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Research Article

Surface Characterization of Electrical Discharge Machined AISI 630 Stainless Steel

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Abstract

AISI 630 (17-4 PH) is a martensitic stainless steel type produced by precipitation hardening heat treatment. It is a material that is difficult to process with traditional manufacturing methods due to its high strength and hardness. Electrical discharge machining (EDM) is often used as a very effective method for processing hard-to-cut materials. One of the most critical parameters in EDM is discharge current. Surface characterization of the samples processed at 7A, 12A, 22A current values was performed by linear surface roughness results, XRD, and SEM analysis. As a result of the study, it was seen that the current significantly affects the surface characterization of AISI 630 (17-4 PH) stainless steel with EDM.

Keywords: Electrical Discharge Machining (EDM), 17-4 PH Stainless Steel, Surface Characterization

Elektro Erozyonla İşlenmiş AISI 630 (17-4 PH) Paslanmaz Çeliğinin Yüzey Karakterizasyonu

Öz

AISI 630 (17-4 PH) çökelme sertleşmesi ısıl işlemi ile üretilen bir martenzitik paslanmaz çelik türüdür. Yüksek mukavemet ve sertliğinden dolayı geleneksel imalat yöntemleriyle işlenmesi zor bir malzemedir. Elektro erozyonla işleme (EDM), işlenmesi zor malzemeleri işlemek için çok etkili bir yöntem olarak sıklıkla kullanılmaktadır. Elektro erozyonla işlemede en önemli parametrelerden birisi akımdır. 7A, 12A, 22A akım değerlerinde işlenen numunelerin yüzey karakterizasyonu, çizgisel yüzey pürüzlülüğü sonuçları, XRD ve SEM analizleriyle yapılmıştır. Yapılan analizler sonucunda akımın, AISI 630 (17-4 PH) paslanmaz çeliğin elektro erozyon ile işlenmesinde yüzey karakterizasyonunu önemli ölçüde etkilediği görülmüştür.

Anahtar Kelimeler: Elektro Erozyonla İşleme, 17-4 Ph Paslanmaz Çelik, Yüzey Karakterizasyonu

1. Introduction

AISI 630 (17-4 PH) stainless steel, a type of martensitic stainless steel, is frequently used in many areas such as aviation, food, chemistry, power plants, and paper industry due to its superior corrosion resistance and strength properties [1, 2, 3]. It is called 17-4 PH stainless steel because it contains 17% Cr and 4% Ni and undergoes precipitation hardening heat treatment. Precipitation hardening heat treatment is carried out by impregnating copper in the crystal structure and subjecting it to grain coarsening at specific temperatures. Thus, the strength of the steel can reach the desired values. Table 1 shows the strength values of 17-4 PH stainless steel. It is understood from the table that heat treatment temperatures affect the strength values very much.

Table 1. Mechanical properties of 17-4 PH stainless steel [4].

Properties	Condition						
	A	H900	H925	H1025	H1075	H1150	H1150 - M
UTS (MPa)	1103	1379	1310	1172	1138	1034	945
0.2% YS (MPa)	793	1275	1207	1138	1103	896	765
Elongation, % in 50.8mm	5	9	9	10	11	12	17
Rockwell Hardness C	35	45	43	38	37	33	31

Since they are produced by precipitation hardening heat treatment, their strength values are very high. For this reason, 17-4 PH stainless steel, which is a material that is difficult to process with traditional processing methods, can be sensitive to high processing temperatures due to the dissolved Cu in its structure. High processing temperatures affect the material properties by causing the Cu atoms to become coarse. For this reason, unconventional machining methods are used to process 17-4 PH stainless steel. One of the frequently used methods to process hard-to-cut materials is electrical discharge machining (EDM) [5-9]. Sparks are created at regular intervals by sending electrical currents on a conductive workpiece with the help of an electrode. These sparks melt a tiny area of the base material, and the dielectric fluid moves these chips away from the workpiece, forming the workpiece. One of the most important results in EDM machining is surface roughness. Since the surface roughness is directly affected by the processing parameters, the EDM machine settings can be adjusted according to the desired surface roughness values.

Nagaraju et al. [10] machined 17-7 PH stainless steel with EDM. They analyzed material removal rate (MRR), surface roughness, and overcut outputs using current, pulse on time, voltage, and gap parameters. When the results of the experiment conducted according to the Taguchi experiment design are examined, it is seen that the parameter that most affects the surface roughness is the current density.

Balamurugan et al. [11] analyzed the material removal rate, surface roughness, and electrode wear rate results by processing 15-5 PH stainless steel with EDM according to the Taguchi experiment design. They defined three levels for each of the parameters voltage, current, pulse on time, pulse off time, electrode shape, and pressure. As a result of the processing studies, it was determined that the parameter that most affects the surface roughness value in both coated and uncoated copper electrodes is current.

Ablyaz et al. [12] examined the surface characterization of duplex stainless steels after the EDM process using parameters of current, pulse on time, pulse off time, electrode type, and dielectric medium. They examined the material removal rate and surface roughness outputs. As a result of the analysis of variance (ANOVA), they determined that the parameters that most affect the surface roughness are electrode type, pulse on time, current, dielectric medium, and pulse off time, respectively.

Kumar et al. [13] processed D3 stainless steel with EDM in their study with the Taguchi experimental design method. By changing the current, pulse on time, and voltage parameters, they examined the outputs of MRR, tool wear rate (TWR), and SR. As a result of the ANOVA analysis, the parameters most affecting the surface roughness were found pulse on time, voltage, and current, respectively. The reason why the current is the least affecting parameter is thought to be due to the low current values and the fact that there is not much difference between the current levels.

Jampana et al. [14] processed AISI 630 stainless steel with EDM. Their processing studies with current, pulse on time, pulse off time, and flushing pressure parameters examined the SR and MRR values. As a result of Taguchi analysis, they concluded that the parameter that most affects surface roughness is current.

According to the literature results, the most critical parameter affecting the surface roughness is discharge current in EDM. Therefore, in this study, the effect of different current values on the surface properties of 17-4 PH stainless steel was investigated.

2. Material and Method

2.1. Edm Studies

Ajan 982 model machining device shown in Figure 1 was used for EDM studies. Three samples were machined for each density level. The processing surfaces of the samples and electrodes were subjected to surface preparation processes before each machining operation. Thus, the effect of surface roughness before processing has been eliminated.

Figure 1. EDM Machine.

AISI 630 SS (17-4 PH) was used as the workpiece and a copper alloy was used as the electrode material. The chemical compositions of the workpiece and copper electrode are given in Table 2 and Table 3, respectively. Chemical analysis of the samples (XRF) was performed and compared with the theoretical values (Table 4). A great deal of agreement was observed between the theoretical values and XRF analysis values.

Table 2. Chemical composition of 17-4 PH stainless steel (wt. %)

C	Mn	Si	P	S	Cr	Ni	Cu	Nb+Ta	Fe
0.07	1.00	1.00	0.040	0.030	15.0	3.0	3.0	0.15	Balance
					17.5	5.0	5.0	0.45	

Table 3. Chemical composition of copper electrode used in machining (wt. %)

Cr	Zr	Cu
1.00	0.1	Balance

Table 4. XRF analysis of 17-4 PH stainless steel (wt. %)

Mn	Si	P	Cr	Ni	Cu	Nb+Ta	Fe
0.45	0.43	0.03	15,72	4.53	3.11	0.29	Balance

Its effect on the processing surface has been investigated by changing the discharge current as of the processing parameter. Parameters such as pulse-on time, pulse-off time, voltage, dielectric fluid, and dielectric pressure were kept constant in all experiments. Machining parameters are given in Table 5.

Table 5. Machining parameters

Parameters	**Levels**
Current	7A, 12A, 22A
Pulse-on Time	50 µs
Pulse-off Time	25 µs
Voltage	60 V
Dielectric Pressure	Level 1

2.2. Surface Roughness Studies

Nanovea brand optical profilometer device was used for surface roughness tests (Fig. 2). Linear surface roughness (Ra, Rz) values were calculated from 9 regions for each sample. Thus, it is ensured that craters, debris, and mounds caused by EDM do not cause errors in the measurement results.

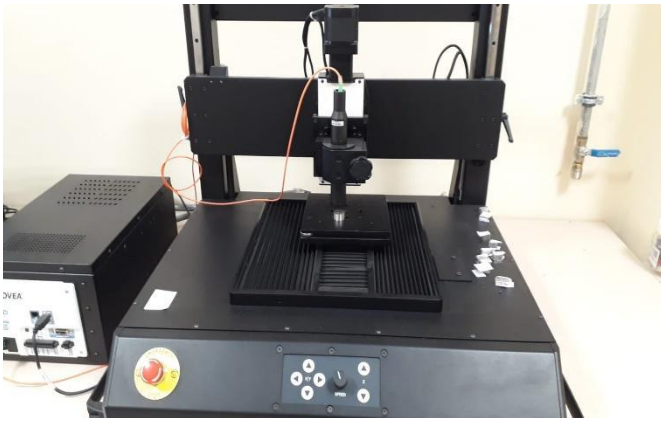

Figure 2. Optical profilometer device.

2.3. XRD and SEM Studies

Due to the partial melting zones and residues formed on the machining surface during EDM, the machining surface may show different characteristics than the main material. XRD experiments were performed on the Bruker Axs D8 Advance model device in order to determine the compounds formed and the mechanisms that cause them.

In order to see the results of the destruction caused by the current on the processing surfaces, SEM images were taken on the Leo 440 model device. Thus, the effects of the current on the machining surface were examined by imaging the structures such as craters, pits, and mounds formed on the surface.

3. Results and Discussion

3.1. Surface Roughness Results

The average linear surface roughness (Ra, Rz) obtained from the profilometer device is shown in Table 6. When the results are examined, it is seen that the surface roughness increases as the current increases. The biggest reason for this is that as the current increases, the intensity of the electrical discharges between the electrode and the workpiece also increases. Increasing forceful electrical discharges rip off larger pieces of material, leaving pits, debris, and large bumps in the workpiece. Thus, Ra, which is the average value of surface roughness, and Rz, which is the average of the largest hillocks and pits, are higher.

Table 6. Surface roughness vs. current

Current	Ra	Rz
7A	2,847	13,5
12A	4,053	22,1
22A	4,417	26,67

A surface roughness graph for each processing parameter is also given in Fig. 3. As can be seen from the graphs, it is seen that as the current increases, the indentations and protrusions also grow. A direct proportion has been determined between the current and the surface roughness values (Fig. 4-5). When Fig. 4 and 5 are examined, when the current reaches 22A from 12A, the roughness value of Rz showed a sharper increase compared to Ra. This explains that increasing current creates deeper pits and higher peaks in the machining surfaces.

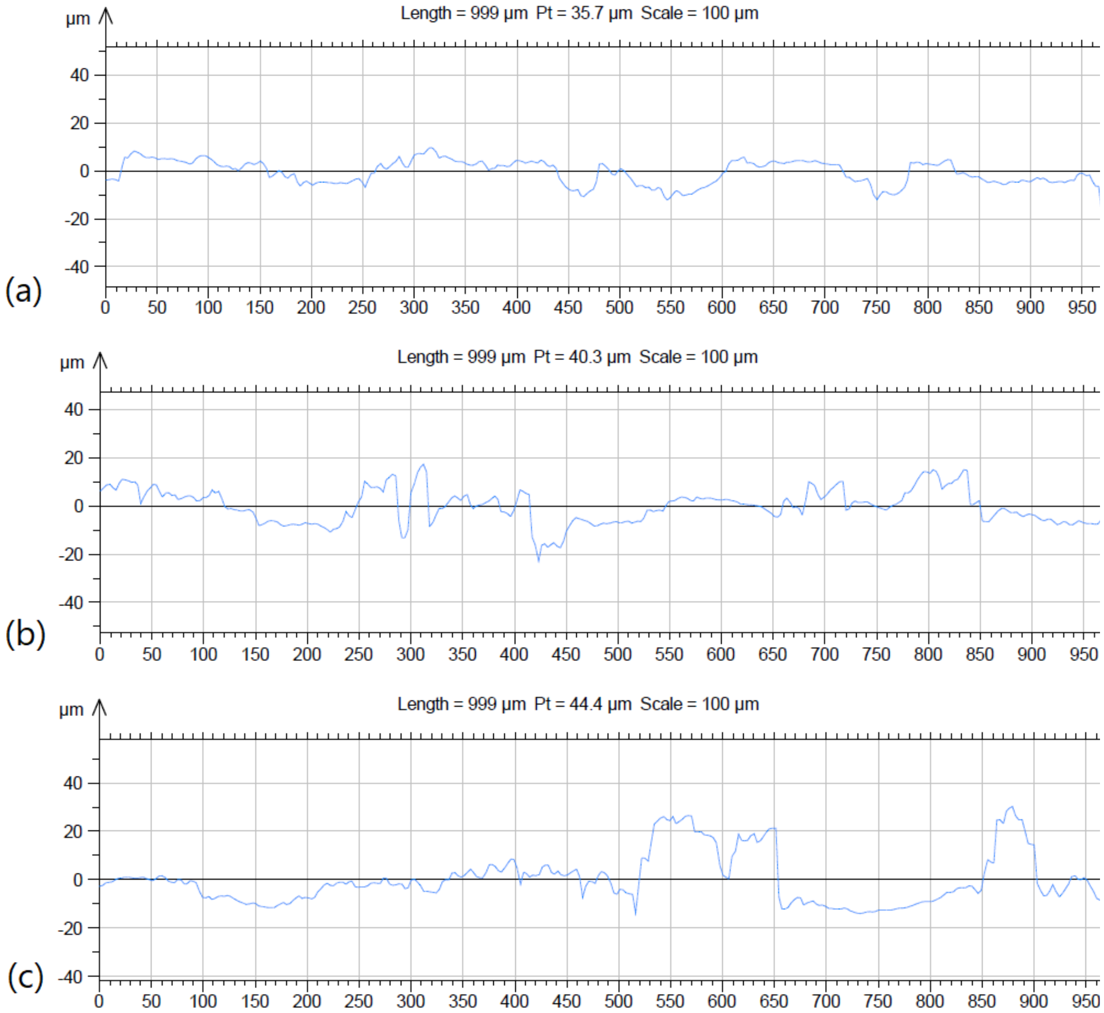

Figure 3. Examples of surface roughness measurement charts of machining surfaces; (a) 7A, (b) 12A, (c) 22A

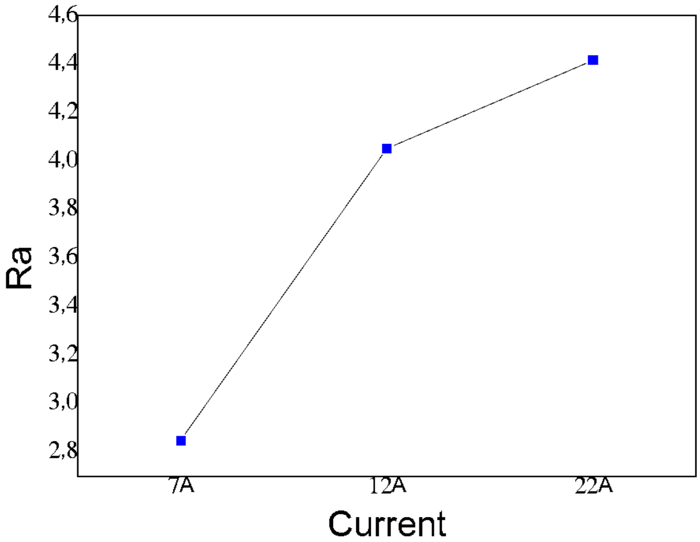

Figure 4. Current vs. Ra

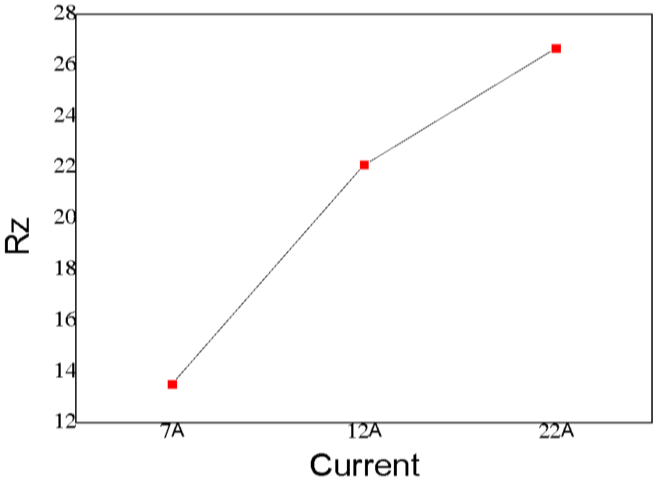

Figure 5. Current vs. Rz

3.2. XRD and SEM Results

The XRD analysis results to determine the compounds formed on the surfaces of stainless steel samples processed at 7A, 12A, and 22 A current intensity are given in Fig. 6. When the XRD analyzes are examined, it is seen that the intensity and sharpness of the peaks increase as the current increases. This shows that the crystallite size grows and expands. It can be interpreted that the rise in the current results in more crystallization on the surface.

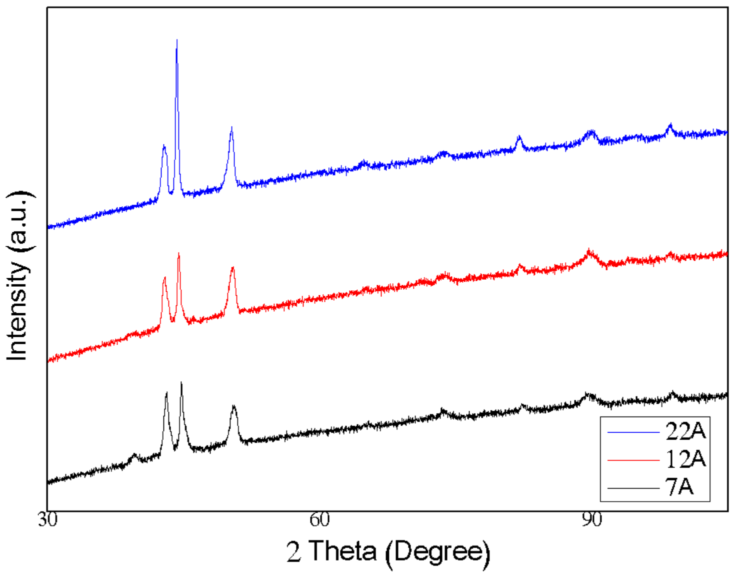

Figure 6. XRD patterns of specimens

SEM images of samples machined with three different parameters are given in Figure 7. All three pictures show melting zones, solidification zones, cracks, and craters. Especially due to the high sparking that occurs as the current increases, there are many solidification zones in the 12A and 22A samples. Because increasing current and sparks heat the material more and provide more melting. It was determined from the images that the surface roughness increased due to the higher MRR that occurs as the current increases.

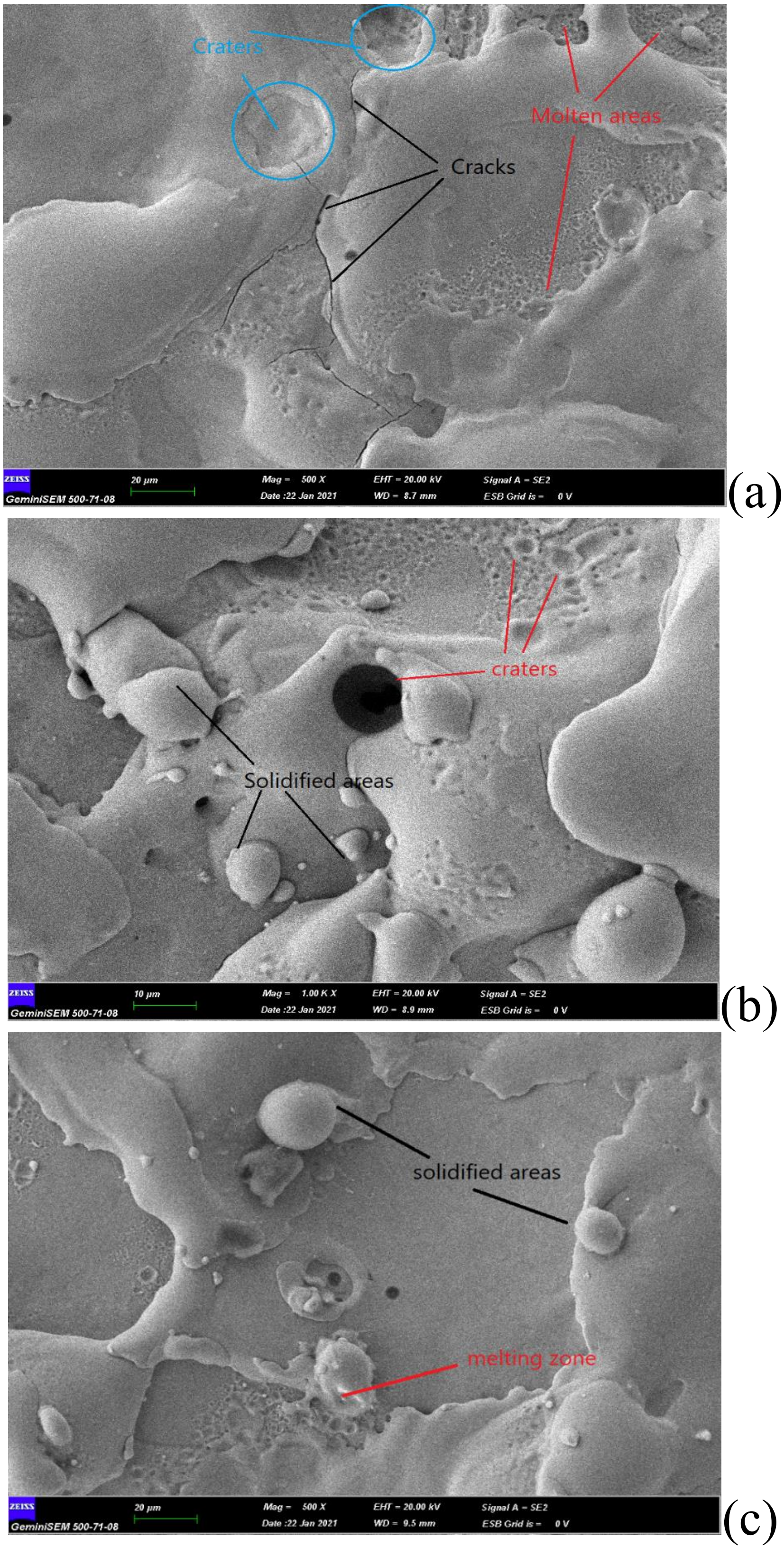

Fig. 7. SEM images of machined surfaces respectively; (a) 7A, (b) 12A, (c) 22

4. Conclusions and Recommendations

Surface characterization was investigated by processing AISI 630 (17-4 PH) stainless steel with 7A, 12A, 22A current values with EDM. As a result of the characterization studies, the following results have been achieved.

- As the current increased, the surface roughness (Ra, Rz) values also increased. This situation arises from the fact that the current intensity increases the MRR and removes more chips from the workpiece.
- When the current increased from 12A to 22A, the Rz value increased more sharply than Ra. This is because as the current increases, the machining surface causes more indentations and protrusions.
- When the XRD patterns were examined, it was seen that the peaks were sharper and larger as the current increased.
- SEM images showed melting zones, solidification zones, cracks, and craters. It is understood from the images that the surface roughness increases as the current increases.

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