SURFACE HARDENING OF METALLIC MATERIALS BY USE OF COMBINED MAT-FORMING TREATMENT AND ELECTROSPARK DOPING

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Abstract: Analysis of the structural state and phase composition of surface metal layers after combined treatment of steel which includes preliminary surface plastic deformation of the workpiece, electrospark doping with use of rotating disk electrode 2 mm thick, made of WC-Co hard alloy and subsequent surface ball smooth rolling, has been performed. It was shown that the use of combined treatment provides a gradient-layered structure with low surface roughness. Phase composition of the obtained layer consist of ferritic α-Fe phase and a number of carbide phases formed during the interaction of the electrode material with steel: F_3W_3C, WC and W_2C semi-carbide. Wear resistance of the material after treatment exceeds similar properties of the original carbon steel up to 4 times.

Keywords: ELECTROSPARK DOPING, SURFACE PLASTIC TREATMENT, MICROSTRUCTURE, HARDNESS, WEAR RESISTANCE.

1. Introduction

The improving and raise of competitiveness of engineering products require the use of new technological processes, allowing to increase the service life and reliability of equipment in the conditions of increasingly stringent requirements for the operational characteristics of products. A promising way for the improvement of the bearing capacity of structural materials is to strengthen their surface layers or to deposit strengthening coatings, that increase the surface strength and wear resistance and, as a consequence, the operational lifetime of the construction and tool materials.

Various methods have been developed to enhance wear resistance of parts of friction units. Each of the currently known methods has its merits and deficiencies limiting their scope. The most common ways to restore the worn surfaces of metal parts at the present time are various types of gas-thermal coating and welding deposition. However, during welding deposition, a large amount of heat is supplied to the part, which leads to skellering and the need for subsequent processing.

Recently electrospark doping (ESD) is becoming more common for obtaining the coatings with high wear resistance of the metallic materials

The spark discharge occurs only in local volume in microscopically small volumes during 100–400 microseconds, when in the local metal-coating contact zone the high-temperature plasma regions appear, which provides the necessary adhesion of the formed coating to the base material. Very high densities of energy flows are realized in this process without the noticeable heating of the specimen under treatment. The process is characterized by an essential inequilibrium, so it is possible to obtain fundamentally new materials in the surface layers of the coatings, which is impossible under the usual equilibrium conditions [1, 2].

The method of electrospark doping differs from other surface treatment methods in its simplicity, reliability, and cost-effectiveness. Depending on the anode material, an extended surface layer with high strength, tribological, and other properties is formed on the work piece [3, 4].

For the instantiation of the ESD processes the devices containing manual or mechanical end electrode vibrators and generators of electrical voltage pulses of a certain shape and duration that are applied to the spark gap (between the electrode and the surface of the workpiece) [5] have found the greatest distribution.

However the ESD methods have some disadvantages as follows: high surface roughness of the treated surface of a workpiece, the presence of cracks, discontinuities and micropores. Besides, such devices have low productivity - up to 3 cm^2/min.

To reduce the roughness introduced by the electrospark doping, the methods based on the mechanical impact on the modified surface are used (surface-plastic strain, running the ball, nonabrasive ultrasonic treatment, etc.), as well as treatment with concentrated energy flows (plasma flow, electron and ion beams, laser beams) [6-9].

Significantly higher performance and surface condition are provided by mechanized devices with a rotating disk electrode, which is pressed against the material of the workpiece with a small controlled force [10].

An effective type of surface treatment of metallic materials is also surface plastic deformation [6, 7]. As a result of its application, due to work hardening in the surface layers, the shape and size of crystal grains are modified, accompanied by changes in the substructure and microstructure of the metal of the surface layer. The hardness of materials increases and compressive stresses are formed, contributing to increased wear resistance and resistance to fatigue failure.

Therefore the **aim** of the present paper is to specify the effect of combined surface treatment on structure and properties of the surface layer of carbon steel subjected to mat-forming plastic processing and electrospark doping.

2. Experimental Procedure

For realization of complex processing of the axially symmetrical bodysurface, a device was developed and made (fig. 1) on the basis of turning-screw-cutting machine, allowing to combine preliminary surface plastic deformation of the workpiece and mechanized ESD process with rotating disk electrode 2 mm thick, made of WC-Co hard alloy installed in a special water-cooled unit, attached to the tool holder.

The design for the surface plastic deformation device (fig. 2) includes a main deformation tool fixed in the carriage - a ball 3 with ∅10 mm hardened to 62-65 HRC, which in the process of operation leans on the bearing 4. The force of pressing the ball 3 to the treated surface at processing is changed by changing the force of the spring 2 compression by the adjusting screw 1.

The surface treatment of the experimental samples was carried out according to the scheme: plastic surface treatment with a ball - electrospark doping - surface treatment of the applied coating.

The microstructure of the alloys was studied on the XJL-17 optical microscope. X-ray phase analysis of the samples was carried out on DRON-3 diffractometer in filtered Co-K_α radiation using step-by-step scanning in the angular range of 20÷130°. The microhardness distribution over the sample section was determined on a PMT-3 microhardness meter.

To assess the comparative wear resistance of the obtained coatings, friction tests were carried out according to the "shaft-insert body" scheme with contact force of 400 N using a M-22M friction machine while cooling a friction couple with water.

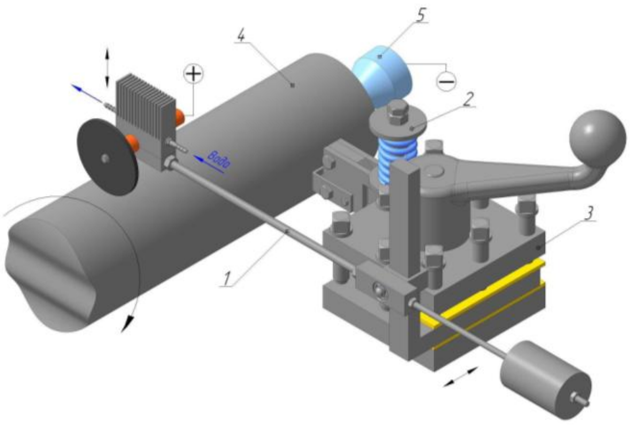


Fig. 1. Three-dimensional scheme of the device for the formation of combined wear-resistant coating: 1 - device for ESD; 2 - unit for surface plastic deformation; 3 - carriage of the turning-screw-cutting machine; 4 - machined part; 5-center

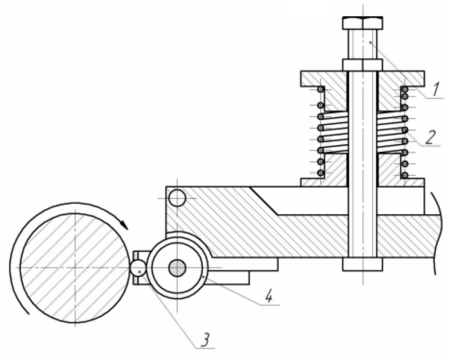


Fig. 2. The scheme of the unit for surface plastic deformation: 1 - adjusting screw; 2 - spring;3 - ball; 4 - bearing

3. *Experimental results and their discussion*

As our preliminary studies had shown [10], the optimum pressing force of the ball to the treated surface of ductile steels is 2.0÷3.5 kN. The increase in pressure leads to a violation of the integrity of the metal on the surface and the emergence of the peeling of the surface. At the same time, the hardness of the parts when rolling should not exceed 50 HRC.

The results of investigations of microhardness and material structure distribution over the depth of the sample (fig. 3, 4) showed that it can be conditionally divided into three zones. The base material I of У7 carbon steel, has a ferritic-pearlitic structure (fig. 4, a, c) with an initial hardness of HV 220÷240.

Intermediate transition layer II (fig. 4), that was formed during the primary surface plastic processing of the specimen, is located at a depth of 100÷250 μm from the surface. It differs in monotonically decreasing hardness from the surface over the layer thickness (from HV 650 to HV 250) (fig. 3) and is of distinctly more fine-grained structure compared to the base metal (fig. 4,c).

The upper layer III of maximum hardness (HV 650-1040) with a depth up to 100 μm (fig. 3, fig. 4, a, b) is formed as a result of the interaction of electrode material (BK8 hard alloy) with surface material of the sample being processed during the electrospark doping.

The layer resulting from the electrospark treatment is characterized by an extremely highly dispersed cellular substructure. According to the X-ray structure analysis and electron microscopy, cited in [1, 11, 12], the dimensional parameters that characterize the coating cellular substructure that was formed in the ESD process is of range within 20-200 nm, that provides entirely new physicomechanical properties of the materials. The separate micropores with size of up to 2 μm are observed in the coating structure too.

It is noteworthy that after the electrospark doping with the rotating electrode and the subsequent surface plastic processing of the coating obtained, the surface is characterized by sufficiently high continuity and low surface roughness, while the electrospark coatings obtained with use of devices with end electrode vibrators are usually characterized by high surface roughness of the treated surface [1, 5].

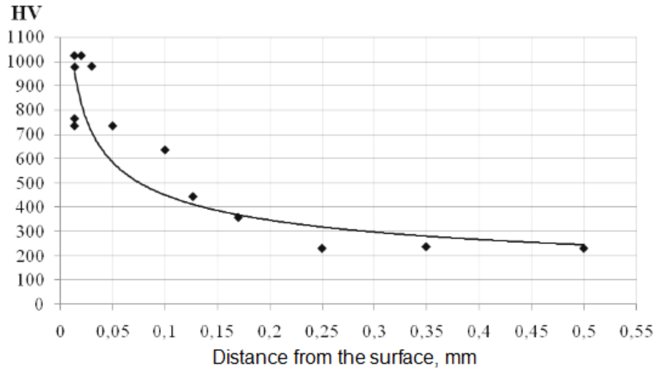
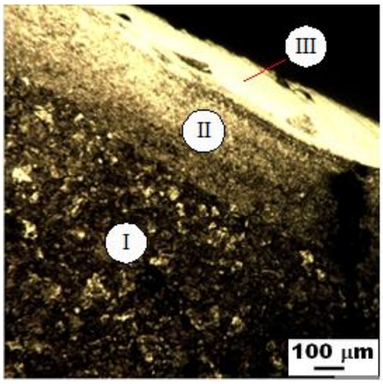
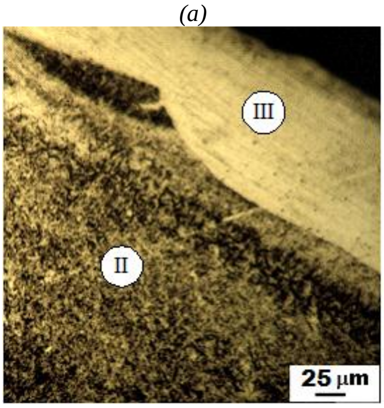


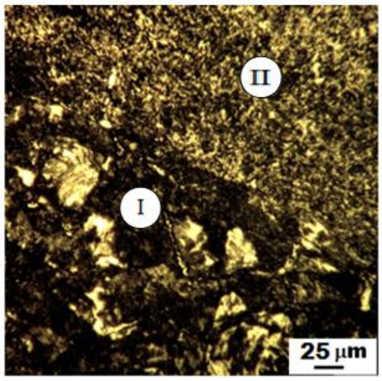
Fig. 3. Distribution of microhardness throughout the depth of the coating



(a)



(b)



(c)

Fig. 4. The microstructure of steel surface subjected to combined superficial plastic processing and electrospark doping: I – carbon steel base material; II - intermediate transition layer; III – the layer of electrospark coating

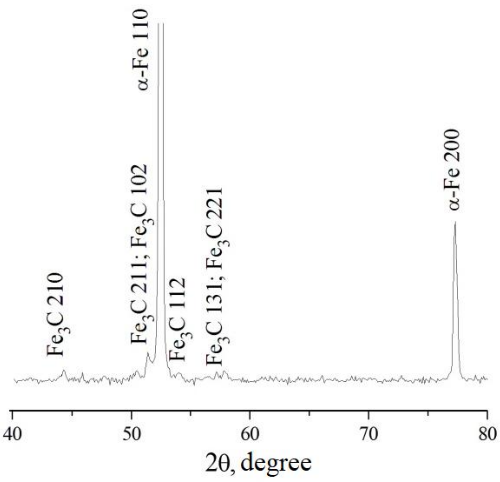
The results of X-ray spectral analysis of the initial material and the layers subjected to various types of processing (surface plastic deformation, ESD) showed that, in the initial state, У7 steel contains α-Fe and cementite Fe_3C phases (fig. 5, a). The value of the bcc lattice parameter of α-Fe is a = 0.28664 nm. The diffraction lines of the matrix α-Fe phase are narrow, which indicates a low concentration of lattice defects (fig. 5a).

X-ray diffraction lines of α-phase from the intermediate layer, obtained after surface plastic deformation, are significantly diffused (fig. 5, b). In particular, the magnitude of the physical broadening of the α-Fe diffraction line increases to the level of $\beta_{220} \approx 21\cdot10^{-3}$ rad, whereas for steel in the initial state, the value of $\beta_{220} \approx 2{,}5\cdot10^{-3}$ rad. Such increase in the value of physical broadening is associated with an increase in the concentration of lattice defects (dislocations, vacancies, etc.) in the α phase in the process of intense surface plastic deformation. The fact that the ratio $\beta_{220}/\beta_{110} \approx \mathrm{tg}\theta_{220}/\mathrm{tg}\theta_{110}$ testifies in favor of this conclusion too.

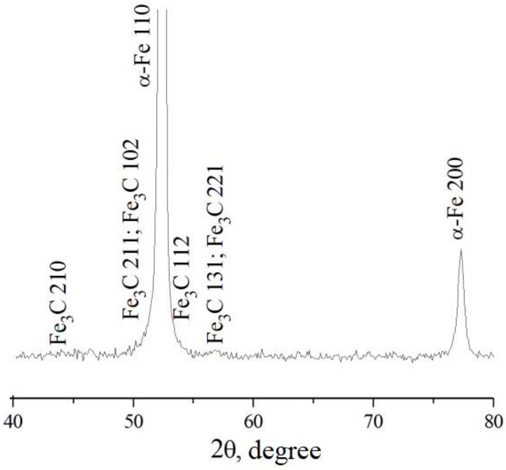
Besides, the value of the crystal lattice parameter of α-Fe significantly increases after surface plastic processingin in comparison with non-deformed steel and reaches values of 0.28679 nm. The authors of [1, 11, 13] consider that such an increase in α–Fe crystal lattice parameter can be caused by deformation-induced dissolution of cementite particles Fe_3C in the process of steel intense plastic deformation when it is rolled.

The analysis of phase composition of the samples upper layer after electrospark doping showed, that in addition to ferritic α-Fe phase, it contains a number of phases formed during the interaction of the electrode material with steel. The predominant compound is F_3W_3C carbide with a cubic lattice, WC, W_2C semi-carbide and possibly high-temperature β-W_2C carbide are fixed (fig. 5, c). The lattice parameter of the α-Fe phase increased in the alloying process from 0.28654 nm of the initial steel to 0.28689 nm for the coating surface.

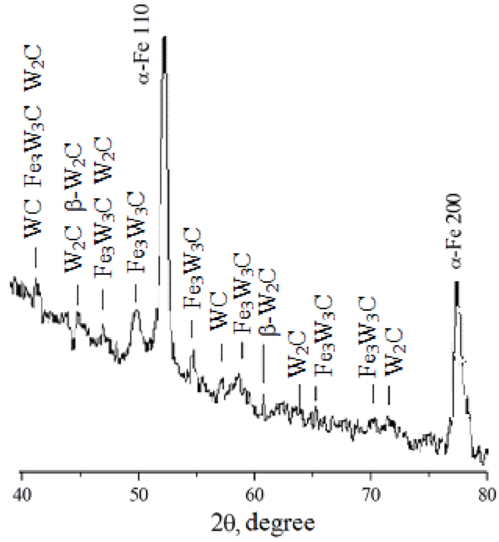
The broadening of the X-ray β_{220} line profile of the surface layer treated with ESD reaches $36{,}141621\cdot10^{-3}$ rad, which indicates the formation of a substructure in the alloyed steel surface. The ratio β_{220}/β_{110} is close to the ratio of the tangents of the angles ($\mathrm{tg}\upsilon_{220}/\mathrm{tg}\upsilon_{110}$), which is caused by a significant deformation of the α-Fe phase crystal lattice. Since the composition of electrodes for electrospark doping includes Co, that can form an unlimited solid solution with iron, and also taking into account the rather high solubility in tungsten iron (up to 30%) at liquidus temperatures, it can be assumed that the increase in α-Fe phase lattice parameter after ESA is conditioned by dissolution of the electrode components in Fe.



(a)



(b)



(c)

Fig. 5. *Fragments of X-ray diffractograms from the internal (a), intermediate (b) and surface (c) layers of the specimens*

Comparative assessment of the wear resistance of the original У7 steel and the material of the samples subjected to complex surface treatment including surface plastic deformation, ESD followed by rolling of the applied layer with a ball showed (fig. 6) that the wear of the original steel after the path of 25 km exceeds the wear of samples subjected to surface treatment for ~4 times, and the amount of wear obtained on the original steel after the path of 50 km (450 mg) is achieved on samples subjected to processing only after 200 km.

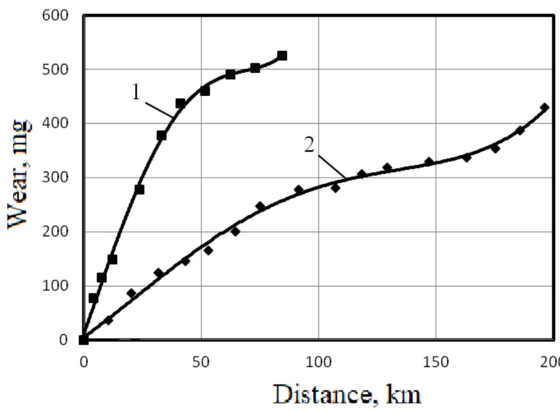


Fig. 6. Dependence of mass wear for the samples from У7 steel (HV 220 ... 240): 1 – samples without surface treatment; 2 – samples subjected to complex surface treatment

4. Conclusions

1. It is shown that the use of combined treatment of steel surface, including surface plastic deformation processing, electrospark doping and additional smooth rolling of the applied coating with a steel roller, provides a gradient-layered structure with entirely new physicomechanical properties and low surface roughness.

2. Based on the X-ray analysis of the surface obtained after the electrospark treatment, it has been established that the phase composition of the layer in addition to the ferritic α-Fe phase contains a number of carbide phases formed during the interaction of the electrode material with steel: F_3W_3C, WC and W_2C semi-carbide. The lattice parameter of the α-Fe phase increased during the doping process from 0.28654 nm for the initial steel to 0.28689 nm of the coating surface, which may be caused by electrode components dissolution in Fe.

3. The efficiency of complex surface treatment of steel is shown, which provides surface layers, the wear resistance of which exceeds similar properties of the original carbon steel up to 4 times.

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