Research of surface microstructure of the steel 40CrNiMo after EDM

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Abstract. The aim of the work is to study the influence of modes of electrical discharge machining, on the microstructure and microhardness of the treated surface of thermally hardened steel 40CrNiMo. To fulfill the task, a sample was made of hardened steel 40CrNiMo. The sample was processed in various modes of electrical discharge machining. Microsections were made from the obtained sample. Metallographic and microdurometric analysis was carried out. The study of the microstructure showed that no clearly defined altered layer was detected in all processing modes. The study of microhardness showed that near the surface of the studied samples there is a drop in the level of microhardness. This phenomenon is caused by tempering during the surface heating during processing. The heat-affected zone does not exceed 1.2 mm, and is minimal under high-performance modes.

1. Introduction
In the modern world, the competitiveness of industrial enterprises is determined by the flexibility of production. First of all, this is achieved by introducing new technologies and processing methods. For the manufacture of spatially complex parts by traditional machining, special technological equipment and expensive cutting tools are required. This approach makes the process of readjusting production time-consuming and highly costly. The use of alternative methods for manufacturing parts by three-dimensional copying, such as EDM, is the most promising [1].

The essence of the electric discharge machining method is the gradual melting of particles of the processed material under the action of current pulses, followed by leaching of the resulting erosion products due to the hydrodynamic forces of the working fluid [2]. This method provides the ability to process materials regardless of their hardness. EDM allows obtaining high geometry accuracy and surface finish [3]. Currently, the method of EDM is widely used for the manufacture of work surfaces of the main parts of machines and mechanisms directly involved in the kinematics of work.

A characteristic phenomenon in EDM is the appearance on the treated surface of an altered surface layer. The composition and properties of the changed layer to a greater extent depend on the modes of electrical discharge machining, the processed material, the material of the electrode-tool, as well as on the composition of the working fluid and the process conditions [4]. Since the properties of the modified surface layer can differ significantly from the properties of the base material, this can adversely affect the operational properties of the parts. The study of the influence of modes of electric discharge machining on the structure and properties of the treated surface is important.

For trouble-free operation of product mechanisms, it is necessary to ensure high reliability of the main parts involved in the kinematics of the nodes. This is achieved by using wear-resistant steel grades
for their manufacture. Steel should have a high complex of mechanical properties, providing high resistance to wear in the range of operating temperatures [5, 6]. For these purposes, alloyed thermally hardened steels are widely used, including 40CrNiMo steel.

The process of electric discharge machining of alloy steels is accompanied by a change in the structure of the surface layer consisting of several zones, Figure 1.

![Figure 1. The surface layer of alloy steel after EDM.](image)

1. The zone of saturation with elements of the working fluid; 2. The deposition zone of the material of the electrode-tool; 3. White layer; 4. The zone of thermal influence; 5. The zone of plastic deformation.

The white layer consists of the molten material of the workpiece, the material of the electrode tool and the products of the pyrolysis of the working fluid. The thickness of the white layer depends on the EDM modes, as well as on the thermal conductivity of the material of the workpiece. When processing steels under mild processing conditions, the white layer is distributed on the treated surface in separate sections, up to 40 microns thick and 250-260 microns long. The size of the white layer in the processing of preheated workpieces in soft conditions is little dependent on the temperature of the workpieces. In rough processing conditions, the white layer completely covers the treated surface, and the maximum layer thickness is 165-310 microns. Under the white layer is a phase transition zone caused by heating during erosion. Depending on the material, this zone may contain microcracks, residual stresses and other defects. The zone of phase transformation is followed by the zone of altered grain structure or the released zone [4]. The surface layer of alloyed steels after electric discharge machining at high pulse energies is qualitatively and quantitatively different from the surface layer after processing at minimum conditions [7].

Overheating of the processed material leads to re-tearing and tempering of the material in the processing zone. In this case, in addition to changing the physicomechanical properties of the material, internal stresses occur, which, in turn, can lead to premature failure of the part during operation, and even in the manufacturing process [8].

An analysis of literary sources showed that, due to the lack of understanding of the issue, predicting the structure and surface properties of structural alloyed heat-strengthened steels after electric discharge machining is difficult depending on the processing regimes, there are no recommendations on the designation of processing modes that provide minimal changes in the surface layer.

The purpose of work is to study the influence of modes of electric discharge machining on the structure and properties of structural heat-strengthened steels, not an example of 40CrNiMo steel.

2. Materials and methods

The studies were carried out on a heat-treated (quenching in oil - 850 °C followed by an average tempering of 450 °C in air) sample of 40CrNiMo steel having, after heat treatment, the structure of
tempering troostite. EDM processing was carried out by copper ET on a Smart CNC machine at reference modes in accordance with Table 1.

| №  | I, A | Ton, us | U, V |
|----|------|---------|------|
| 1  | 2    | 40      | 50   |
| 2  | 2    | 150     | 50   |
| 3  | 8    | 40      | 100  |
| 4  | 8    | 150     | 100  |

The microstructure was studied on microsections using an OLYMPUS GX 51 light microscope at magnifications up to 1000. Image processing was performed using OLYMPUS Stream Motion software. Sections were made by pressing samples in a metkon ECOPRESS 100 automatic mounting press and then grinding them on sandpaper with grain sizes from r240 to r1500. After that, polishing was carried out on the canvas using diamond paste. To reveal the structure, the microsection was etched with a 4% solution of nitric HNO3 acid in ethanol.

Microdurometric tests were performed on a PMT-3 microhardness tester. The hardness on the PMT-3 microhardness meter was determined by the method of the reconstructed print by indentation of a tetrahedral diamond pyramid with a square base at a load of 25 grams with a holding time of 10 s.

3. Results
After the implementation of the planned modes of electrical discharge machining, the test samples were cut in cross section using wire cutting EDM machine EcoCut. Next, microsections were prepared in accordance with the claimed methodology, on which microhardness paths were applied with a PMT-3 device from the treated surface deep into the core of the sample. A cross-sectional microstructure was also examined using an Olympus GX-51 microscope. The microhardness measurement results are shown in Figures 2-5.

![Figure 2](image1.png) **Figure 2.** Dependence of microhardness along the depth of steel 40CrNiMo from the surface to the core after EDM according to mode No. 1

![Figure 3](image2.png) **Figure 3.** Dependence of microhardness along the depth of steel 40CrNiMo from the surface to the core after EDM according to mode No. 2
A study of the depth distribution of microhardness under various modes of electric discharge machining (modes No. 1 and No. 3 are low-power, and modes No. 6 and No. 8 are powerful) showed that a decrease in the microhardness level is observed near the surface of the samples under study, which is apparently caused by heating the surface of the samples in the process of electrical discharge machining. The process of additional release of the original structure has occurred. This heat affected zone does not exceed 1.2 mm. Moreover, a preliminary analysis showed that when working in high-performance, powerful modes, a minimal zone of thermal influence is observed, which is caused by a shorter exposure time of the heating to the part due to greater productivity, as well as greater erosion of the part.

The results of the study of the microstructure of the samples after EDM are presented in Figures 6-9.

**Figure 4.** Dependence of microhardness along the depth of steel 40CrNiMo from the surface to the core after EDM according to mode No. 3

**Figure 5.** Dependence of microhardness along the depth of steel 40CrNiMo from the surface to the core after EDM according to mode No. 4

**Figure 6.** The microstructure of the surface of steel 40CrNiMo after electrical discharge machining mode No.1

**Figure 7.** The microstructure of the surface of steel 40CrNiMo after electrical discharge machining mode No.2
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The initial structure of the studied steel is a dispersed tempering troostite with a hardness of 440-460 HV. Under all processing modes by metallographic analysis methods, a clearly defined so-called “white layer” was not revealed. This indicates that there is no overheating of a significant part of the surface to temperatures above the melting point and kneading of the material of the electrode-tool, synthetic oil and electrode-parts. Dispersed tempering structures are observed throughout the depth of 40CrNiMo steel.

4. Conclusions
Based on the results of the experiment and analysis of the data obtained we can draw the following conclusions:
1. Metallographic studies of the surface of 40CrNiMo steel after various modes of electrical discharge machining showed that the “white layer” is not detected using light microscopy methods.
2. An analysis of the distribution of microhardness in depth from the surface to the depth of the 40CrNiMo steel under study after various modes of electrical discharge machining showed the presence of a heat-affected zone, which is characterized by a drop in hardness at the surface of the samples as a result of additional tempering under the influence of heating during the action of the electrode tool.

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