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Modified Tool Steel Surfaces by Electrical Discharge Treatment in Electrolyte

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ABSTRACT

Of great importance for tools performance and working capacity are the tool steels surface properties such as high hardness and wear resistance which can be significant improve by surface modification. Basic techniques with wide application in this area are PVD and CVD technologies for thin films deposition of hard materials including nitrides, carbides, borides and carbonitrides. In the present work are described the opportunities of electrical discharge treatment in a suspension of boron carbide in electrolyte as a process for surface modification of tool steels and obtaining of layers with high hardness, wear resistance and corrosion resistance. The modification goes by a high energy thermal process in a very small volume on the metallic surface involving melting, vaporisation, activation and alloying in electrical discharges, and after that cooling of this surface with high rate in the electrolyte. Metallic surface after electrical discharge treatment in electrolyte has a different composition and structure in comparison with the metallic matrix which determines different properties. The modified surfaces are investigated by XRD, SEM, AFM, light microscopy and micro hardness testing.

KEYWORDS: ***tool steels, modified surfaces, electrical discharge treatment in a suspension of boron carbide in electrolyte***

INTRODUCTION

Surface modification of metals and alloys in a wider sense includes all types of surface treatments and coatings that result in change in composition and microstructure of the surface layer. There are different methods for modifying the surfaces of structural alloys, dictated by the performance requirements of the alloy in its service environment. One of the approaches, traditional for the steels, is to modify the surface region of engineering alloys via diffusion of different elements and forming a layer with determinate chemical composition, microstructure and properties. These are the commonly used in practice methods for thermo chemical treatment of metals which extended with the methods for physical vapor deposition and chemical vapor deposition form the basic modern techniques for surface engineering regarding to metals. Another approach involves coating of alloy surfaces via plasma spraying, electrospark deposition, modifying the surface by ion implantation or

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sputter deposition of selected elements and compounds, etc. In recent years a particular attention is directed to the advanced methods for surface modification of metals such as laser surface treatment, electrical discharge machining and plasma electrolysis, which give a modified surfaces with specific combination of microstructures and properties and considerably extend the application areas of basic materials. They form recast layers on the metallic surface after attacking with high energy stream such as laser or electrical discharges for a very short time and pulse characteristics that involve local melting and after that rapidly cooling. The recast layer can be with the same chemical composition as the substrate, but with different microstructure and properties in result of nonequilibrium phase transformations during the rapidly cooling, or with a different chemical composition, microstructure and properties in result of attending diffusion process of surface alloying. In recent years of scientific and practical interests is the electrical discharge machining (EDM) for obtaining of recast layers on steels with different characteristics and properties, mainly high hardness, wear resistance and corrosion resistance. The electrical discharge machining uses electrical discharges to remove material from the workpiece and with each spark produces temperature of about 8000-20000 °C. This causes melting and vaporizing of small volumes of metal surface and after cooling in the dielectric fluid the melted zones are transformed in recast layer with specific structure. This recast layer is also named white layer and it crystallizes from the liquid metal cooled at high rate in the dielectric fluid. The depth of this top melted zone depends on the pulse energy and duration. Under the high temperature of discharge column, the white layer can dissolve carbon from the gases formed in the discharge column and receives higher carbon content than the base material and hence show increased resistance to abrasion and corrosion. Better surface properties have been obtained by machining with powder metallurgy electrodes containing alloying elements which diffuse in the workpiece surface. Fine powders mixed in the dielectric offer another way for achieving desirable surface modification.

At Plasma Electrolysis the processes are of similar nature as EDM and it can be obtained recast layers with the same characteristics. Significant differences are the replacing of liquid dielectric with electrolytes and in result of that increasing the distance between the electrodes which causes displacement of electrical discharges on boundary electrode-electrolyte. There are developed on technology level processes for plasma-electrolysis oxidation and plasma-electrolysis deposition.

Such a method as EDM and Plasma Electrolysis is the Electrical Discharge Treatment in Electrolyte, where the modification goes by a high energy thermal process in a very small volume on the metallic surface, involving melting, vaporisation, activation and alloying in electrical discharges and after that cooling of this surface with high rate in electrolyte. The high energy process put together with nonequilibrium phase transformations in the metallic system causes considerable modifications of the metallic surface and obtaining of layers with finecrystalline and nanocrystalline structure. The metallic surface after electrical discharge treatment in electrolyte has a different structure in comparison with the metal matrix which determines different properties. It is observed remarkable increasing of hardness, strength and corrosion resistance related to the nonequilibrium phase transformations and the obtained finecrystalline microstructure. The investigations show that obtained on tools layers have higher hardness, wear resistance, tribocorrosion resistance and corrosion resistance, which give better performance, considerable increasing of working life and wide opportunities for industrial application.

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EXPERIMENTAL PROCEDURE

For the electrical discharge treatment in electrolyte is developed a laboratory device, shown in Fig. 1, giving opportunities for treatment of workpieces with diameter up to 20 mm. The electrolyte *3* is in active movement by mixing from a magnetic stirrer *4*. After passing of electric current with determinate characteristics through the electrolyte between the workpiece *1* and electrode *2* starts an active sparking on the workpiece surface. The sparking characteristics depend on different factors such as parameters of the electric current, type and composition of the electrolyte, movement of the workpiece and electrolyte.

For the investigations are used specimens of three types of steels: high-speed tool steel EN HS 6-5-2, low-alloy cold-work tool steel EN 90CrSi5 and EN C 105 carbon tool steel.

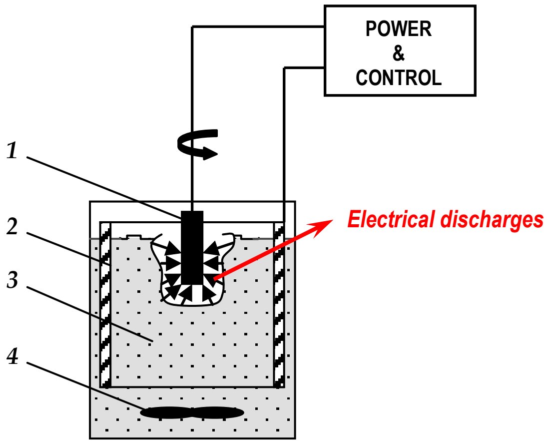

Fig. 1. Electrical discharge treatment in electrolyte: *1 – workpiece, 2 – electrode, 3 – electrolyte, 4 – magnetic stirrer*

The workpieces from high-speed tool steel are drills and punches with diameter 4 mm and 6 mm and structure after the typical heat treatment for tools of this steel. The workpieces of 90CrSi5 and C 105 steels are cylindrical specimens with 6 mm diameter and structure after quenching and tempering. They are connected as a negative electrode of a 25 kW DC power supply and are immersed in the electrolyte to a depth of 20 mm. The anode is a cylinder from austenitic stainless steel sheet. The electrolyte composition and its characteristics are of great importance for the process parameters and for the microstructure and properties of the modified layers. By these experiments the electrolyte is on water basis and in it are dissolved glycerol and sodium carbonate. In the electrolyte is suspended fine sized B_4C. The boron content of the electrolyte and the opportunity for its accelerated diffusion by activation in electrical discharges on the metallic surface increases the tendency for borides formation and grain size refinement in the modified layers. Sparking characteristics depend on different factors such as parameters of the electric current, type and composition of the electrolyte, movement of the workpiece and electrolyte. For the experiments between the electrodes is applied direct current with voltage from 100 to 240 V. The time of treatment is from 2 to 10 minutes. In Fig. 2 is shown the active sparking around the workpiece in the region of 200 – 240 V.

After the treatment the phases and structure on the modified surfaces are investigated by XRD with Cu K_α radiation. The metallographic investigation is carried out by Zeiss light microscopy with Hanneman microhardness testing, ISI SS40 and JEOL JSM 35 CF scanning electron microscopy, Nanosurf easyScan 2 atomic force microscopy.

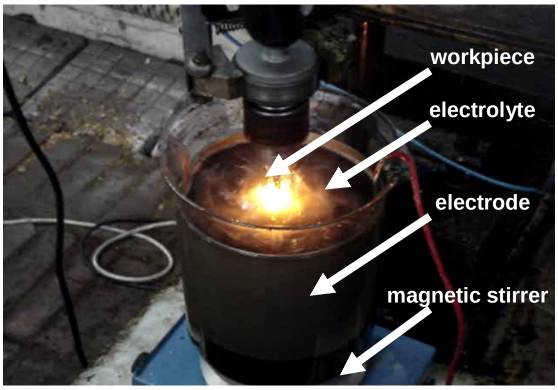

Fig. 2. Active sparking around the workpiece in the region of 200 – 240 V

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RESULTS AND DISCUSSION

HS 6-5-2 tool steel

The microstructure of quenched and triple-tempered HS 6-5-2 steel is shown in Fig. 3. After this heat treatment the structure consist of carbide particles in a matrix of tempered martensite.

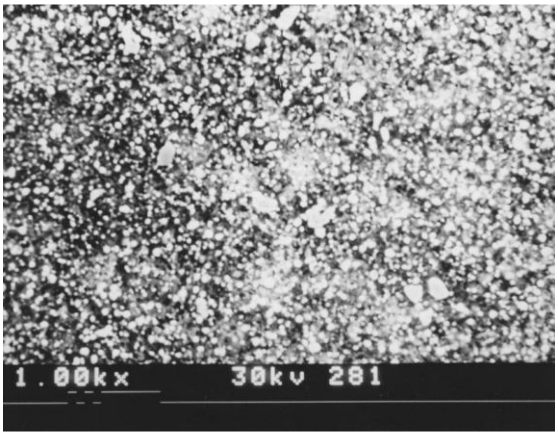

Fig. 3. SEM micrograph of HS 6-5-2 steel after quenching in oil from 1220 ºC and triple tempering at 550 ºC

Metallic surface after electrical discharge treatment in electrolyte receives a different structure in comparison with the metal matrix which determines different properties. In most cases on the surface is formed a recast white layer (Fig. 4) with fine- or nanocrystalline structure. It is a result of high energy local heating and melting by electrical discharge impact on the metallic surface and following quenching in the electrolyte with high rate from liquid phase. The boron presence in the electrolyte and its accelerated diffusion in the metallic surface under the influence of applied electric field increase the tendency of steel grain size refinement. The specific properties of the recast white layer in a case of high-speed tool steels are the remarkable high hardness, strength and corrosion resistance related to the nonequilibrium phase transformations in the high alloyed metallic system.

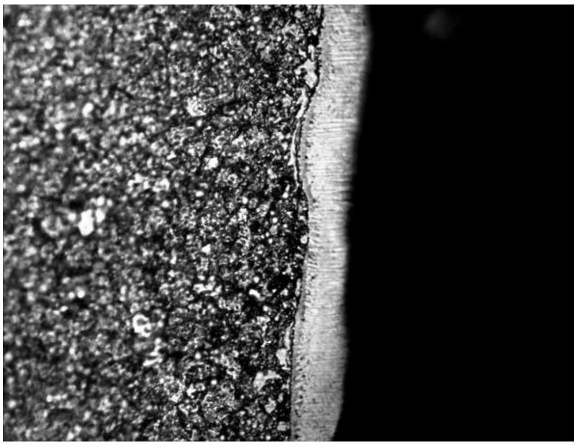

Fig. 4. Recast white layer on HS 6-5-2 steel after electrical discharge treatment in electrolyte, 800x

The structure of the modified surface is of dependence on electrolyte characteristics, electric current parameters and duration of treatment. By lower voltage the obtained recast white layer is inhomogeneous and local deposited on the metallic surface – Fig. 5.

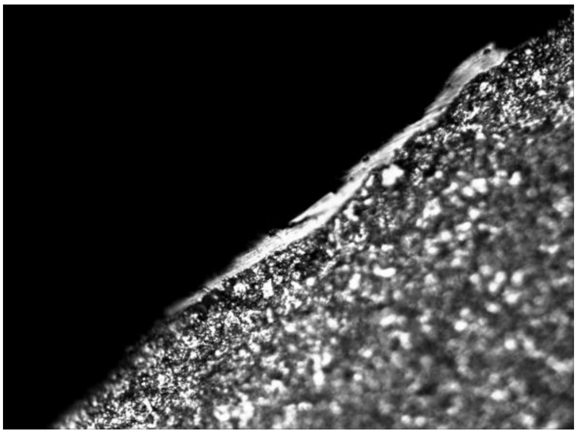

Fig. 5. Area of local deposited white layer on HS 6-5-2 steel surface after electrical discharge treatment in electrolyte for 4 minutes at 180 V, 800x

Voltages above 200 V give a very high intensity of sparking on the metallic surface with enough energy for melting and dissolving of the carbides and because of that it is obtained an approximately compact recast layer with homogeneous structure. By the high speed quenching from liquid state the solubility of alloying elements remains very high in a supersaturated solid solution and after the

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nonequilibrium phase transformations it is formed metastable structure with high hardness and wear resistance. In Fig. 6 is shown SEM micrograph of obtained recast layers for 2 minutes at 220 V. The modified surface is homogeneous and has very high corrosion resistance. The microhardness of white layer in these cases reaches HV 1700.

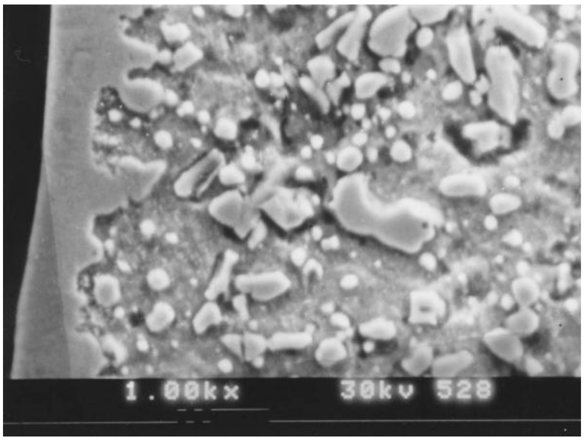
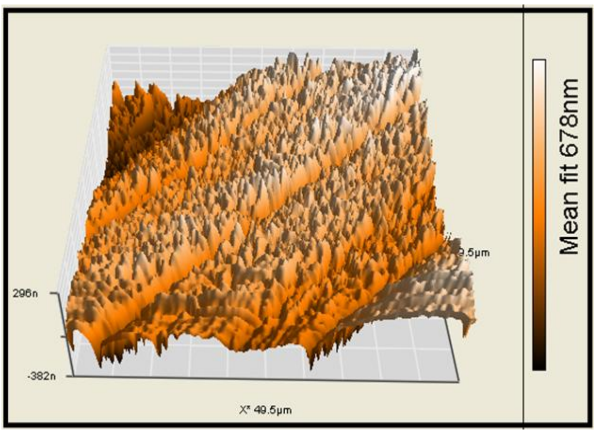
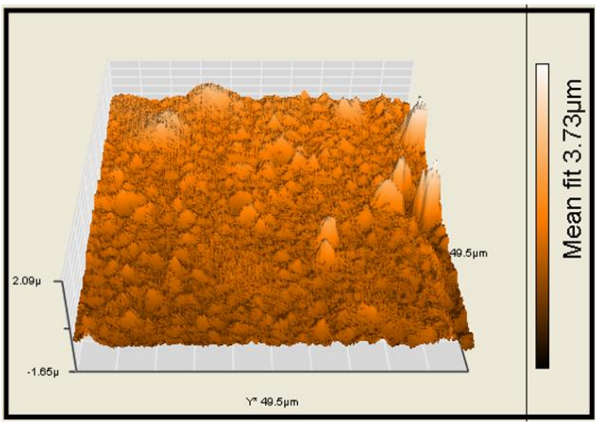


Fig. 6. SEM micrograph of modified HS 6-5-2 steel surface for 2 min at 220 V

The AFM investigation shows a significant change in roughness of workpiece surface after electrical discharge treatment in electrolyte. The grinded surface before treatment with a clear illustrated direction of grinding is transformed after that in a homogeneous surface in a result of active sparking on workpiece surface – Fig. 7.



a



b

Fig. 7. AFM view of workpiece surface: *a – before treatment, b – after treatment*

The XRD investigation of the modified by electrical discharge treatment in electrolyte high-speed steel surface shows a significant difference between the recast layer and bulk material. The modified surface has typical diffraction patterns for nanostructured materials (Fig. 8). The XRD analysis also proves a mass transfer of boron from the electrolyte and its diffusion in the surface layer. In the modified steel surface along with carbides typically for the high-speed steel structure Me_2B also is presented (Fig. 9).

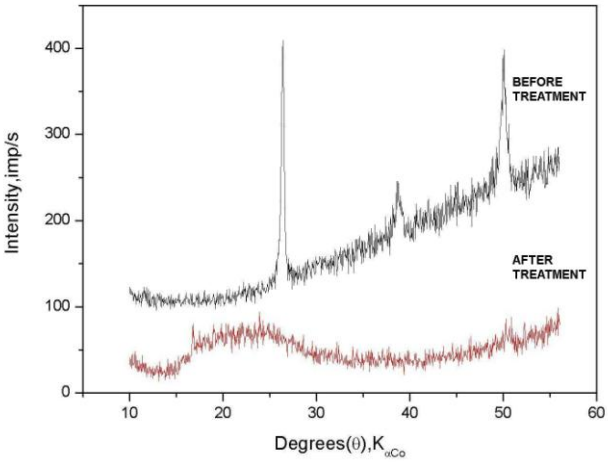


Fig. 8. XRD patterns of HS 6-5-2 steel surface before and after electrical discharge treatment in electrolyte

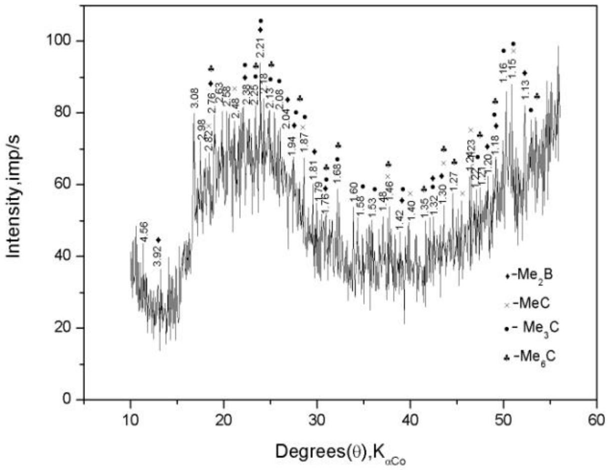


Fig. 9. XRD patterns of HS 6-5-2 steel surface after electrical discharge treatment in electrolyte

90CrSi5 tool steel

On the modified 90CrSi5 steel surface can be observed (Fig. 10) a white area with situated in it coarse martensitic plates. The microhardness of the white area is higher than the martensite and reaches HV 1100 – 1200.

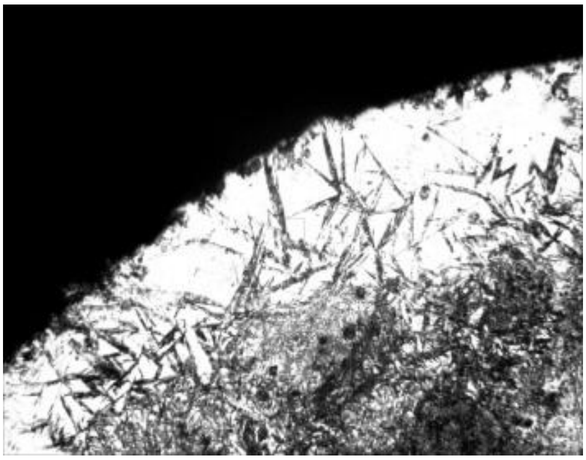


Fig. 10. Modified surface of 90CrSi5 tool steel at 180 V for 3 min, 250x

For specifying of surface phase composition is made a XRD analysis. From the XRD patterns (Fig. 11) it can be seen that along the martensite and carbides, which are typical for the steel, in the structure present borides Fe_2B and FeB that give the higher microhardness of white zone in surface layer.

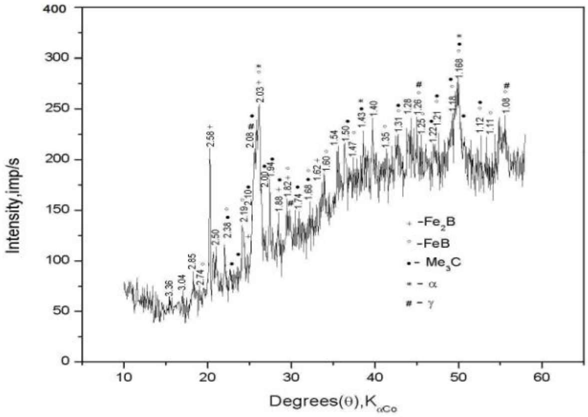


Fig. 11. XRD patterns of modified 90CrSi5 steel surface after electrical discharge treatment in electrolyte

C 105 tool steel

On the modified C 105 tool steel surface can be observed (Fig. 12) a white layer with presence of defects such as pores and microcracks (Fig. 13). The microhardness of the white layer is in the range HV 1000 – 1300.

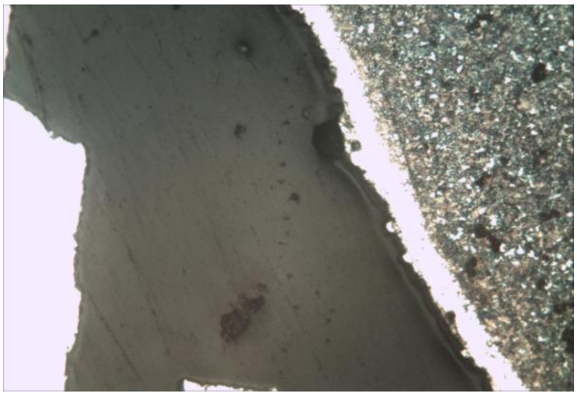


Fig. 12. Optical micrograph of modified C 105 steel surface at 200 V for 3 min, 400x.

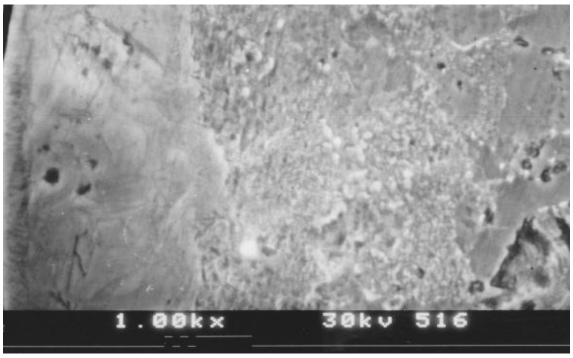


Fig. 13. SEM micrograph of modified C 105 steel surface

CONCLUSIONS

The high energy process of electrical discharge treatment in electrolyte and the nonequilibrium phase transformations in the high alloyed metallic system of HS 6-5-2 steel causes considerable modifications of the metallic surface and obtaining of layers with finecrystalline and nanocrystalline structure. On the modified surface of 90CrSi5 steel can be observed a white area with situated in it coarse martensitic plates. On the modified C 105 tool steel surface can be observed a white layer with presence of defects such as pores and microcracks. The modified surfaces have high hardness, strength, wear- and corrosion resistance. The investigations show that obtained layers on HS 6-5-2 steel reach microhardness of about HV 1700. The microhardness of the modified 90CrSi5 steel surface is HV 1100 – 1200 and for the C 105 steel HV 1000 - 1300. The XRD analysis proves a mass transfer of boron from the electrolyte and its reactive diffusion in the metallic surface. In the modified steel surfaces present Me_2B and MeB.

ACKNOWLEDGEMENT

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