INFLUENCE OF ELECTRICAL DISCHARGE PULSE ENERGY ON THE SURFACE INTEGRITY OF TOOL STEEL 1.2713

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Abstract

Electrical discharge machining (EDM) is precision method of manufacturing complex shape with conductive materials, which is widely used in aerospace, automotive and mold making industries. In EDM material is removing with the series discharges occurring in the gap between two electrodes. Resulting of thermal removal process are specific properties of surface roughness, metallurgical transformations and micro-cracking. This paper is considered on influence of electrical discharge energy on surface integrity. Properties of surface texture and microstructure of tool steel 1.2713 after EDM was described. The experiments were conducted using copper electrode while varying discharge current, pulse duration and pulse interval. Observations of metallographic structure show that discharge energy have a strong influence on thickness of recast layer and heat effect zone. The effect of the parameters of EDM process on surface integrity was described and discussed.

Keywords: Electrical discharge machining, EDM, surface roughness, discharge energy, metallographic structure

1. INTRODUCTION

Modern technology enhances the reliability of machines and parts through proper surface quality. Electrical discharge machining (EDM) is precision method of manufacturing hard, complex shape, conductive materials. EDM is the nonconventional technique of producing parts such as injection molds, forging, aircraft parts. The EDM process involves the removal of material from the workpiece due to series of electrical discharges occurring between the workpiece and the work electrode [6, 7]. The electrodes are immersed in the dielectric fluid. The quality of surface after EDM process does not always meet the expectations. It is necessary to use additional technological operations improving properties of the surface layer, which in consequence leads to an increase in manufacturing costs [1, 2, 5]. The quality of surface layers is one of the most important factors determining its ability to various operating requirements: abrasion resistance, hardness, corrosion resistance, resistance to thermal shocks, coating quality and more [3, 23]. The elimination of the disadvantages of the surface integrity of EDM materials can be realized by: electro discharge mechanical alloying [12, 19, 20], use of powders in dielectric [8, 18, 21], laser surface modification [11], or use of additional processing polishing surface [13]. Research on electrical discharge machining processes conducted at scientific centers around the world is primarily aimed at increasing the efficiency of machining while ensuring a specific surface integrity [4, 9, 10,14-17, 22]. However, influence of discharge pulse energy on the surface integrity are not enough described. In this paper the effect of discharge pulse energy on surface integrity of tool steel 1.2713 was investigated and discussed.

2. EXPERIMNENTAL SET UP

The purpose of the experimental research was to determine influence of electrical discharge pulse energy on the surface integrity tool steel 1.2713. This type of material was chosen because of its wide range of applications on die matrices, matrices inserts, hydraulic and mechanical press dies, which are primarily manufactured using EDM. Tool steel 1.2171 is characterized by high dimensional stability and cracks resistance with dynamically changing pressures and rapid heating and cooling during operation. Experimental investigations were carried out on the EDM machine of Charmilles Form 2LC ZNC. The machined samples steel 1.2713 hardened up to 52 HRC has dimensions of 12 x 12 x 3 mm, electrode was copper and commercial EDM fluid 108 MP-SE 60 was used as the dielectric. Investigation of surface integrity of tool steel 1.2713 after EDM process included analyses of surface texture and metallographic structure. Roughness parameters were measurements on the form Talysurf series 2 scanning profilometer and microscopic observations was carried out on Nikon optic microscope.

Measurement circuit has been developed to determine the current-voltage characteristics of generators machines. Conducted experimental research analyzed pulse current and voltage which was recorded in the memory of the oscilloscope card. Application developed in LabView environment was responsible for control of oscilloscope and transferring recorded data to the computer's hard disk, in a continuous process of EDM. Investigated machining conditions of electrical discharge was: pulse current in the range I_c = 3 - 14.3 A, pulse duration in the range t_{on} = 13 - 400 μs, pulse interval in the range t_{off} = 11 - 170 μs. The rest of parameters of electrical impulses were hold constants: open voltage U_0 - 225 V, discharge voltage U_c - 25 V.

3. RESULTS AND DISCUSSION

The process of removing material from the work surface is completely different from traditional machining methods. The processes occurring during EDM: thermal, chemical and mechanical are the causes of the specific surface properties, which is characterized by the following features. Other part of the surface layer - the surface texture is formed by overlapping traces of individual electrical discharges a new metallographic structure of the surface is formed. Microstructure defects occur in the form of micro-cracks.

3.1. Surface texture

The surface texture after EDM is formed by the overlap of individual electric discharge and is random. Depending on the pulse energy, there are significant differences in its properties. The shape and depth of individual craters depend primarily on the machining parameters used: current, pulse duration, time interval, discharge voltage. The 3D analysis (**Figure1**) of the surface obtained after EDM for roughing and finishing operations shows that the shape of the resulting roughness is a direct result of the applied parameters.

a) b)

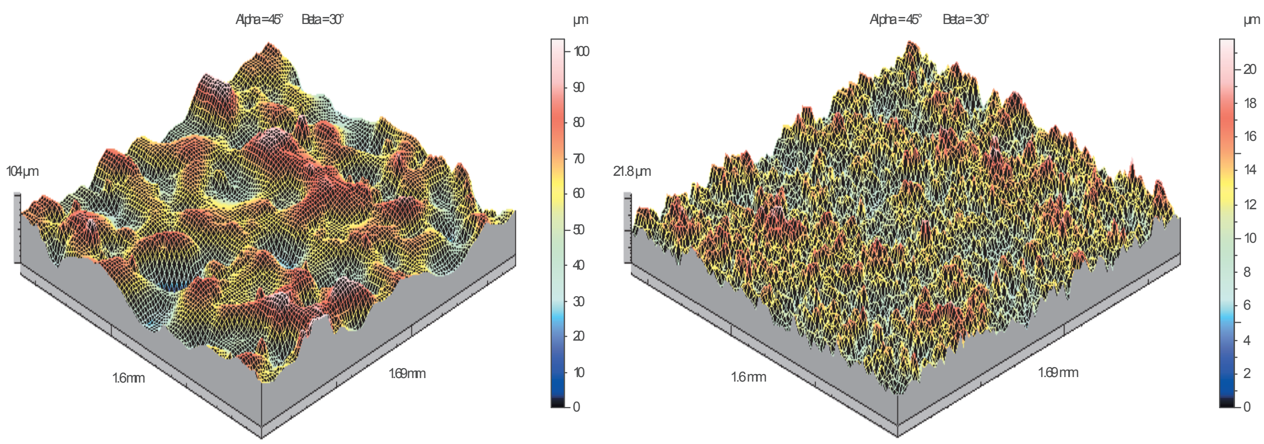

Figure 1 Surface texture after EDM: (a) I_c = 14.3 A, t_{on} = 400 μs, t_{off} = 150 μs, E = 172 mJ, (b) I_c = 3.2 A, t_{on} = 13 μs, t_{off} = 11 μs, E = 1.2 mJ

The discharge voltage U_c has a main influence on the ionization of the channel through which the current flows. For higher discharge voltage, it is possible to set a larger gap between electrodes and thereby facilitate its rinsing and draining of the dielectric products. Discharge current I_c directly affects the amount of eroded material. Maximum current values are used for roughing to ensure proper process performance. Depending on the material of the working electrode, the maximum current density should not exceed 15 A / cm^2 for copper electrodes and 25 A / cm^2 for graphite electrodes. Pulse duration t_{on} associated with the current determines the amount of thermal energy delivered to the workpiece. With the increase in pulse duration and current, both the diameter and the depth of the craters increase. Time interval t_{off} is responsible for stabilizing conditions in the gap (remove erosion products, deionization of the discharge channel).

Analyses of influence discharge energy on roughness parameters *Ra* shows (**Figure 2**) that the parameters of the roughness are mainly dependent on the value of electric discharge energy. With the increased discharge energy roughness parameter *Ra* is increasing. However, these relations are not directly proportional. At low currents (about 3 A) increasing the pulse time (and therefore energy) does not result in a significant increase in the *Ra* parameter. With the same current and with the increasing the pulse time t_{on}, only the diameter of craters changed but the value of *Ra* not changed. With the increasing pulse duration and current, the diameter and the depth of the craters increase. Heat generated in the discharge are delivered to the workpiece and causes melting and evaporation more volume of material.

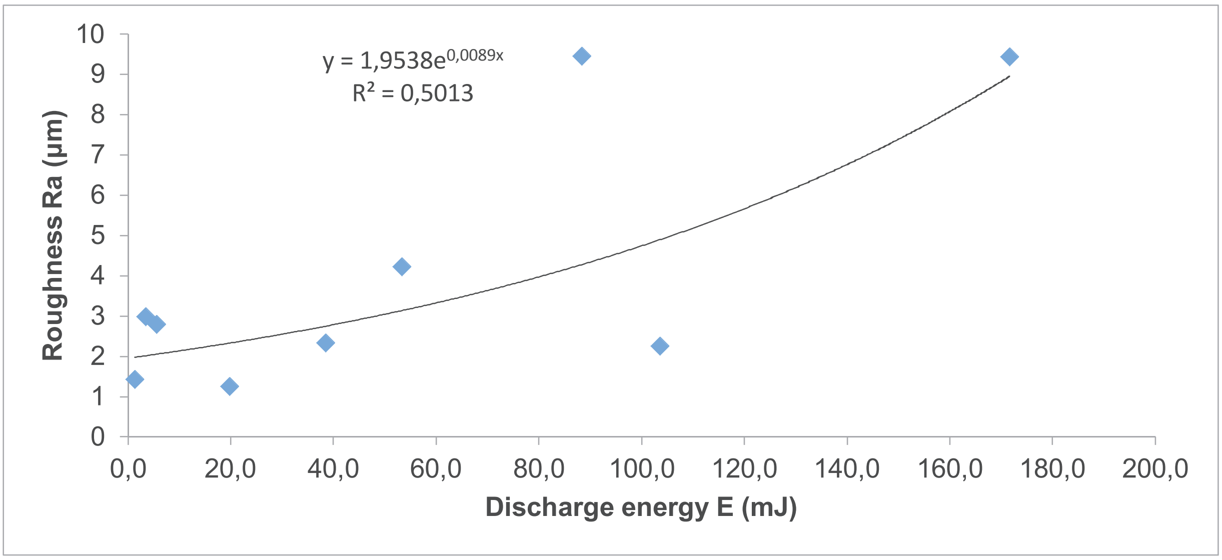

Figure 2 Influence of energy on surface roughness

3.2. Metallurgy structure

EDM is characterized by the impact local thermal processes, resulting change in the surface layer. Based on microscopic studies, three characteristic sublayers have been identified (**Figure 3**): external melting (white layer), heat affected zone (HAZ - which are visible in the form of a light structure directly under the white layer) and tempered layer. The white layer (Wl) is formed by melting and rapidly solidifying the thin metal layer on the surface of the crater. The white layer in its structure may has a chemical decomposition both the core material and the working electrode. This is due to the process of electric discharge, which results in the melting and evaporation of both the workpiece and the working electrode. Under the white layer is heat affected zone, with increased hardness relative to the core material. This layer is built of martensite and residual austenite. The resulting structure formed by the diffusion of carbon from the pyrolysis of the oil and rapid heat dissipation. Under the HAZ, there is a tempered zone. The tempered layer is formed by influence of discharge energy which causing heating of this material zone and then it’s cooling by transport the heat to the bulk. Occurrence of individual layers was observed for all samples.

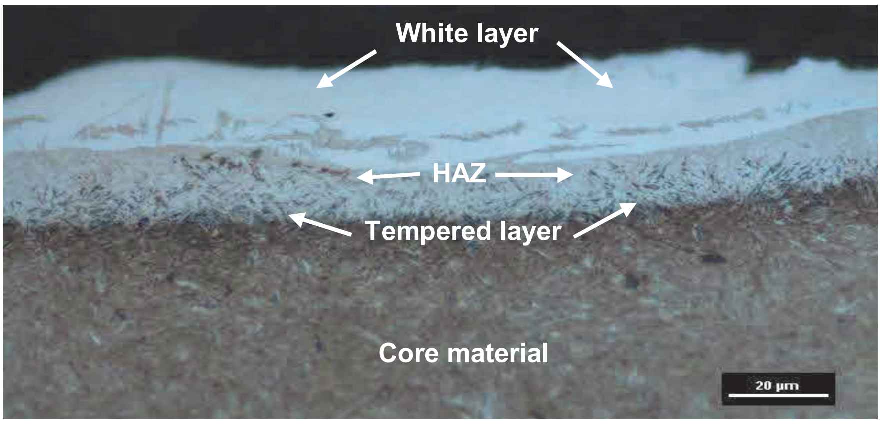

Figure 3 Metallographic structure after EDM process

The basic elements of the metallographic structure which have influence on properties of surface integrity are the thickness of the white layer. The thickness of the white layer was measured in 10 sections for each of the samples. Influence of discharge energy on the thickness white layer show **Figure 4**. The white layer is characterized by high variations in thickness (from 3 µm to 28 µm). The average thickness of the white layer depends mainly on the amount of thermal energy supplied to the workpiece. Increasing the amplitude of the current at the lowest pulse time does not significantly change the WI thickness. This is due to the small amount of eroded material. With grow of discharge energy *E* increase the amount of melted and evaporated material. As a consequence, more molten material which is not remove from the crater, re-solidifies on the surface.

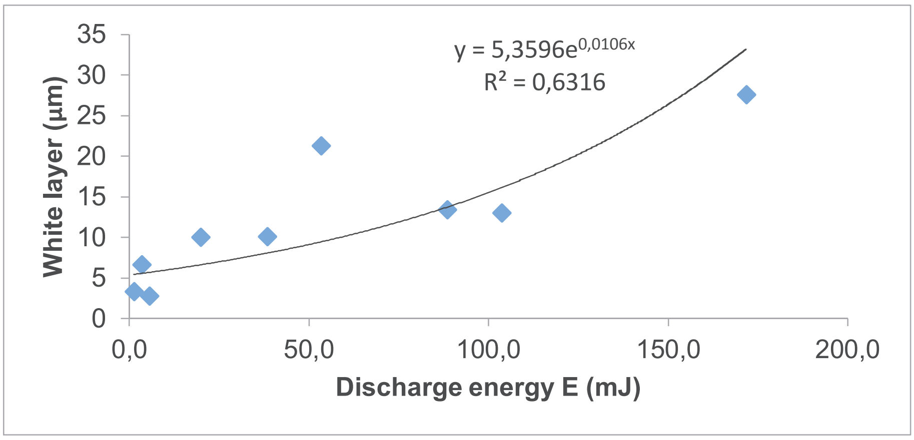

Figure 4 Influence of energy on thickness of the white layer

Electrical discharges lead to local melting, material evaporation, removal of erosion products and rapid re-solidification of the molten metal. The described processes caused to the generation of typical microstructure defects of material such as micro-cracks. Their cause is the thermal stress generated by the effects of thermal energy electric discharge. The molten material is "ejected" from the plasma channel, while a thin layer of molten metal remains on the surface of the material core at a much lower temperature. As a result of the cooling and solidification of the molten layer, a shrinkage is produced which resist the core material and consequently generates tensile stresses. Exceeding the maximum tensile strength of the material cause micro-cracks (**Figure 5**). Micro cracks are an undesirable effect, resulting in reduced fatigue resistance and corrosion resistance. Based on the analysis of images of the metallographic structure of the surface after EDM, micro-cracks have been found on the surface of the crater and are usually directed perpendicular to the HAZ. Micro-cracks in most cases propagate to the end of the white layer. In rare cases, a propagation crack has been observed penetrating into the core of the material.

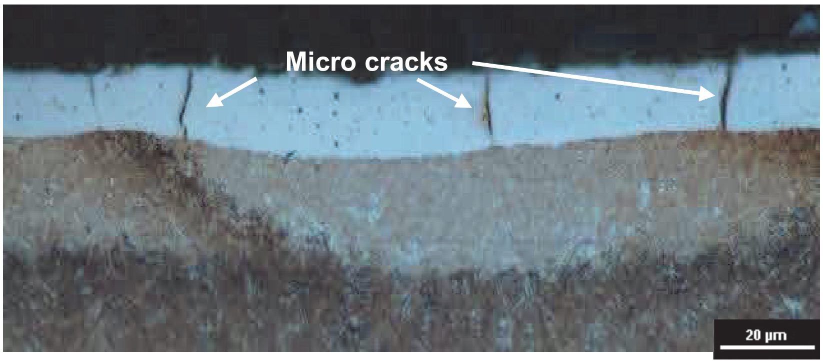

Figure 5 Metallographic structure - micro cracks in the white layer for machining parameters: Uc = 25 V, Ic = 3.2 A, t_{on} = 206 µs

4. CONCLUSIONS

Experimental studies and their analysis show that the main factors influencing the surface texture after EDM is the discharge energy. For short pulse times and the smallest current values, the surface texture is characterized by a high density of vertices. The increase in current and pulse time increases the diameter and power of the discharge channel. Its leading to the generation of roughness of much greater height and distance between the individual vertices. The surface texture after EDM is isotropic. It is possible to obtain remaining surface texture properties by appropriately selecting the process parameters of electrical impulses. The time interval between pulses does not significantly affect the change in surface texture properties, but it plays an important role in the stability of the process. Too short time interval in relation to pulse duration and current values may inhibit removal product of erosions from the gap. Their concentration reduces the dielectric resistance and causes a locally increased number of electrical discharges.

On the basis of microscopic studies, three characteristic layers were found: white layer, heat affected zone (HAZ), and tempered layer. Thickness of white layer depends of the discharge energy, and increase with increasing discharge energy.

Micro-cracks are typical defects of surface integrity after EDM process. In most cases micro-cracks propagate to the end of the white layer.

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