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PLASMA HARDENING OF HEAVILY LOADED PARTS OF SOIL-CUTTING MACHINES

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The influence of plasma hardening on hardening processes of heavy-duty and, therefore, wear parts of working elements of soil-cutting machines has been studied. It is shown that surface plasma hardening of ploughshare made of structural steel 65Mn in the hardened zone with thickness of 0,8 mm leads to formation of gradient-layered (mixed) structure consisting of finely dispersed mixture decay products of fine-grained austenite with variable microhardness in the range of 760 – 395 HV. It is confirmed that the creation of gradient-layered structure and features of its formation after the surface plasma treatment are explained by ultrahigh heating and cooling rates, unattainable with traditional methods of heat treatment.

Keywords: structural steel, 65Mn, plasma hardening, heavy-loaded parts, gradient-layer structure, microhardness

INTRODUCTION

In Republic of Kazakhstan ploughshares and tines of cultivators are used made of inexpensive carbon and low-alloy steels of L53, 40Cr, 65Mn type. Hardness of goods made of these steels in delivery condition does not exceed 25 – 30 HRC (250 – 300 HV), strength is about 900 – 1 200 MPa, impact toughness is within the range 0,2 – 0,6 MJ/m^2.

Application of special heat treatment methods allows to achieve higher properties of replaceable parts which harden to hardness of 50 – 60 HRC, strength exceeds 1 200 MPa and impact toughness is within 0,8 – 0,9 MJ/m^2. Along with this, European companies Conit-Kverneland (Norway), Plasmabid-Rabe (Germany), Overum (Sweden) have developed and implemented knowledge-intensive technologies using plasma methods of hardening parts. A distinctive feature of these products is a two- or three-layer structure of the transverse (hardened) layer, the so-called dissipative (gradient-layered) structure.

Surface layers of products have a strength of 1 200 – 1 800 MPa and hardness up to 65HRC [1,2]. The relatively plastic core in this case provides increased impact toughness of parts. It should be noted that improvement of hardness and wear resistance of ploughshare and lancet tines material by using expensive and scarce alloying elements (W, Mo) is currently limited [3,4].

DATA AND RESEARCH METHODS

Surface plasma treatment of ploughshares and tines of cultivators made of manganese steel 65Mn (GOST 14659 - 2004) was carried out on a mobile certified manual plasma hardening unit UDGZ - 200. During plasma hardening the plasmatron moves along the treatment surface at the speed providing the critical hardening speed. The quenched part is cooled at super high speed due to the small volume of heated metal, because plasma heating by high-energy jet, in contrast to traditional heating methods, is characterized by its local nature [5]. The high energy concentration in the plasma arc allows to heat up only a thin surface layer of the processed material, so that the required cooling rate is provided by the heat sink in the part body and the hardening occurs without appropriate cooling with water. Methods of intensified cooling are used to harden thin-walled parts that do not have sufficient mass. In practice it is of great interest when the cooling rate required for hardening is provided by a rational combination of plasma hardening mode parameters, allowing to obtain the given depth and hardness of the surface layer. In this case, it is important that the main parameters of plasma hardening mode are interrelated when heating the surface of the part with plasma arc [6]. In particular, at surface plasma treatment of lancet legs of cultivators and plowshares the determining value has the speed of plasma torch movement, its influence on the structure, properties (hardness) and depth of hardened zone. The movement speed of plasmatron was 30 – 50 mm/s, the flow rate of plasma-forming gas varied in the range of 7,0 – 9,0 min^{-1}, the distance between the cut of plasmatron nozzle and processed surface was 10 mm, the level

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of plasma arc current was 120 – 125 A at voltage of 40 V. Preliminary experiments showed that the angle of electrode sharpening affects the stability of plasma jet combustion. Formation in the process of work on the end of the electrode micro-fusion site can lead to the movement of the arc spot and, accordingly, the loss of heat and power of the plasma arc. Microhardness was determined with the ISOSCAN OD micro-hardness tester by the Vickers method in accordance with the international standard ISO 6507 under the load of 0,5 N. As experiments have shown, the most responsible moment is a correct position of an electrode in a torch, thus the electrode should not protrude from the ceramic nozzle, and be at its level or be sunk on 0,5 – 1,0 mm. The electrode must be strictly in the center of the ceramic nozzle hole [7].

RESEARCH RESULTS AND DISCUSSION

Metallographic studies show that the mechanical properties (strength, hardness) of plasma-hardened parts are determined by the shape, size, orientation of grains (subgrains) and the nature of their distribution in the volume of metal. Figure 1 shows the initial structure of steel, consisting of lamellar pearlitic colonies surrounded by a ferrite mesh, which is characteristic of the structure of the hot-rolled state with cooling of the rolled metal in calm air.

Figure 1 Initial steel structure (hot-rolled state)

After plasma hardening, due to the high temperature gradient, a fine-dispersed gradient-layered structure is formed in surface layer, consisting of a mixture of low-temperature austenite decay products (Figure 2).

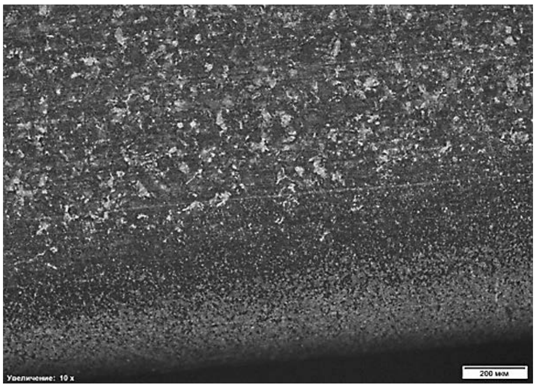

Figure 2 Gradient-layered structure of plasma-hardened steel (optical microscopy)

Structural peculiarities and microhardness of the hardened layer of ploughshare, as well as surface hardness of the investigated samples are given in Table 1.

The depth of the hardened layer for ploughshares made of 65Mn steel is 0,8 mm with microhardness along the section in the range of 760 – 390 HV. In the hardened layer of the sample a gradient-layered (dissipative) structure was formed, consisting of a fine-dispersed mixture of products of decay of fine-grained austenite.

At a distance of 15μm from the surface the structure is a martensitic-bainitic mixture with microhardness 760 HV. It is followed by a zone of bainite-troostite structure with microhardness of 615 HV. In the microstructure of these layers the presence of a small amount of residual austenite is observed, the amount of which (15 – 20 %) depends on the depth of the hardened layer. Further a narrow zone of troosto-sorbitic structure (595 HV) smoothly passing to the initial ferrite-perlite state is formed.

Table 1 **Structural peculiarities and microhardness of the hardened layer of the investigated samples from steel 65Mn**

Distance from the surface/mm	Microstructure	Micro hardness by Section/ HV	Surface Hardness/ HRC
0,15	Martensit-bainite	760	(45-50)
0,30	Bainite-troostite	615	
0,45	Troostite-sorbitol	595	
0,80	Perlite+ferrite	390	

Figure 3 shows the scanning electron microscopic structure (SEM) of the lamellar perlite with the measured interlayer spacing of the ferrite-cementite mixture. It can be seen that the cementitic particles in perlite are presented as parallel plates, and the inter-plate spacing between ferrite and cementite in different perlite colonies varies from 237,6 nm to 633,8 nm with a microhardness of 390 HV.

In [8] it was shown that in steels with a predominant structure of lamellar pearlite, the hardening processes

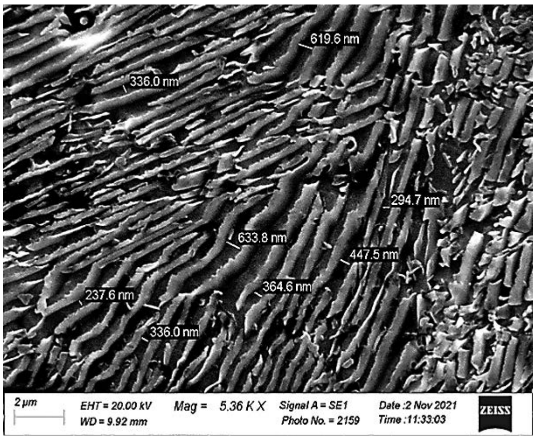

Figure 3 SEM structure of lamellar perlite (the interplanar distances of ferrite-cementite mixture are indicated)

are greatly influenced by cementitic plates, because they are an effective obstacle to the movement of dislocations. The martensitic transformation of carbon steel occurs when the temperature drops below the martensitic transformation start point (230 – 250 °C) at a cooling rate greater than 150 °C / s. [9]. The cooling rate on the working surface of the coulter reaches values of 700 – 800 °C / s, and at a distance of ~ 2 mm from the surface changes in the range 100 – 120 °C / s. Under this condition, the temperature regimes necessary for complete course of martensitic transformation in the surface layer of ~2mm thickness are observed. Outside this surface layer, structures consisting of a mixture of martensite with bainite-troostite and troosto-sorbit, which is observed experimentally (Figures 4 - 6). These data are in accordance with the results of experimental studies [10].

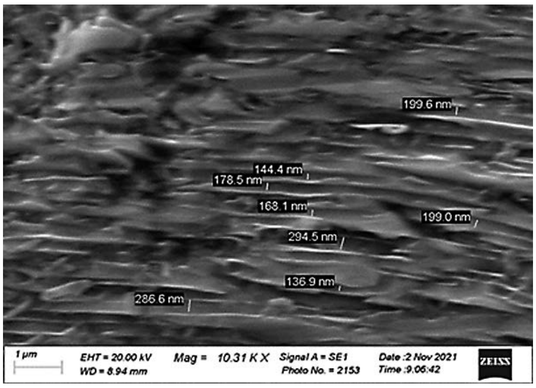

Figure 4 SEM structure of the surface zone, represented by lamellar (needle) martensite

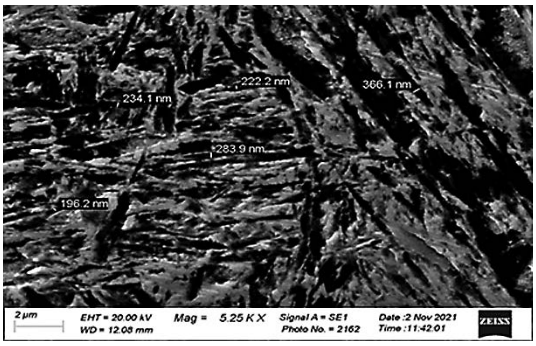

Figure 5 SEM structure of the intermediate zone, represented by bainite of pinnate form

As can be seen from Figures 5 and 6 in the direction from the surface to the central zones, the maximum value of the interlayer distance increases from 366,1 nm to 499,2 nm, indicating a decrease in the degree of hardening.

The specific feature of plasma treatment of parts is the extremely high rate of heating (~1 500 – 3 000 °C /s) and cooling (700 – 800 °C / s) which is associated with a strong grain refinement during plasma hardening. As a result, as the transformation shifts (α→γ) in the area of high temperatures, the nucleation process plays an increasing role, and nucleation growth is largely suppressed. As a result, fine-grained austenite is formed, which transforms into strongly martensite with a developed substructure, characterized by high hardness and wear resistance [11]. By regulating the amount of energy introduced, it is possible to create such conditions of transformation (α→γ), when the only possibility of transition of initial phases is the process of nucleation of austenite grains. Moreover, the peculiarities of alloys hardening under rapid heating are associated with the fact that the transformation (α→γ) in them occurs under nonequilibrium conditions in contrast to traditional methods of thermal hardening with slow heating. In superfast heating, there is no soak required for the transformation (α→γ), dissolution of carbides with subsequent redistribution of carbon and alloying elements. Therefore, the formed austenite has different concentrations of dissolved carbon atoms and alloying elements in contrast to the homogeneous distribution during slow furnace heating. To confirm these provisions, studies to determine the chemical composition of steel by the depth of plasma hardening and the unhardened zone were carried out on a spark spectrometer SPECTROLAB of Leica Microsystems. The data of the chemical analysis of the plasma hardening depth and the non-hardened zone presented in Table 2 confirm the chemical microheterogeneity of the structural and phase components of the investigated steel.

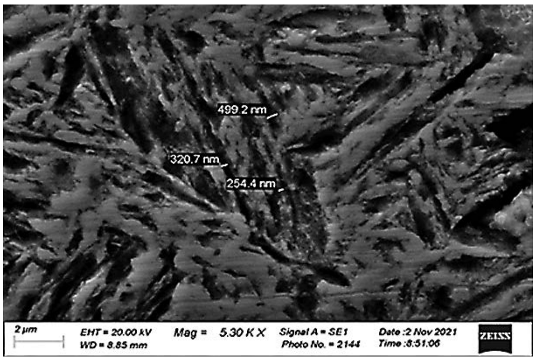

Figure 6 SEM structure of the heat-affected zone (HAZ), represented by a trosto-sorbit blend

Table 2 **Chemical composition data on the depth of plasma hardening and the non-hardened zone**

Zone names	Chemical composition / %					
	C	Si	V	Mn	Fe	W
t 2	0,06	0,002	-	0,063	0,855	0,008
t 3	0,5	0,002	0	0,06	0,87	0,02
t 4	0,002	-	0,001	0,065	0,87	0,009
t 5	0,05	0,0005	0,001	0,062	0,86	0,018
t 6	0,047	0,0035	-	0,072	0,87	-
t 7	0,035	0,004	-	0,068	0,89	0,002
t 8	0,02	0,0018	0,0027	0,07	0,88	0,019
t 9	0,027	0,0025	0,0023	0,065	0,88	-
t 10	0,03	0,004	-	0,074	0,86	0,026
t 11	0,04	0,004	0,001	0,069	0,88	-
Basic	0,008	-	-	0,059	0,90	-

It can be seen that the carbon content along the depth of the hardened zone varies from 0,002 to 0,06 % (at). The same micro heterogeneity along the depth of the hardened zone has other permanent steel impurities (Si, Mn, V, etc.). At heating parameters and cooling rate, typical for plasma treatment, processes related to homogenization of liquid and solid solutions do not have time to complete in the volume of individual grains and it promotes creation of nonequilibrium metastable structures of high hardness with good resistance to wear and microseizure during friction.

CONCLUSION

The creation of gradient-layered structure and features of its formation after surface plasma treatment are explained by ultra-high heating and cooling rates, unattainable by traditional methods of heat treatment. This leads to the fact that the structural and phase components of steel after plasma treatment are characterized by increased dispersion and a higher level of internal residual stresses, as well as a pronounced chemical micro heterogeneity.

The surface plasma hardening of ploughshare made of 65Mn steel in the hardened zone with thickness of 0,8 mm yields the gradient-layered (mixed) structure consisting of finely dispersed mixture of decay products of fine-grained austenite with changing microhardness in the range of 760 -395 HV. Changing heating parameters (time of exposure, heating rate) it is possible to control austenite grain size by the moment of start of ($\alpha \rightarrow \gamma$) transformation, and, changing cooling parameters, to control martensite dispersity during reverse ($\gamma \rightarrow \alpha$) transformation, consequently, properties of machined material.

The technical result of ploughshare hardening by plasma hardening is an increase in wear resistance of ploughshare in comparison with serial parts subjected to traditional heat treatment and a significant reduction of costs for the hardening process.

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Note: The responsible for English translate is Gulden Samiyeva, Nur-Sultan.