# HARDNESS AND STRUCTURE CHANGES AT SURFACE IN ELECTRICAL DISCHARGE MACHINED STEEL Č 3840

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**Abstract:** The electrical discharge machining (EDM) of both hard and soft materials became an important technique in industrial applications. This technique has an advantage in producing of structural/tool parts of complex geometry. The EDM is based on electrical phenomena, when the treated surface undergoes to erosion. The first step in EDM, the melting of thin surface layer, frequently is neglected. In this paper the changes of hardness and structure at surface layer, after EDM is applied on steel Č 3840, will be discussed.
The steel Č 3840 was quenched and tempered to hardness of 63 HRC, at surface, and than machined by electrical discharging. The changed, white, layer is just a product of melting and decarburization processes. The white layer is registered at surface by using a metallographic investigation. Hardness profile is measured from surface to the interior of material. The achievement of local high temperatures during EDM is resulting on melt and erosion of material. Besides of these effects, during EDM were happened some minor but not a neglectible effects, primarly on structure changes on treated surface. It would be espected that melting, even an evaporation of melted metal, and further the phase transformation have an important influence on the starting structure.
**Key words:** Electric discharge machining, white layer, structure and hardness changes

## 1. INTRODUCTION

Dynamic developments in some specific industries (as like: avio, cosmic, nuclear, and also in plastic moulding) have resulted in application of large number of new materials and tools. A large number of these materials are characterized by one or more next properties: high hardness, high strength (yield point or tensile strength), a considerable corrosion resistance, reliable mechanical properties (especially toughness) at high or at cryogenic temperatures, and similar demands. The production of such machine parts, both structural and tool parts, from material of mentioned properties than became a pretty complicated and rather expensive. The using a conventional production methods, for example as turning and/or milling, became a hardly feasible, first from technical demands and secondly from the economic effects.
One of the successful technologies for manufacturing very hard but a soft material represents the Electric Discharge Machining (EDM) method. While the traditional manufacturing methods by cutting are based almost on the mechanical principles, then the EDM is based on the electrochemical phenomenon.
Even though an English scientist (Pristley) has discovered (1770) the erosion effect, during electrical discharging the material, this effect has not attracted any serious attention for a along period of time. After a decades and centuries, the Russian engineer Boris Romanovich Lazarenko has developed (1943) EDM technology. After a while, this technology is broaded all over the world.
When an electrical spark is established between working piece (anode) and tool (cathode) the discharging becomes extremely intensive, even uncontrolled with local overheating. This heating will change not only the structure of parent material but a local remelting will happened. For the better understanding the influence of EDM on metal, in this paper will be discussed more detailed some metallurgical changes in steel Č 3840, which belongs to a group of tool steels with stabile dimensions and relatively high hardness values after quenching and tempering.

The observed structural changes will, among other things, influenced on toughness loss and on dimensional stability of treated material. All of these occurrences at EDM will decrease the expected working time. On the basis of registered behavior during EDM here will be given some recommendations for avoiding an undesirable effects, i.e. for removing the layer with changed structure.
Here is examined the steel but there are signs[1] that structure changes of processed material should be rigorously restricted if they are existing on eroded components intended to use in avioindustry. Changes in fatigue of material, especially in avioindustry, may have lead to a catastrophic result.
The application of EDM technology is constantly growing and by author's opinion there is missing of necessary knowledge for successful manufacturing of neither machine or tool part, from the raw material to the desired geometry. There is hope that here discussed EDM of Č 3840 steel will be interesting for every one who is dealing with machining (turning, milling, grinding) but for all others who are involved in quenching, and particularly in chemical heat-treating (like nitriding), etc. For EDM, the chosen steel Č 3840 is eroded by using a copper electrode with positive polarity and an average current of 25 A.

## 2. ELECTRIC DISCHARGE MACHINING

First examinations of EDM were provided on studding the erosion in electric contactors due to electric spark. For making a difference, the electric erosion in such contact elements represents a harmful effect. During examination of erosion in mentioned contactors, they were submerged into liquid dielectric, and explorers (Lazarenko at all) were found small dotted parts of eroded metal at the bottom of the dish. The origin of dotted material leads to the electrical discharge appearance, and the whole method is named *electrical discharge machining*. The principle of EDM is pretty simple and necessary equipment is shown at Fig. 1.

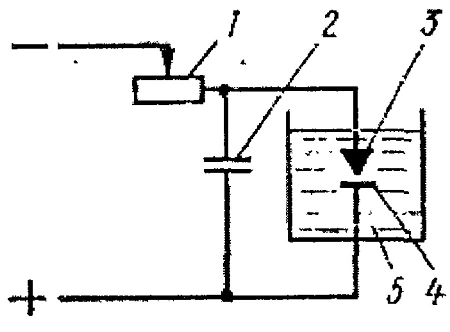


**Fig. 1.** Scetch of equipment for electrical discharge machining

The working part (4) is connected as an anode and tool is connected as a cathode (3). For establishing the EDM process serves a condenser batteries (2), so that charging of condenser is regulated by using a rheostat (1).
The room between anode and cathode is full of dielectric fluid (5). The electric discharge depends from the distance anode–cathode, further from kind of impulse signal, and of course from another properties of working material and dielectric liquid.
Physical, electrical and metallurgical processes which have take place during EDM in dielectric fluid can be divided as follows: a) mechanism of discharging, b) time developed discharging in channel, c) energy distribution, d) heat transfer processes and e) material transfer processes.

On EDM phenomena a great influence have a type and shape of impulse between electrodes, and this fact make investigations more complex. The thermal effects of electrical discharging on hardness and structure changes onto eroded material will be subject in this paper.

## 3. CHANGES IN STRUCTURE

So high temperatures will, no doubt, lead to changes in structure. Used steel is quenched and tempered to hardness of 63 HRC, with structure of tempered martensite. As a consequence of breaking the impulse current, melted metal is undergoing to rapid solidification just on the periphery of crater. Partially evaporated metal will, also as a consequence of breaking the impulse current, condensed. After these have happened, the surface may have look as overweld surface. Out of melting zone, the temperatures are indeed lower but they are still on the high level than temperatures of tempering of steel. This tempering is caused by EDM and this assumption is agreed by metallographic examination of eroded surface, as can be seen from Fig.2.

Melted and solidified metal and partially condensed vapor, as a cloud at Fig. 2, have made a thin layer (1). Such layer may have greater roughness that previously layer. By selection the proper values in EDM (as like: current, impulse, polarity and other electrical parameters) it's possible to get a finished layer with lower roughness than grinded surface. The high spark temperature may have led to local evaporation, even a carbon from the treated surface. This is known as a decarburization process.

1. solidifield and condensed layer
2. white layer
3. tempered layer

**Fig. 2.** Metallographic structure at surface of qunched and eroded steel Č 3840, x 400

If decarburization takes place the amount of ferrite in the steel will be increased. After rapid cooling is applied than on the melted surface will be produced so called "white" layer. Such white layer consists of cementite carbide, austenite and ferrite. Just below the white layer will be quenched layer, according to Fig. 2. Further, the third layer from the center of spark is tempered layer. This tempering is of course a result of electric discharging of base material. The tempered (or annealed) material always has o lower hardness than quenched material.

## 4. TEMPERATURE AND HARDNESS CHANGES

The electric spark or an arc can produce a high local temperature. The exactly determination of temperature distribution around the electric discharging practically is impossible, firstly from missing data about heat transfer (i.e. conductivity), secondly from the beginning configuration at electrode's surface, etc.

The temperature changes are indeed responsible for hardness changes in treated material. The temperature gradient during discharging constantly is decreased from the center to the spark/arc periphery. Developing

heat is divided on heating the base material, melting and even a evaporation of treated material. But, if an electric discharging is provided for a long time than stationary state will be established. In such stationary state a new-formed heat will not lead to melting or evaporation. From that reason it's clear that impulse current must be used during electric discharging.
By using a detailed calculation of temperature distribution it's possible to determine boundaries between liquid metal, zone of phase transformation in solid state (if they are existing) and tempering zone. The tempering zone is of particularly interest for quenched (hardened) steel. The nature of temperature distribution, i.e. termical zones, is shown at Fig.3.

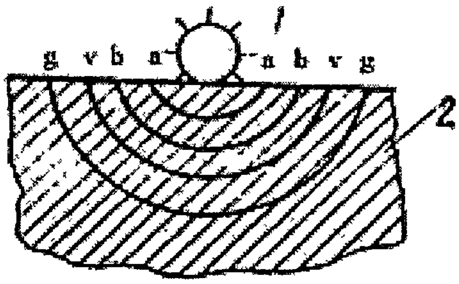


**Fig. 3.** Distribution of main termical zones in material during EDM

The point-like source (1) is emitting heat at equidistant manner on all sides. The heating of work piece (2) is a direct function from distance between electric current source and work piece: when the distance is decreasing the heating is more intensive, and vice versa. Zone of largest heating is signed by arc **a-a**, see Fig. 3, and this zone at the same time is a melting zone. Further heat transfer is signed by concentric arcs **b-b, v-v** and **g-g,** according to heat waves.
The temperature distribution at point just under impulse current source is a function of impulse energy, distance from the heat source, density of working material, and other parameters, which can be found in appropriate literature[1]. High temperatures in the center of spark will lead to evaporation of some components from melted and overheated liquid metal. In other zones some another metallurgical changes may happened. From this reason, the hardness will be also changed. The nature of hardness change is shown at Fig. 4.

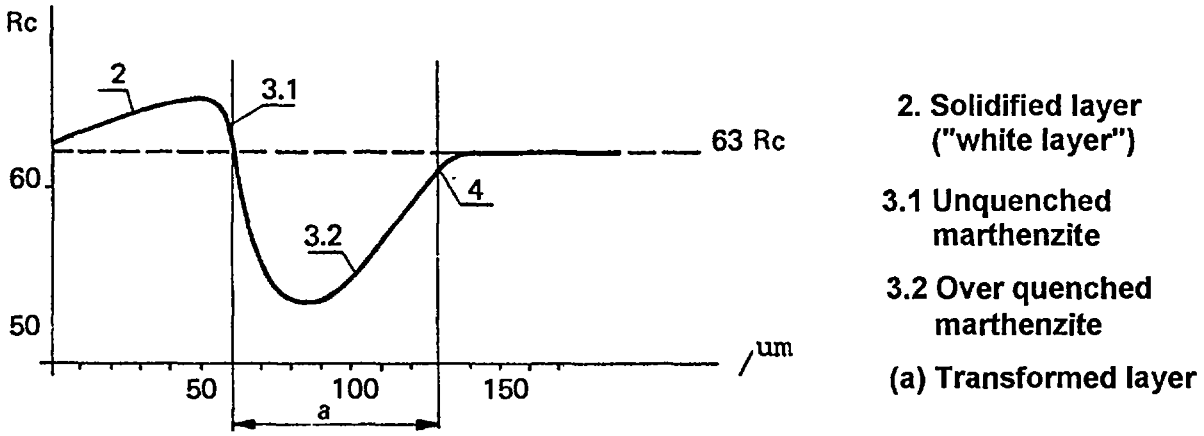


**Fig. 4.** Hardness profile at surface after EDM, steel Č 3840

Lower hardness just below the surface can be explained by remelting and evaporation process, firstly by losing the carbon contest. The depth of layer with changed hardness, marked (2) as at Fig. 2, is about 70 µm, see Fig. 4. The greater lowering of hardness is registered at tempering zone, zone 3 from Fig. 2. The range of lowering hardness in this case is about 120 µm, marked as (a) at Fig. 4. After distance (a) the hardness is again 63 HRC, i.e. on the level of parent material (quenched and tempered).

# CONCLUSION

Achieving of high local temperatures during EDM has a favorable influence on melting and erosion of metal, and on that way it's possible to shaping raw material to the desired geometry. Besides of positive effects in EDM for obtaining a desired shape, there is existing one minor but not neglected effect: under the influence of high local temperatures the structure at the surface is undergoes to change, as registered by metallographic examinations. As a consequence of melting and rapid solidification a white thin layer is formed. Hardness and structure are changed after application of EDM.

The appearing of white layer, especially when the tool steel is working material, may cause the limitations in usage of such tool. From that reason, in eroded tool steel becomes necessary to remove mentioned white layer. For removing this white layer in technological list operations must be predicted one mechanical operation (fine grinding or grinding +polishing) with a satisfactory allowance for final machining.

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