Recast layers on high speed steel surface after electrical discharge treatment in electrolyte

D. Krastev, V. Paunov, B. Yordanov
University of Chemical Technology and Metallurgy, Sofia, Bulgaria
krastev@uctm.edu

ABSTRACT. In this work are discussed some experimental data about the obtaining of recast layers on the surface of high speed tool steel after electrical discharge treatment in electrolyte. The electrical discharge treatment of steel surface in electrolyte produces a recast layer with specific combination of structure characteristics in result of nonequilibrium phase transformations. The modification goes by a high energy thermal process in electrical discharges on a very small area on the metallic surface involving melting, alloying and high speed cooling in the electrolyte. Obtained recast layers have a different structure in comparison with the metal matrix and are with higher hardness, wear- and corrosion resistance.

KEYWORDS. Recast Layers; High Speed tool steel; Electrical discharge treatment in electrolyte.

INTRODUCTION

The recast layers on metals and alloys are mainly created by treating the surface with high energy stream such as laser, ion beam or electrical discharge for a very short time and pulse characteristics. The high energy attack on the surface involves local melting and in many cases vaporizing of metal microvolumes. After the cooling, on the treated metal surface a recast layer with different structure and properties from the substrate is formed. This recast layer can be with the same chemical composition as the substrate or with different one if in the thermal process suitable conditions for surface alloying are created. When the recast process is not controlled there are on the surface microcracks and pores which have negative influence on the surface properties and the recast layer must be removed. In the controlled recast processes it is possible to produce surface layer with determinate chemical composition, thickness, structural characteristics and properties, which are unique for the material with the very high hardness, corrosion- and wear resistance. The basic techniques that give opportunities in this direction are laser surface treatment, electrical discharge machining and plasma electrolysis.

Laser surface treatment is widely used to recast and modify localized areas of metallic components. The heat generated by the adsorption of the laser light provides a local melting and after controlled cooling is obtained a recast layer on the metal surface with high hardness, wear resistance and corrosion resistance. The laser surface melting is based on rapid scanning of the surface with a beam focused to a power density scale of 10^4 W/cm^2 to 10^7 W/cm^2. Quench rates up to 10^8 - 10^{10} K/sec provide the formation of fine structures, the homogenization of microstructures, the extension of solid solubility limits, formation of nonequilibrium phases and amorphous phases or metallic glasses, with corrosion resistance 10–100 time higher compared to crystalline [1]. Laser surface melting is a simple technique as no additional materials are introduced, and it is especially effective for processing ferrous alloys with grain refinement and increase of the alloying

elements content in solid solution. In fact the process has been employed for improving the cavitation erosion and corrosion resistance of a number of ferrous alloys.
The laser surface melting can be combined with a simultaneous controlled addition of alloying elements. These alloying elements diffuse rapidly into the melt pool, and the desired depth of alloying can be obtained in a short period of time. By this means, a desired alloy chemistry and microstructure can be generated on the sample surface and the degree of microstructural refinement will depend on the solidification rate. The surface of a low-cost alloy, such as low carbon steels, can be selectively alloyed to enhance properties, such as resistance to wear and corrosion [2].
Electrical discharge machining is a thermoelectric process that erodes workpiece material by series of discrete but controlled electrical sparks between the workpiece and electrode immersed in a dielectric fluid [3]. It has been proven to be especially valuable in the machining of super-tough, electrically conductive materials, such as tool steels, hard metals and space-age alloys. These materials would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine intricate shapes that would be impossible to produce with conventional cutting tools. In EDM process, the shapes of mold cavities are directly copied from that of the tool electrode, so time-consuming preparation work must be done on the fabrication of the corresponding tool electrode.
The electrical discharge machining uses electrical discharges to remove material from the workpiece, with each spark producing temperature of about 8000-20000 ºC. This causes melting and vaporizing of small volumes of the metal surface and after cooling in the dielectric fluid the melted zones are transformed in recast layer with specific structure. The EDM modified surface consists from two distinctive zones [4-6]:

- Recast layer
- Heat affected zone

The 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. Below the top white layer is the heat affected zone with changes in the average chemical composition and possible phase changes.
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 [7].

MATERIALS AND EXPERIMENTAL PROCEDURES

The objects of study are specimens with diameter 6 mm which are made from HS 6-5-2 steel with structure after the typical heat treatment for tools of this steel. In this most popular high speed steel the tungsten content is reduced to 6 % while it is additionally alloyed with 5% molybdenum and vanadium content is about 2 %. The steel is quenched in oil from 1220 ºC and after that triple-tempered at 550 ºC for 2 hours each. The measured hardness of the specimens is 63-65 HRC. The electrolyte composition and its characteristics are of great importance for the process parameters and for the microstructure and properties of recast 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.

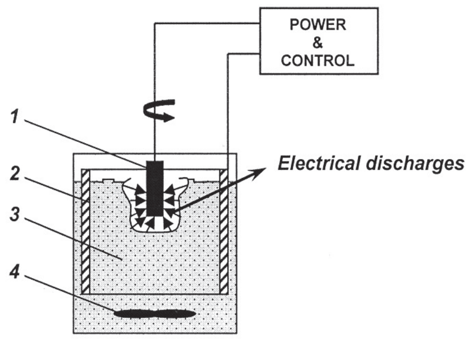

Figure 1: Electrical discharge treatment in electrolyte: 1 – workpiece, 2 – electrode, 3 – electrolyte, 4 – magnetic stirrer.

For the electrical discharge treatment in electrolyte is developed a laboratory device, shown in Fig. 1 [8,9], giving opportunities for treatment of cylindrical 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

suspended electrolyte between the workpiece *1* which is on the cathode 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. The high-alloy steel gives an opportunity for higher effectiveness of treatment on structure and properties of modified surfaces after the nonequilibrium phase transformations from liquid state. Under the high temperature of discharge column, the surface layer can dissolve activated elements formed in it from the electrolyte and receives structure with different characteristics and properties.
For the experiments between the electrodes is applied direct current with voltage from 80 to 240 V. The time of treatment is from 1 to 10 minutes. The investigations show that the optimal time is 3 minutes. Obtained layers have been investigated by light microscopy, SEM, XRD and Hanneman microhardness testing.

RESULTS AND DISCUSSION

The electric discharges generate an enormous amount of heat, causing local melting on the workpiece surface and thereupon it is rapidly quenched from the liquid state by the electrolyte. This recast area has a specific structure, which can be composed of several microscopic metallurgical layers, depending of machining conditions. The high rate of the recasting process gives opportunities for formation of metastable phases and considerable decreasing of grain size. The electrolyte type is of great importance for the chemical composition, microstructure and properties of the recast layer. The melted and resolidified layer during this process is also referred as the "white zone", since generally no etching takes place in these areas at the metallographic preparation. The structure of recast layer can be seen after SEM investigation on Fig. 2.

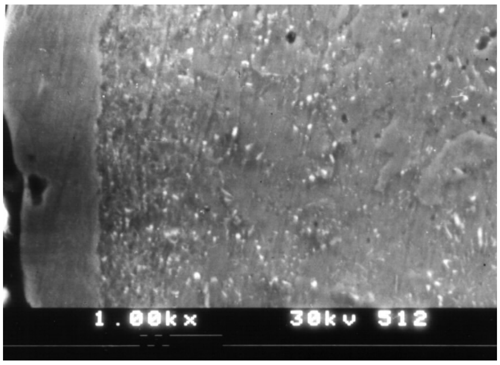

Figure 2: SEM micrograph of recast layer on HS 6-5-2 steel after electrical discharge treatment in electrolyte

At short times of treatment it is not observed diffusion of elements from the electrolyte in the modified surface, but it is available diffusion process inside the workpiece between the white layer and the matrix – Tab. 1. The strong carbide-formed elements such as Mo, W, and V diffuse from the white layer to the matrix and Cr, Co in the opposite side.

Chemical element	Matrix of workpiece	White layer
Si	<0.01	<0.01
Mo	5.58	4.87
V	2.30	1.63
Cr	4.25	4.52
Co	<0.01	0.19
Ni	<0.01	<0.01
W	8.34	5.75

Table 1: EDS analysis of modified workpiece from HS 6-5-2 steel

The specific properties of recast white layer in a case of tool steels are the remarkable high hardness, strength and corrosion resistance related to the nonequilibrium phase transformations in the high alloyed metallic system. The white

layer characteristics, its homogenous structure and thickness, are of dependence on the electric current parameters and on the duration of treatment. By lower voltage the obtained recast white layer is inhomogeneous and local deposited on the metal surface.
The treatment time increasing in this case shows an insignificant influence on process. In Fig. 3 is shown an optical micrograph of surface microstructure after electrical discharge treatment in electrolyte at 150 V for 3 minutes. The thickness of obtained layer is under 0.01 mm.

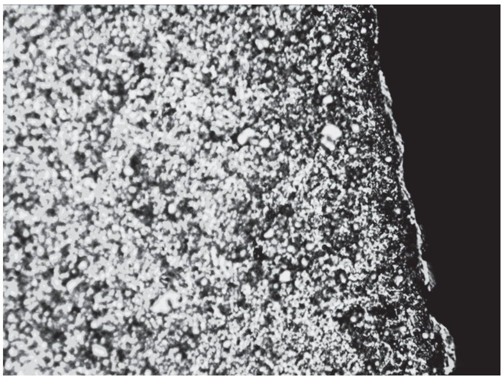

Figure 3: Optical micrograph of modified HS 6-5-2 steel surface at 150 V for 3 min, 800x.

The investigations show that it is possible to obtain a white layer on the high-speed tool steel surface at voltages of about 100 V, Fig. 4, but the electrical discharges energy is insufficient for dissolving of carbides and the hardness of the modified surface can not receive the expected high level.

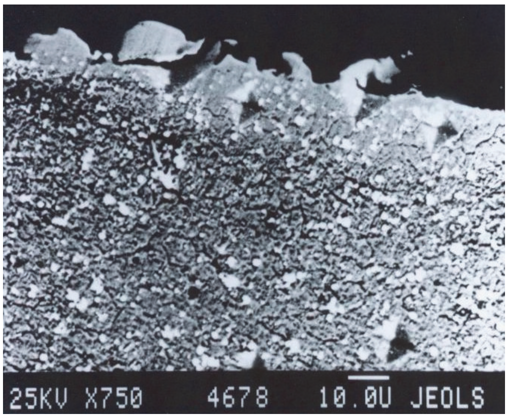

Figure 4: SEM micrograph of modified HS 6-5-2 steel surface at 100 V, 2 min.

The voltages above 200 V give a very high intensity of sparking on the metal surface with energy enough for melting of the metal and dissolving of the carbides and it is possible to obtain compact recast layer with homogeneous structure. By the high speed quenching from liquid state the solubility of the alloying elements remains very high in a supersaturated solid solution and after nonequilibrium phase transformations metastable structures with high hardness and wear resistance are formed. In Fig. 5 an optical micrograph of the recast layers obtained after 3 minutes treatment at 200 V is shown. The thickness of the obtained white layers is about 0.05 - 0.06 mm. The modified surface has a very high corrosion resistance and the microhardness of the white layer in these cases reaches more than HV 1500.
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 (Fig. 6 and Fig. 7). The modified surface has typical diffraction patterns for nanocrystalline structures. The XRD analysis also proves the 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 is also presented.

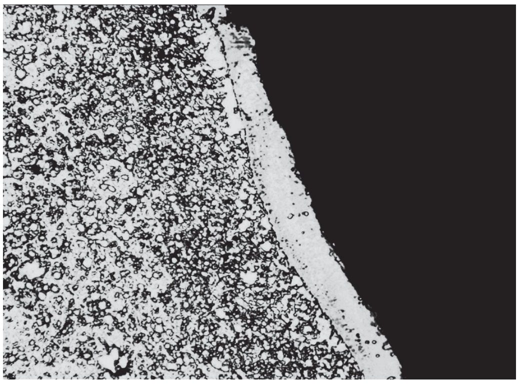

Figure 5: Optical micrograph of modified HS 6-5-2 steel surface at 200 V for 3 min, 800x.

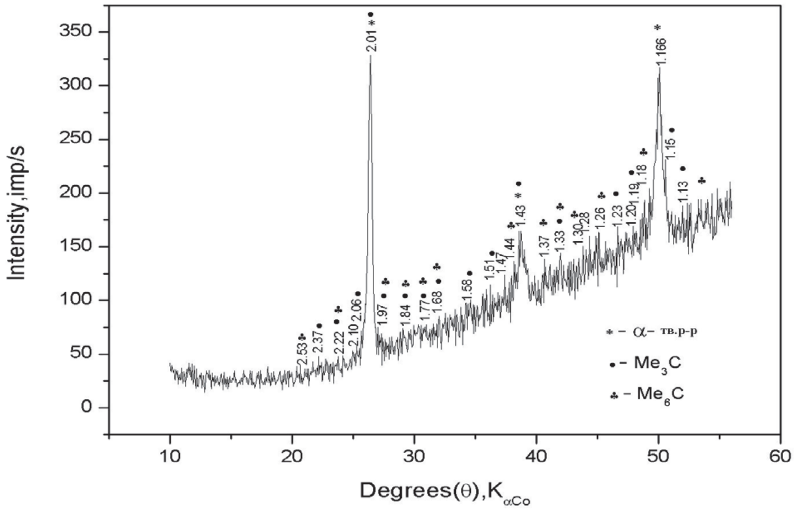

Figure 6: XRD patterns of HS 6-5-2 steel surface before electrical discharge modification in electrolyte

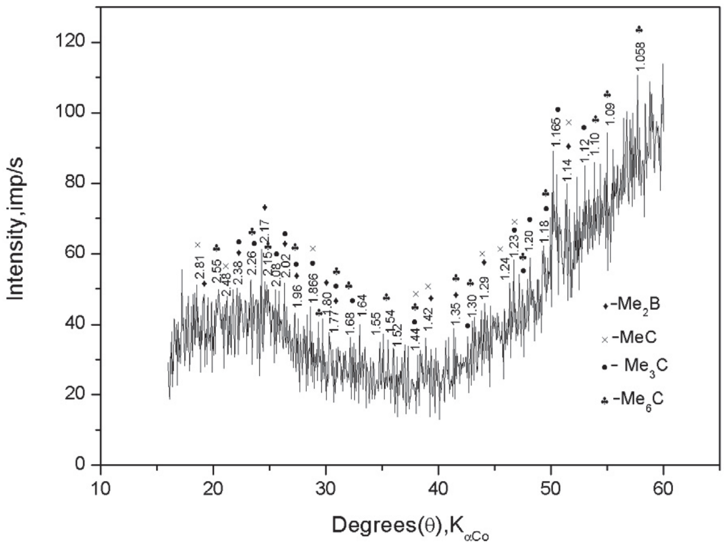

Figure 7: XRD patterns of HS 6-5-2 steel surface after electrical discharge modification in electrolyte

Homogeneous structure of the recast layer can be observed by a higher magnification on SEM micrograph in Fig. 8. The modified surface has a very high corrosion resistance and can not be etched. The microhardness of the white layer in these cases reaches HV 1500–1600 compared to HV 780–820 of the core.

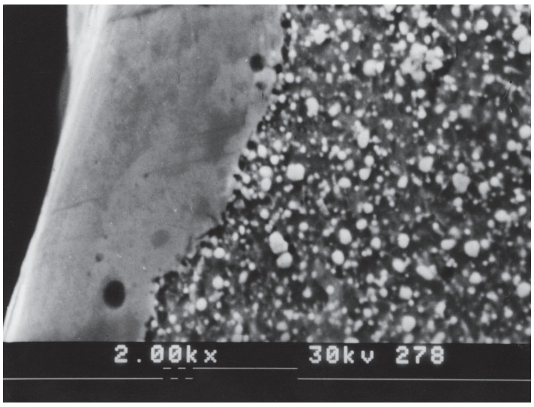

Figure 8: SEM micrograph of modified punch surface.

Combination of high voltages with increasing duration of the electrical discharge treatment causes a significant heating of the workpiece, melting the surface and penetrating of the diffusion process in depth to the grain boundaries (Fig. 9). The surface recast layer in this case has ledeburitic structure with higher concentration of carbon and boron.

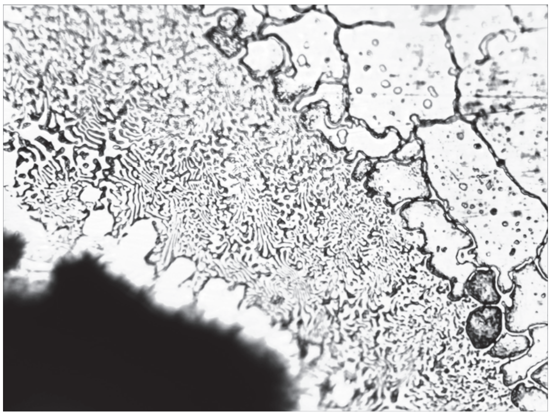

Figure 9: Optical micrograph of the recast layer on HS 6-5-2 steel after electrical discharge treatment in electrolyte at 230 V for 10 min, 800x

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 recast layers with finecrystalline and nanocrystalline structure. The modified surfaces have high hardness, strength, wear- and corrosion resistance related to the supersaturated solid solution of alloying elements in the obtained recast white layer and the nonequilibrium phase transformations by the high quenching speed from liquid state. Investigations show that obtained recast layers reach a thickness about 0.05 mm. The hardness of the modified layers can vary considerably and depend of the treatment conditions, electrolyte composition and microstructure, but in principle it is higher then the hardness of the typical microstructure of this steel. The microhardness of the recast layers measured by Hanneman test shows values after the different treatments up to 1600 HV which are very higher than the microhardness of HS 6-5-2 steel microstructures after the typical heat treatment. The experiments show that tools with such surface hardness have higher wear resistance and working capacity.

REFERENCES

[1] Bommi, V. C., Mohan, K. M., Prakash, S., Surface Modification of Martensitic Stainless Steel Using Metal Working CO_2 Laser, Proceedings of International Symposium of Research Students on Materials Science and Engineering, Chennai, India, (2004) 20-22.
[2] Davis, J. R., Surface Engineering for Corrosion and Wear Resistance. ASM International, Materials Park, Ohio, (2001).
[3] Asif Iqbal, A. K. M., Khan A. A., Influence of Process Parameters on Electrical Discharge Machined Job Surface Integrity. American Journal of Engineering and Applied Science, 2(3) (2010) 396-402.
[4] Kumar, S., Singh, R., Singh, T. P., Sethi, B. L., Surface Modification by Electrical Discharge Machining: A Review. Journal of Materials Processing Technology, 209 (2009) 3675-3687.
[5] Zhao, W. S., Fang, Y., Wang, Z. L., Li, L. H., A Surface Modification Method by EDM and Its Applications to Cutting Tools, Materials Science Forum, 471-472 (2004) 750-754.
[6] Ho, K. H., Newman, S. T., State of the Art Electrical Discharge Machining (EDM). International Journal of Machine Tools & Manufacture, 43 (2003) 1287-1300.
[7] Yerokhin, A. L., Nie, X., Leyland, A., Mathews, A., Dowey, S. J., Plasma electrolysis for surface engineering, Surface and Coatings Technology, 122 (1999).
[8] Krastev, D., Yordanov, B., About the Surface Hardening of Tool Steels by Electrical Discharge Treatment in Electrolyte, Solid State Phenomena, 159 (2010), 137-140.
[9] Krastev, D., Improvement of Corrosion Resistance of Steels by Surface Modification. In: Corrosion Resistance, Shih, H, Ed.; InTech, (2012) 295-316.