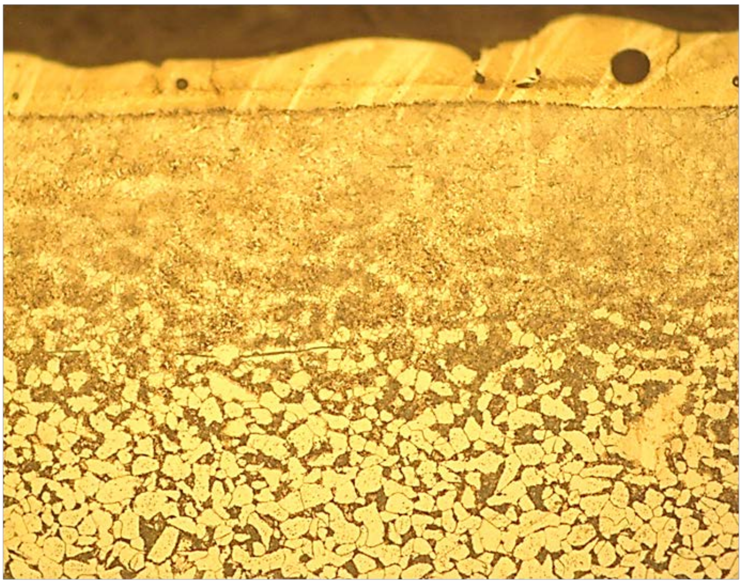
The microstructure of the deposited layer of sample No. 4 (x500)

Figure 4 – Photographs of microstructures of sample No. 4 with electric spark and vibration arc treatment in the presence of PG-10N-01 carbide powder at various magnifications

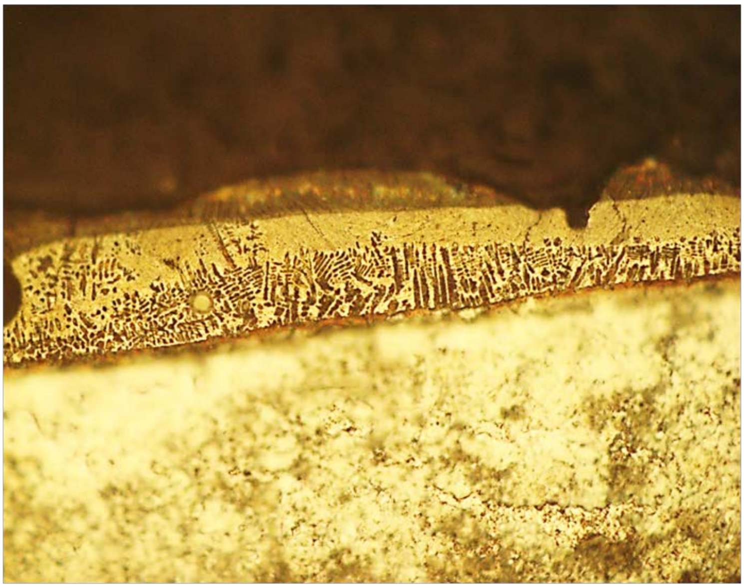
Figure 5 shows photographs of the microstructures of sample No. 5 with vibration arc and electric spark treatment. The depth of the ZTI, visually determined by the change in structure of sample No. 5 is 0.1 - 0.15 mm. The microstructure of the ZTI is sorbitol tempering. The coating of sample No. 5 has the structure of a zaeutectoid steel. The dendritic structure of crystallites indicates a relatively slow cooling of the surface layer. The boundaries of both vibro-arc and electric spark treatment of the sample surface are clearly visible.



The microstructure of the ZTI sample No. 5 (x100)



The microstructure of the ZTI sample No. 5 (x500)



The microstructure of the coating material of sample No. 5 (x500)

Figure 5 – Photographs of the microstructures of sample No. 5 with vibration arc and electric spark treatment at various magnifications

Here are some of the results of the study of the microhardness of samples in the depth of the material (Fig. 6x7). From the graphs it can be seen that the microhardness of the surfaces of products after their treatment with vibro-arc and electric spark discharges even without the presence of metal-ceramic powders increases by more than 3.0 times.

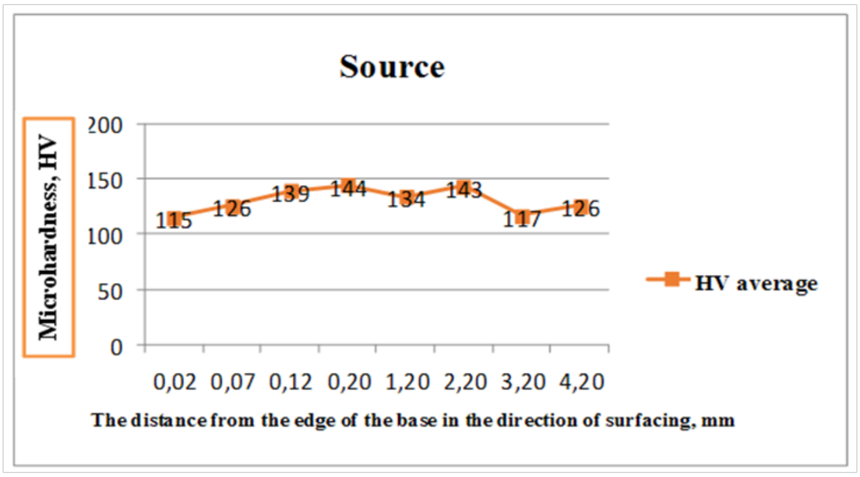


Figure 6 – Microhardness of the initial sample in terms of material depth

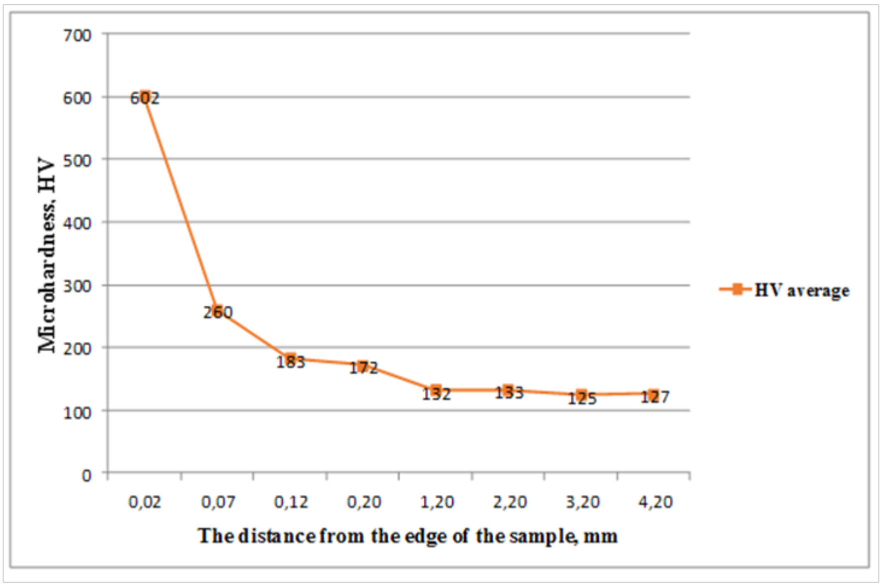


Figure 7 – Microhardness of sample No. 5 treated with vibro-arc and electric spark discharges in the depth of the material

Data on the elemental composition of the modified surface layer are presented in table 1. It can be seen that vibro-plasma treatment dramatically changes the structure of the surface layer of the product. The formation of a new structure of the surface layer of the material of the part occurred not only with alloying of the electrode elements, but also with the appearance of various compounds.

Table 1 – Title

Element	Source sample		Sample with spark machining		Sample with vibro-arc treatment	
	Weight, %	Atomic, %	Weight, %	Atomic, %	Weight, %	Atomic, %
C	5.60	21.59	12.55	40.01	20.24	43.88
O	-	-	4.77	11.41	15.91	25.89
Si	0.22	0.36	-	-	0.88	0.81
Mn	0.86	0.72	0.58	0.41	2.43	1.15
Fe	93.32	77.33	58.14	39.87	60.37	28.15
Na	-	-	0.45	0.75	-	-
Cl	-	-	0.26	0.29	-	-
V	-	-	0.17	0.13	-	-
Co	-	-	4.92	3.20	-	-
Sn	-	-	1.32	0.42	-	-
W	-	-	16.83	3.51	-	-
Ca	-	-	-	-	0.17	0.11

Note: During electric spark treatment, the electrode is a tungsten-cobalt rod, while the vibration-arc treatment is performed on a copper-graphite rod.

4. Conclusions

1. The surface layer formed by vibroplasma is a new composite structure. The upper thin layer consists of anode material modified by elements of the cathode material and the interelectrode medium. Under the top layer is a modified hardened layer consisting of a mixture of anode and cathode materials. Underneath is a heat affected zone formed as a result of pulsed heat. Its structure differs from the structure of the material of the workpiece by the structure and grain size. The hardening of the base material in the depth of the part during electrospark machining occurs by 0.5 - 1.0 mm, during vibration arc processing - up to 3-4 mm.

2. The presence of ceramic-metal powders in the discharge zone during vibroplasma treatment introduces significant changes in the technological process of hardening the surface layer of the product and allows one to obtain higher physicomechanical parameters of the product surface. In this case, the microhardness of the surface layer of the product increases by more than 3.0 times. Considering that hardness and wear resistance are directly proportional, it can be argued about the possibility of increasing the life of the product by plasma technology by 3.0 or more times.

3. The results will be useful, both in scientific and practical terms for understanding the essence of the processes under the influence of concentrated energy flows on the surface.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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