Performance Evaluation of Cryogenically Treated Cu-Cr-Zr Alloy Electrodes in Electro Discharge Machining of AISI P20 Tool Steel

[1]Abdurrahman Cetin, [2]Gultekin Cakir, [3]Necati Ucak *[3]Adem Cicek
[1]Sakarya Vocational School of Higher Education, Sakarya University, Sakarya, Turkey
[2]Cumayeri Vocational School of Higher Education, Düzce University, Düzce, Turkey
*[3]Faculty of Engineering and Natural Sciences, Department of Mechanical Engineering, Yıldırım Beyazıt University, Turkey

Abstract

In this study, the effects of cryogenic treatment on performance of Cu-Cr-Zr alloy electrodes in electro discharge machining (EDM) of AISI P20 tool steel were investigated experimentally. The tool performance was evaluated in terms of electrical conductivity (EC), electrode wear rate (EWR), workpiece wear rate (WWR) and average surface roughness (Ra) of machined surfaces. The EDM tests were conducted at pulse currents of 4A, 8A, 12A and 16A and pulse durations of 25ms and 50ms. In addition, the effects of process parameters on EWR, WWR and Ra were also analyzed for both cryogenically assisted EDM and conventional EDM. Electrodes were cryogenically treated at -140 °C for 30 min. and then tempered at 175 °C for 1 h. Experimental results showed that treated electrodes were less worn than the untreated ones.

Key words: EDM, cryogenic treatment, surface roughness, wear rate.

1. Introduction

Conventional cutting processes are inadequate to machine all of engineering materials with excellent mechanical and physical properties. In addition to difficult-to-cut materials, more complex geometries, tighter tolerances and higher surface quality are required in some industries such as aircraft, automobile, tool, mold making. Conventional machining processes are frequently inefficient to meet these requirements [1]. Therefore, new manufacturing methods called nontraditional manufacturing processes have been developed in past several decades. Unlike traditional methods, in nontraditional manufacturing methods, mechanical, thermal, chemical, electrical energy or combinations of these energies are used instead of cutting tools.

One of these methods is electro discharge machining (EDM) widely used in industrial area. In EDM, machining process occurs between electrode and workpiece by using precisely controlled electric sparks in the dielectric liquid [2]. EDM process is not restricted by strength and hardness of materials. This non-conventional manufacturing method can be applied to any conductive engineering material [3]. Due to lots of advantages in machining of a variety of high strength and complex components which are impossible to machine with traditional methods, EDM is a popular research topic for researchers. To enhance its performance characteristics, EDM process needs improving in terms of better material removal rate, lesser tool wear rate and improved

*Corresponding author: Adem Cicek. Address: Faculty of Engineering and Natural Sciences, Department of Mechanical Engineering, Yıldırım Beyazıt University, 06010, Ankara TURKEY. E-mail address: acicek@ybu.edu.tr, Phone: +903123241555Fax: +903123241505

surface quality. In order to achieve more efficient machining, the effects of process parameters, electrode materials and design and manufacture of electrodes are other major areas of EDM research [4]. Due to the fact that electrode wear rate directly effects dimensional accuracy [5] and the manufacturing costs, EDM electrodes are the most important parts [6] to improve quality of process and reduce process costs. Cryogenic treatment (CT) is one of the processes to improve tool and workpiece quality. It has various advantages like providing more wear resistance for cutting tools, decrease in residual stresses and the retained austenite content, better fatigue strength, hardness, and thermal conductivity [7, 8]. It has lots of applications in physics, chemistry, biology, medicine and engineering [9]. There are several experimental research works to find its effects on machining performance of EDM. Yildiz et al. [10] investigated the effects of cold and cryogenic treatments on beryllium-copper alloy electrodes in EDM. They reported about 20-30% increase in material removal rate by cold and cryogenic treatment processes. Gill et al. [11] studied the effects of deep cryogenic treatment on machinability of titanium alloy in EDM drilling. Results of their experimental study showed that deep cryogenic treatment of Ti-6246 alloy considerably improved machinability in EDM drilling. They observed improvement up to 8.5% for material removal rate, 37.78% for tool wear rate for different drilling times and also significant improvement for surface roughness. Ram et al. [12] carried out parametric analysis on the effect of CT on the work piece material in EDM process. After establishing the optimal process parameters, they compared the effects of treated and untreated workpieces on EDM parameters. Their experimental study showed that CT improved material properties in terms of material removal rate and surface finish. Mathai et al. [13] studied the effects of CT on tool electrodes during EDM. They reported that wear rate of tool electrodes reduced after CT and comparatively fewer influence of CT on material removal rate and surface roughness was observed.

Literature survey showed that CT has significant beneficial effects on electrodes such as further improved wear resistance and better surface quality. The objective of this study is to assess performances of treated and untreated EDM electrodes at different combinations of EDM parameters in terms of electrode wear rate (EWR), workpiece wear rate (WWR) and average surface roughness (Ra) in EDM of AISI P20 tool steel with Cu-Cr-Zr alloy electrodes.

2. Materials and Method

2.1. Test Materials

Cu-Cr-Zr alloy is used as an electrode material in experimental research. Chemical composition of Cu-Cr-Zr electrode is given in Table 1. To observe the effects of CT, electrodes were divided into two groups as treated and untreated electrodes. A group of treated electrodes were cryogenically treated at -140 °C for 30 min and then tempered at 175 °C for 1 h. Untreated ones were used as received.

Table 1. Chemical composition of Cu-Cr-Zr alloy electrode

Cr	Zr	Cu	HB
1.00	0.10	Balance	120-140

AISI P20 tool steel commonly used for plastic injection molds and tooling and casting dies was selected as workpiece material. Chemical composition of AISI P20 tool steel is shown in Table 2.

Table 2. Chemical composition of AISI P20 Steel

C	Si	Mn	Cr	Mo	Ni	S	HB
0.40	0.25	1.5	1.90	0.2	1.0	0.001	280-325

2.2 EDM Tests

A King ZNC K3200 model EDM machine was used for drilling the holes with diameter of 10 mm. The EDM tests were conducted at pulse currents of 4A, 8A, 12A and 16A and pulse durations of 25ms and 50ms. Other machining parameters were kept constant for all tests. Experimental conditions are given in Table 3. At these conditions, treated electrodes were compared to untreated ones in terms of EDM performance and surface quality. Petrofer dielektrikum 358 mineral based oil was used as dielectric fluid.

Table 3. Materials and EDM parameters

Workpiece material	AISI P20 tool steel
Electrode material	Cu-Cr-Zr
Dielectric fluid	Petrofer dielektrikum 358 mineral based oil
Pulse current	4A, 8A, 12A, 16A
Pulse durations	25ms and 50ms
Machining time	20 min

In order to obtain accurate values, the EDM experiments for each combination of machining conditions were repeated three times and study results were accepted as mean value of these test results. Each machining tests was performed for 20 min for both treated and untreated electrodes.

3. Results and Discussion

3.1. Electrical Conductivity

It was reported in literature that the cryogenic treatment increased the homogeneity of the crystal structure of copper alloys, dissolving gaps and dislocations of the alloying elements and consequently, the resulting improved structural compactness improved electrical conductivity [10, 14]. For this reason, EC of Cu-Cr-Zr electrodes were measured using a SIGMATEST D2.068 device to analyze the effects of CT on EC. Mean value of four EC measurements were accepted for both treated and untreated electrodes. EC measurements showed that EC of electrodes increased from 44.16 *m/ohm*.mm^2 to 45.46 *m/ohm.mm*^{2} with CT.

3.2. EWR and WWR Results

In order to calculate the wear rate of workpieces and electrodes, masses of workpieces and

electrodes were determined before (MBT- Mass Before Testing) and after (MAT-Mass After Testing) the EDM process using an analytical balance with 250 g capacity and 0.0001 g accuracy. EWR and WWR were calculated with following equations:

$$EWR = (MBT_{electrode} - MAT_{electrode})/t \text{ (gr/min)} \quad (1)$$

$$WWR = (MBT_{workpiece} - MAT_{workpiece})/t \text{ (gr/min)} \quad (2)$$

Where, t is machining time. With these equations, treated and untreated specimens were compared with regard to EWR and WWR performances. Figure 1 indicates the experimental results for EWR. When EWR values of treated and untreated electrodes were compared, experimental results showed that treated electrodes were less worn than untreated ones by about 7% and 3% at 25ms and 50ms pulse durations respectively. CT decreased the wear rate of electrodes due to their increasing electrical and thermal conductivity. Figure 2 shows 8x magnified SEM pictures of treated and untreated electrodes.

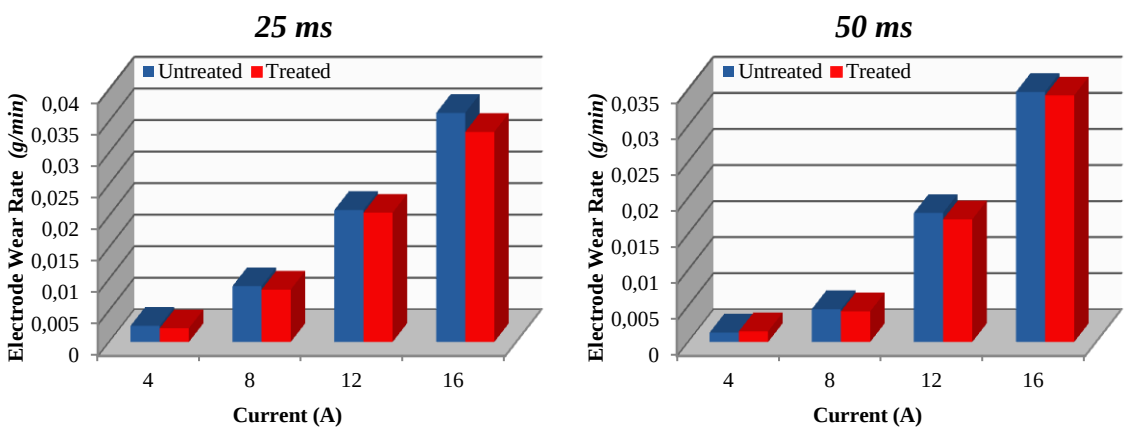
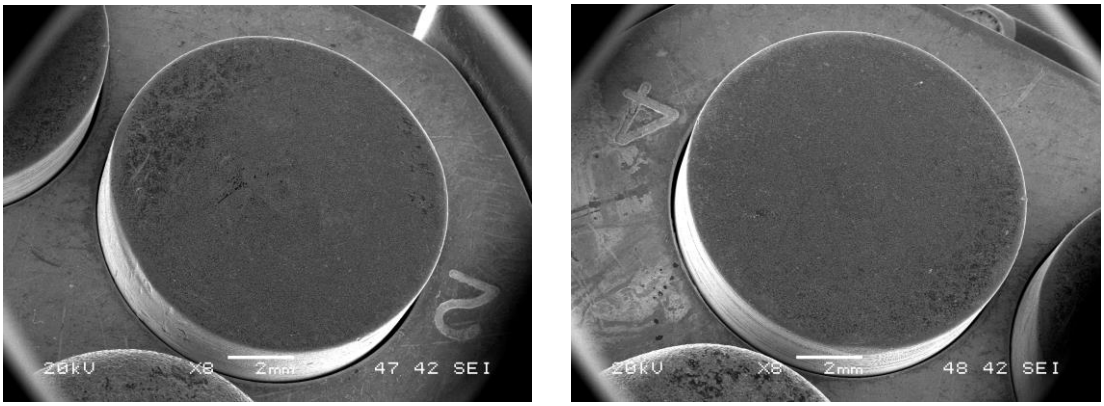


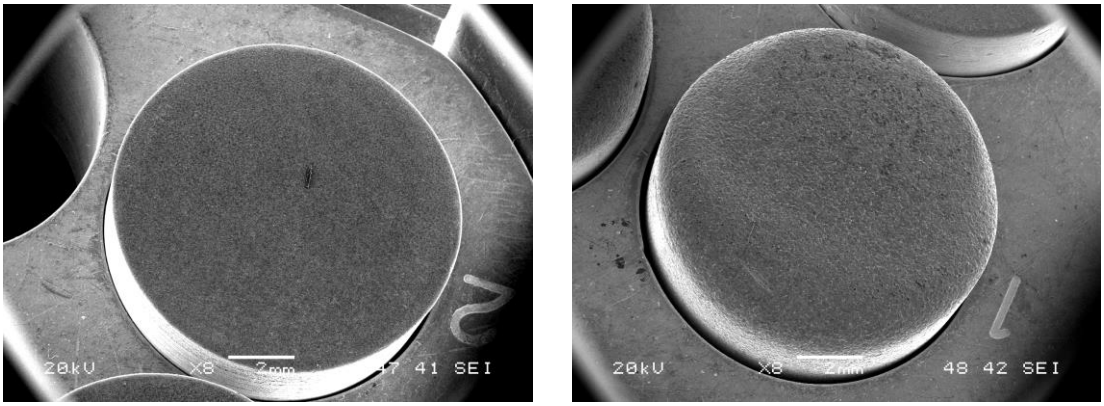
Figure 1. EWR values at 25ms and 50ms pulse durations.

EWR substantially increased with increasing pulse current (Figure 3). The EWR from 4A to 12A increased by about 1431% for treated electrodes and 1315% for untreated electrodes at 25ms pulse duration, and 2218% for treated electrodes and 2537% for untreated electrodes at 50ms pulse duration. On the other hand, increasing pulse durations led to decreases in the EWR [15, 16, and 17] (Figure 4). From 25ms to 50ms pulse duration at the same currents, averagely 29% decrease in wear rate of untreated electrodes and 24% decrease in wear rate of treated electrodes were observed. It is well-known that EWR increases with increasing pulse current and decreasing pulse duration [15].



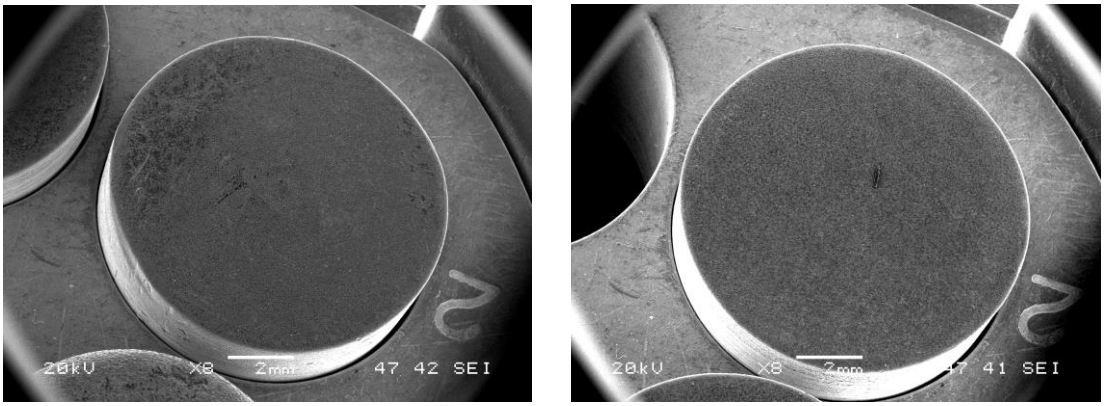
a) b)

Figure 2. The effect of CT on electrode wear of, a) Treated, b) Untreated electrodes at same machining conditions



a) b)

Figure 3. The effect of current on electrode wear, a) 4A current, b) 16A current at 50ms pulse duration



a) b)

Figure 4. The effect of pulse duration on electrode wear, a) 25ms pulse duration, b) 50ms pulse duration at 4A current

On the other hand, WWR values under different currents and pulse durations are shown in Figure 5. WWR decreased averagely 4% due to the effects of CT. This treatment provides better electrical and thermal conductivity to materials, which reduces bulk electrical heating, so there is less excessive melting of the tool and the workpiece and therefore resulting lesser WWR [18]. Also according to Figure 5, WWR values are higher at 25ms than ones at 50ms. The probable reason for this could be that with high pulse-on duration, workpiece is melted more and needs longer pulse-off time to remove melted particles. However, if pulse-off time is too short (as 5 ms in this study), melted part of the workpiece cannot be removed by dielectric liquid, due to lack of sufficient time so it remains in the spark gap, so resulting in decreasing WWR [19].

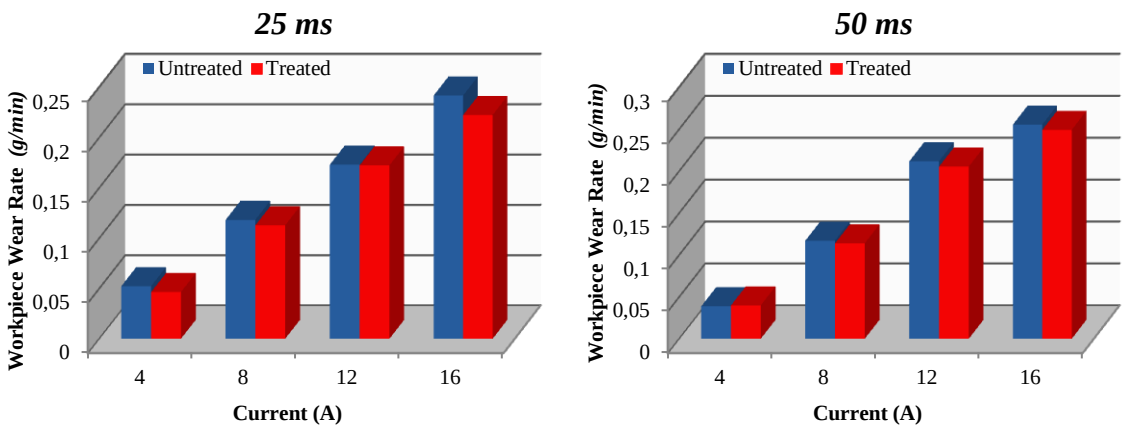


Figure 5. WWR values at 25ms and 50ms pulse durations.

3.3. Surface Roughness (Ra)

The roughness of the machined bottom surfaces for each machining condition was measured using a Taylor Hobson Surtronic 25 portable surface roughness tester and the Ra values were accepted as mean value of three determinations on bottom surface of the hole. Figure 3 indicates Ra measurements results.

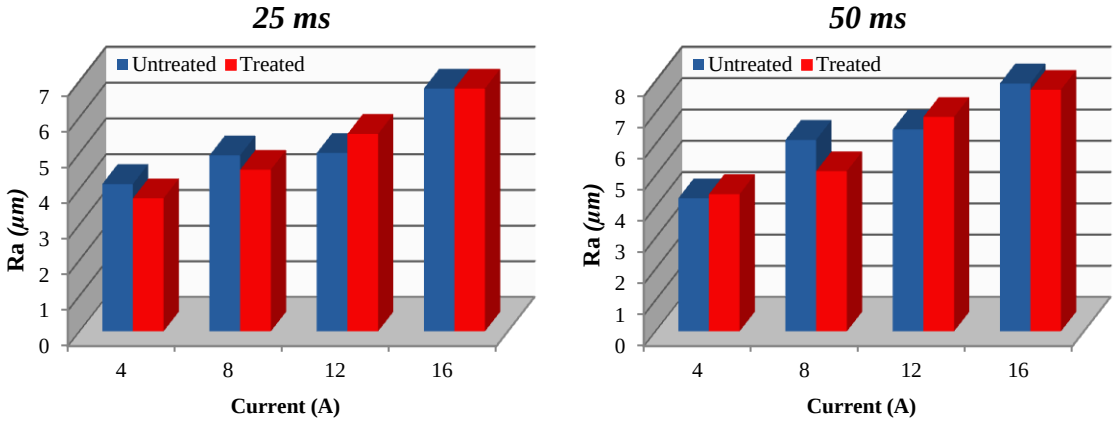


Figure 6. Ra values at 25ms and 50ms pulse durations.

It is well-known that EDM process takes place by the formation of craters due to the sparks and it is clear that smaller crater dimensions result in better surface quality. Thus, increase of the energy of pulse, increases WWR and decreases surface quality [20] as can be seen from test results. According to means of data, there is about 21.5% increase in Ra from 4A to 12A currents. Although untreated electrodes Ra is better than treated ones in some conditions, it was observed that treated electrodes have averagely 1.3% and 2.7% better surface quality at 25ms and 50ms pulse durations respectively.

Conclusions

In this study, effects of CT on EDM process were investigated at different working conditions. Experimental results showed that EWR and Ra values were lower in EDM process in which cryogenically assisted electrodes were used. Further there is a slight increase in EC. It is recommended that further studies can be carried out at different EDM parameters such as deeper cryogenic temperatures and different tempering temperatures.

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