Influence of Coolant on the Performance of Electro Discharge Hole Drilling

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ABSTRACT

In the present study, a comparative study of hole-EDM drilling of die steel, namely as DIN 1.2080 using electrical discharge machining method was performed in order to discover the effects of coolant types, namely distilled-water, kerosene and water. The electrical parameters of electrical discharge machining process were taken as constant. the performance parameters were defined as machining speed, electrode wear, surface roughness value (R_a) and white layer thickness. The experimental results reveal that the increasing the current causes decreasing in machining speed, increasing in white layer thickness, increasing in electrode wear and decreasing in surface quality of electrical discharge machining process. The distilled-water has comparatively better results than the other coolant types. The results indicated that machining speed 101 mg/min, electrode wear 4,9 mg/min and surface roughness value R_a 2,7 µm were obtained by using distilled-water at 10 A current level.

Keywords: EDM, EDM Drilling, Coolant, Kerosene, Distilled-water.

Soğutma Sıvısının Elektriksel Erozyon Delik Delme Performansı Üzerine Etkileri

ÖZ

Bu çalışmada, delik elektriksel erozyon işleme yöntemi kullanılarak DIN 1.2080 kalıp çeliğine 2 mm çapında delikler delinmiş ve farklı soğutma sıvılarının performansa etkileri incelenmiştir. Musluk suyu, saf (de-iyonize) su ve kerosenin kullanıldığı deneysel çalışmada elektriksel erozyon işleme parametreleri sabit tutulmuştur. Performans parametreleri olarak; iş parçası işleme hızı elektrot aşınması, yüzey pürüzlülük değeri (R_a) ve beyaz katman tabakası kalınlığı alınmıştır. Deney sonuçları, elektriksel erozyon parametrelerinden akımın artması, işleme hızını yavaşlatmış, beyaz katman tabakasını arttırmış, elektrot aşınmasını arttırmış ve yüzey kalitesini kötüleştirmiştir. Ayrıca soğutma sıvısı olarak de-iyonize suyun kullanımı diğer soğutma sıvılarına göre daha iyi sonuçlar vermiştir. Sonuç olarak, 101 mg/dak işleme hızı, 4,9 mg/dak elektrot aşınması ve 2,7 µm ortalama yüzey pürüzlülük değeri, 10 A akım değerinde de-iyonize su kullanıldığında elde edilmiştir.

Anahtar Kelimeler: EEİ, EEİ Delik Delme, Soğutma Sıvısı, Kerosen, De-iyonize Su.

1. INTRODUCTION

Electrical discharge machining (EDM) is one of the advanced metal cutting process that it takes place the conventional machining processes such as drilling and milling. EDM is proficient of machining complex geometries and advanced materials that are specified as hard to machine materials. EDM processes are classified into three main categories such as Wire-EDM, Sink-EDM and Hole-EDM. sink-EDM is used for manufacturing the dies whose shape is the reversed of the electrode tool. Wire-EDM is used to manufacture extrusion dies brass and copper electrodes are used in wire-EDM process. High diameter to depth ratio holes are drilled by Hole-EDM process by using 6 mm to 0.3 mm tabular brass and copper electrodes. Drilling small holes is one of the main machining processes; approximately 35% of all manufacturing time is spent to drill holes. Conventional drilling techniques cannot be employed to produce narrow holes on advanced materials as tool breakage/wear and slow machining speed cause imprecise hole sizes and improper surface characteristic. The performance of advanced parts such as combustion chambers and turbine blades directly related to the great number of slight cooling holes for hot components.

Conventional cooling holes have diameter from 2 to 4 mm and have length to diameter ratio from 1 to 200 [1]. Electrical discharge machining process takes away microchips from the workpiece surface by aid of a sequence of repetitive electrical flushing. The EDM process is accomplished by applying a sequence of distinct discharges between the workpiece and the electrode cooled by a coolant. By using hole-EDM process; injection mould cooling holes, fuel injectors, turbine blade holes and starting holes of wire-EDM are machined [2-4]. The main performance parameters of hole-EDM process are the machining speed, electrode wear, surface quality and the white layer thickness [1]. In all EDM processes, white layer (recast layer) is generated. The workpiece profile, surface quality and the

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dimensional accuracy are directly related to the white layer characteristic [5].

Eyercioglu et al. [1] reported that the effect of EDM parameters is more important than the effect of the other parameters on hole-EDM process. Yilmaz and Okka [6] investigated the single and multi-channel copper and brass electrodes in hole-EDM process for Inconel and titanium alloys. They concluded that the brass electrodes have better MRR and EW performance then copper electrodes. And also, they showed that the single-channel electrodes have better performance than the multi-channel electrodes. Though, the surface quality is better when using multi-channel brass electrode. Kuppan et al. [7] reported that MRR is affected by duty factor, tool rotation and current, while current and pulse on time effect the surface quality. Singh et al. [8] studied the effect of EDM parameters over performance parameters of sink-EDM and they concluded that taper angle, MRR, surface quality and increase whereas the pulse on-time and current were higher. Özgedik [9] studied the history of the electric discharge machining process as a non-traditional manufacturing area. The performance of the Wire-EDM process [10-12] was studied and the effects of input parameters on performance were discussed by some researchers. In micro hole-EDM process, the effect of pulse energy on surface quality and workpiece geometry for blind holes was studied by Ekmekci et al. [13]. The effects of input parameters on the response parameters for example surface quality and average circularity of the drilled holes in nickel-based super alloy was studied by Yadav et al. [14]. Janmanee and Muttamara [15] studied the effect of EDM parameters on EWR, MRR and taper angle of AISI 431 martensitic stainless steel. The recast layer creation was much thinner by using oxygen-assisted hole-EDM machining process. Gov [16] investigated that the effects of the dissolved oxygen in the coolant on the hole-EDM performance parameters such as MR, EW, surface quality, over cut, taper and WLT. The results showed that the increasing in the oxygen dissolution in the coolant, improving the performance parameters. The vibration effects on EDM performance was studied by Çogun et al.[17, 18] they concluded that the EDM performance was improved by using vibration on EDM process. The variations of machining performance outputs were studied with the EDM parameters for metallic powder mixed coolant in EDM by Çogun et al. [19] it is reported that the powder concentration and powder type in the coolant and the pulse-on time were current output parameters of EDM process. The powder mixed EDM was studied by Ekmekci et al. [20], the SiC powder mixed distilled water was used as coolant fluid. They concluded that the surface morphology extremely affected the powder as means of secondary discharges and particle migration from dielectric liquid. Some researcher studied the different coolant types, especially water was used as coolant in EDM process [21-23]. Yan and Chen [24] studied the effect of different coolant for the titanium alloys, and showed that when kerosene is used as a coolant, the material removal rate is lower and electrode wear rate is higher compared to the distilled-water. The urea added distilled-water was studied by Yan et al.[25] It is indicated that the nitrogen decomposed from the coolant, resulting in good wear resistance of the machined surface after EDM. In this study, electro discharge hole drilling process was applied to DIN 1.2080 die steel by using single-channel brass electrode and three types of coolants (Distilled-water, kerosene and water). In the study the electro erosion parameters of arc on-time (T_{on}), arc off-time (T_{off}), and capacitance (C) kept constant and the effect of the current (I) and coolant types on the performance parameters such as machining speed (MS), electrode wear (EW), average surface roughness value (R_a), and white layer thickness (WLT) were examined.

2. MATERIAL AND METHOD

Experiments were performed by using JS-EDM AD-20 type hole electrical discharge machine. The samples were prepared by 10x10x40 mm DIN 1.2080 die steel which were cut by wire electro discharge machining. Each face of the samples was ground by emery papers gradually and polished by using 1 µm diamond suspension before drilling. 2 mm diameter single-channel brass electrode was used for drilling the holes which were drilled on the centre of the matched polished faces vertically (Figure 1.). The major electrode material properties are given in Table 1. Experiments were performed in three repetitions and the performance parameters were defined by the average of these three measurements. EDM parameters such as current, arc on-time, arc off-time, and capacitance were chosen as the optimum values which were reported by Eyercioglu et al. [1] The list of the EDM parameters are given in Table 2.

Table 1. Electrode Properties

Electrode	Brass
Melting point (ºC)	900-950
Thermal conductivity (W/m-ºK)	160
Electrical resistivity (ohm-cm)	4.71
Specific heat capacity (J/g-ºC)	0.38

Table 2. Experimental Parameters

Fixed parameters	Value
Time on, T_{on} (µs)	30
Time off, T_{off} (µs)	10
Capacitance C (µF))	1422
Voltage (volt)	30
Electrode rotation (rpm)	200
Coolant pressure (bar)	100
Electrode polarity	Negative (-)
Variable parameters	
Coolant types	Distilled-water, Kerosene, Water
Current, I (Ampere)	10,11,12

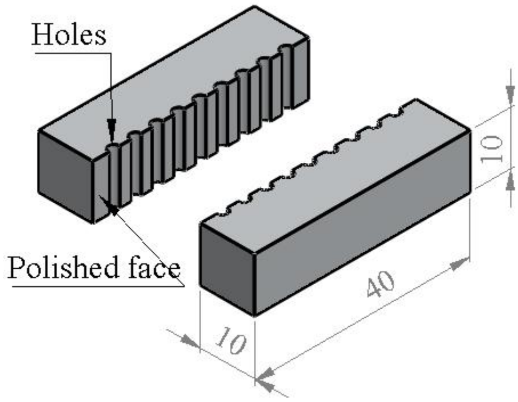

Fig. 1. Photograph of the specimen

EDM drilling process is schematically explained in Figure 2. Spark intensity is concentrated on the tip of the electrode in EDM drilling process. This spark intensity causes high erosion at the tip of the electrode rather than the other portion of the electrode. This high erosion causes the taper on the tip. The electrode is initially flat and sharp edges (Figure 2-a). Taper is created during the EDM drilling process due to the high-level erosion (Figure 2-b). This taper causes the taper at the exit of the EDM drilled hole (Figure 2-c). This view is known as bullet protrusion. Because of the leaving electrode tip from the specimen, the cooling and chip removal is stopped and this event causes the burning on surface or welding of electrode with workpiece surface.

surface. And the effects of the coolant types on the performance were investigated.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Machining Speed

EDM is defined as the high-energy sparks that occur between the workpiece and electrode cause material removal and evaporation. In EDM process, the machining speed is defined as the amount of material removal at unit time. In EDM process high machining speed is intended and the studies are performed at this situation. In this study, the specimens were weighed before and after the experiments by using 0,1 mg sensitive Shimadzu AUX220 digital balance. The machining time was measured by using digital stopwatch. And the machining speed was calculated by equation (1).

$$\text{MS}\left(\frac{\text{mg}}{\text{min}}\right) = \frac{\text{initial weight} - \text{final weight}}{\text{Machining time}} \qquad (1)$$

In this study, three types of coolants and three types of current level were used. The effects of coolant types versus current on machining speed for DIN 1.2080 die steel are shown in Figure 3. When machining speed is considered according to the current, the MS is decreased as the current increased for all coolant types. The better MS was obtained at 10 A current value as approximately 100 mg/min for this workpiece material. When MS of the coolant types are compared, distilled-water has the better machining speed than the other coolants. And the kerosene type coolant performed better machining speed

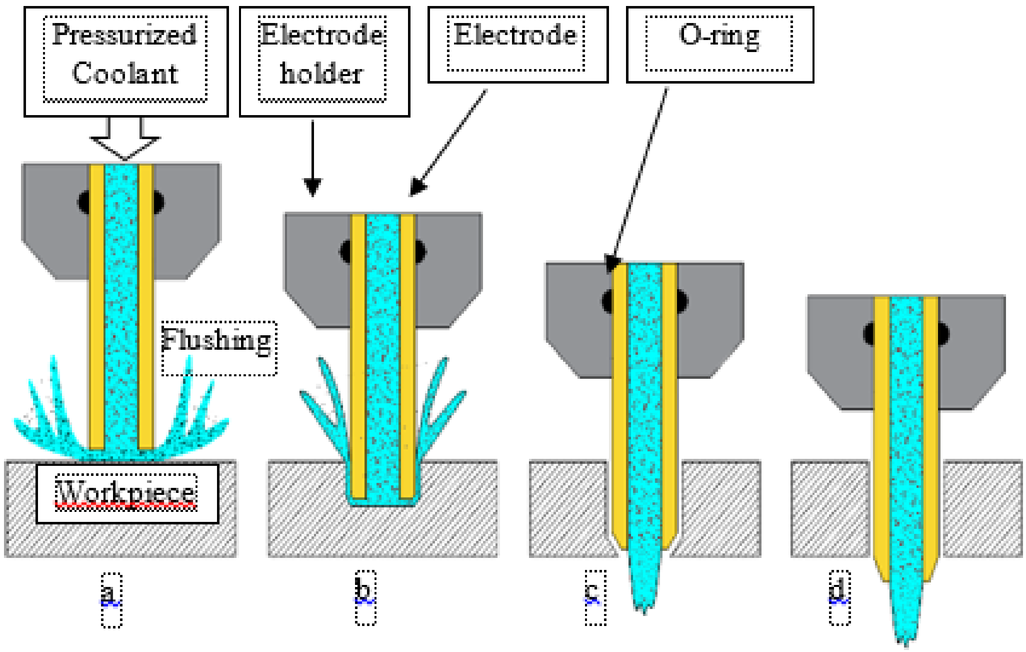

Fig. 2. Electrode wear (a) initial stage; (b) taper starting; (c) full taper; (d) leaving specimen

In this study, the performance parameters are defined as machining speed, electrode wear, surface roughness value (R_a) and white layer thickness of the workpiece compared to the tap water.

Figure 3 shows the response trends for the influence of distilled-water on MS. More sparking time prolongs the melting and vaporization phenomenon. With the use of distilled-water, wider discharge channel and longer energy discharge cycles were resulted, which eventually prolonged melting and evaporation and resulted in higher MS [26]. The higher MS obtained in the case of distilled-water maybe due to higher thermal conductivity which could have allowed more thermal energy transfer toward the sparking area.

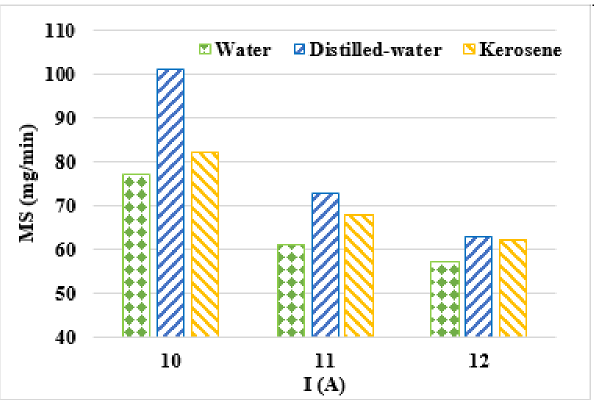

Fig. 3. Machining speed

3.2. Electrode Wear

In EDM process, high temperature sparks provide the chip removal from the workpiece at the same time these sparks erode the electrode. This erosion is known as electrode wear in EDM process. In EDM drilling process, machined geometry is directly related to the electrode wear, so the minimum electrode wear gives better geometric performance on workpiece. In this study, the electrodes were weighed before and after the machining by 0,1 mg precision digital balance. And the electrode wear was calculated by using equation (2).

$$EW\left(\frac{mg}{min}\right) = \frac{\text{initial weight} - \text{final weight}}{\textit{machining time}} \qquad (2)$$

In present study, the electrical parameters of t_{on}, t_{off} and capacitance (C) were taken constant and the effect of the current and coolant types on the electrode wear was examined. EW is generally depending on the EDM parameters, electrode and coolant [27]. It is shown in Figure 4; the electrode wear is lower for distilled-water then kerosene and water type of coolants for all current levels. And the kerosene type coolant has the lower electrode wear compared to the water.

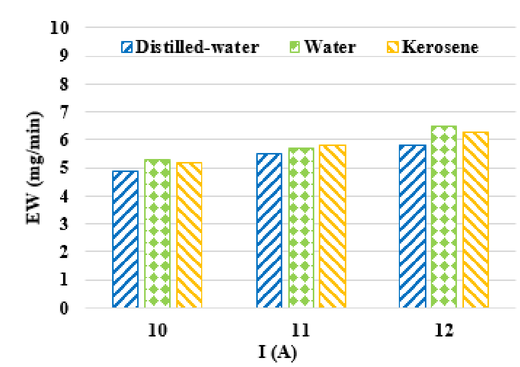

Fig. 4. Electrode wear

Figure 4 shows the response plots for the influence of coolants on EW. Using kerosene and tap water reduce the area for striking positive ions on work surface due to narrow plasma discharge channel. Higher ions in the kerosene and tap water ensure fresh gap condition for subsequent sparking cycles by allowing reionisation of the ionized gap condition and minimizes the chances of unwanted arcing [28]. Lower MS obtained in case of kerosene and distilled water may be due to withstand ionized state for longer duration and longer material erosion cycles of electrode.

3.3. Surface Roughness

In EDM drilling process, the average surface roughness value (R_a) is related to the electrical parameters of the EDM. In the present study, the EDM electrical parameters were taken as constant. The surface roughness value (R_a) was measured by using Mitutoyo SJ 401 stylus type surface roughness measuring machine. Measures were performed according to the standard tables as the cut-off length 0.8 and sampling length 4 mm. The surface roughness value was taken as the average of the 3 measurements of each hole. In this study, the results show that the use of distilled-water as coolant provides better surfaces quality, the R_a value was measured about 2,7 µm for distilled-water. The kerosene type of coolant performed the surface roughness value of nearly 3,0 µm at 10 A current value. Approximately 4,2 µm surface roughness value was obtained by using water at 12 A current value. And also, the results concluded that the current increasing, increases the surface roughness value from 2,7 to 4,2 gradually.

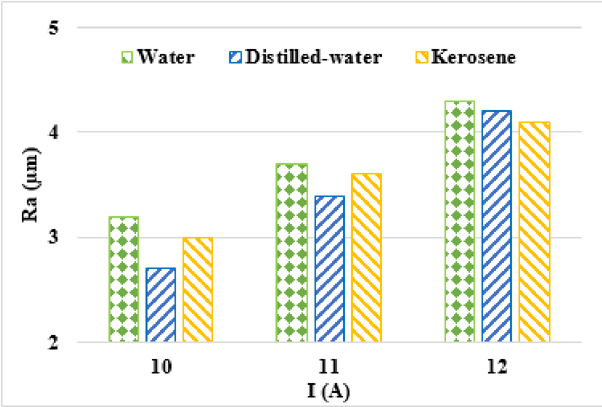

Fig. 5. Surface roughness

Results in Figure 5 show the response trends for average surface roughness value (R_a) under the influence of coolants. Sparks strike on the work material more intensely at higher current causing more material to be ejected due to impact force developed. Furthermore, an increase in energy due to current increases energy penetration in the material surface which eventually results into deeper and wider craters which in turn results into coarser surface [26, 29]. However, resulted lower R_a in the case of distilled water may be due to wider discharge channel and longer energy discharge cycles were resulted, which eventually prolonged melting and evaporation and resulted in lower R_a value.

3.4. White Layer Thickness

In all types of EDM processes, white layer is generated, related to the high electrical discharge that is caused by the high temperature generation and sudden cooling between the workpiece and electrode. This white layer has very hard and brittle properties. Thermal stresses are generated in the white layer and it causes the micro cracks which lays from white layer to main material [30]. These micro cracks tend to develop from the white layer to main material and they decrease the fatigue strength and service life of the part [30]. Through the EDM drilling of holes, white layers are created at the side wall of each hole. The WLT at the wall of the hole was measured since it is the surface exposed to continuous machining throughout the hole-EDM drilling process. In this section, the effects of electrodes and current coupled with the hole-EDM drilling process on average white layer thickness were compared. Moreover, as white layer thickness was not uniform throughout the machined surface, a representative average white layer thickness was determined. Figure 6 shows that white layer thicknesses of the EDM drilled holes were changing from 10 µm to 20 µm. The WLT increases when the current increases. The distilled-water type coolant has the lower WLT of 12 µm then the kerosene and water ones. White layer thickness increases when the current increases. The WLT of 19 µm was obtained by using water type of coolant at 12 A current level.

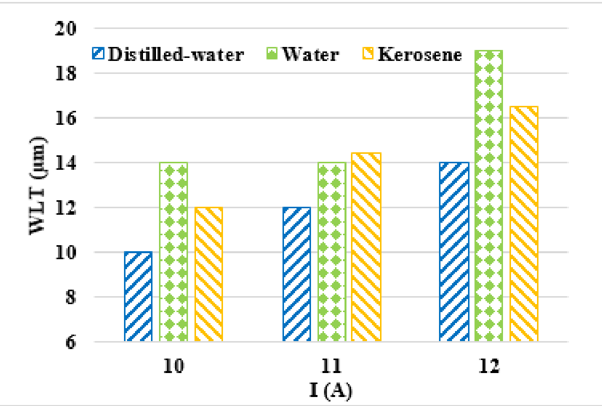

Fig. 6. White layer thickness

Figure 6 represents the effect of coolants on the behaviour of WLT. It can be seen that kerosene and tap water influenced the WLT to a marginal extent. Using distilled water ensures fresh gap condition for subsequent sparking cycles by allowing reionisation of the ionized gap condition. Also, smaller and shallower craters are formed due to reduced sparking time to decrease WLT. However, lower WLT obtained in the case distilled water may be due to lower ion content which could have allowed uniform energy density on the work material surface which in turn resulted into shallower and smaller crater formation [29].

4. CONCLUSIONS

The outcomes of this study can be concluded as:

- Nearly 50 percent decrease in MS has been achieved by using the distilled-water compared to the kerosene and water types of coolant. This provides a significant improvement of the machining time for EDM drilled deep holes.
- MS is decreased as the current increased for each condition. The better MS was obtained at 10 A and distilled-water type of coolant.
- Electrode wear is reduced approximately 20% by using distilled-water. This means, electrode life increased and also manufacturing cost decreased.
- EW is increased as the current increased for all coolants. The minimum EW (4,9 mg/min) was obtained at 10 A and distilled-water.
- Surface roughness value is increased as the current increased for all coolants. The better surface quality was obtained at 10 A and distilled-water type of coolant.
- Approximately 30 percent surface improvement has been achieved by using distilled-water.
- Nearly 30% white layer reduction was obtained by using distilled-water as coolant. It can be expected that the service life and fatigue strength of the workpiece will be improved by decreasing the white layer thickness.

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