

Experimental Investigation of the Effects of Electrodes on EDM Hole Drilling Process

Kürşad GÖV*

Gaziantep University, Faculty of Aeronautics and Astronautics, Aircraft and Aerospace Engineering Department, GAZİANTEP

(Received : 24.08.2016 ; Accepted : 19.10.2016)

ABSTRACT

In this experimental comparative study, holes were machined to the DIN 1.2379 die steel by using Electrical Discharge Hole Drilling (EDHD) method. The effect of the different electrode materials, channel type and machining current on EDHD performance was investigated. In the experiment, single and multi-channel brass and copper electrodes were used. The performance parameters were defined as machining speed (MS), electrode wear (EW), surface roughness (Ra) and white layer thickness (WLT). The experimental results reveal that the single-channel brass electrode has comparatively better MS and lower EW than the multi-channel brass and copper electrodes. Also, the surface quality and WLT of the single-channel brass electrode has the better values than the others.

Keywords: EDHD, Machining Speed, Electrode Wear, Surface Roughness, White Layer Thickness.

EEİ Delik Delme İşlemine Elektrot Etkilerinin Deneysel İncelenmesi

ÖZ

Bu kıyaslamalı deneysel çalışmada, elektro erozyonla delik delme (EEDD) yöntemi ile DIN 1.2379 kalıp çeliğine delikler delinmiştir. Farklı malzeme ve kanala sahip elektrotların ve elektrik akımının EEDD performansı üzerine etkileri incelenmiştir. Pirinç ve bakır elektrotların tek ve çok kanallı tiplerinin kullanıldığı çalışmada, performans parametreleri olarak işleme hızı (İH), elektrot aşınması (EA), yüzey pürüzlülüğü (Ra) ve beyaz katman tabakası kalınlığı (BKT) dikkate alınmıştır. Deneyler neticesinde, tek kanallı pirinç elektrotun çok kanallı pirinç ve bakır elektroda göre işleme hızının yüksek ve elektrot aşınmasının düşük olduğu ortaya konulmuştur. Ayrıca Ra ve BKT değerleri tek kanallı pirinç elektrot kullanıldığında diğer elektrotlara göre daha iyi sonuçlar vermiştir.

Anahtar Kelimeler: EEDD, İşleme Hızı, Elektrot Aşınması, Yüzey Pürüzlülüğü, Beyaz Katman Tabakası.

1. INTRODUCTION

Electrical Discharge Machining (EDM) is one of the most important abrasion-free machining methods for manufacturing complex component shapes of hard, brittle and advanced materials. Hole EDM is recognized and accepted as the third method of ED machining along with sinker EDM and wire EDM. The hole EDM machine is given in Figure 1. Hole EDM is an improved method of utilizing EDM to drill small holes in conductive material at speeds that are typically faster than those achieved with conventional EDM [1]. The tubular electrode is held in either a special holder, chuck, or collet. The electrode is sealed by a grommet to assure that all the high pressure dielectric is forced through the hole centre. The spindle rotates to evenly distribute the wear on the electrode, assist in the removal of the debris, and assure that the hole is round. The electrode is guided by a guide assembly which is located in line with the spindle axis just above the top of the workpiece. This assures that the hole will be in the correct location. As the electrode enters and sparks into the workpiece, it is

surrounded by high pressure dielectric fluid emanating from the inner diameter of the tube. The high pressure dielectric fluid forces the debris out of the gap toward the top of the hole and also has the effect of stabilizing and self-centring the electrode in the hole (Figure 2). The rapid rotation of the electrode by the rotating spindle hole may also have a hydro-dynamic centring effect.

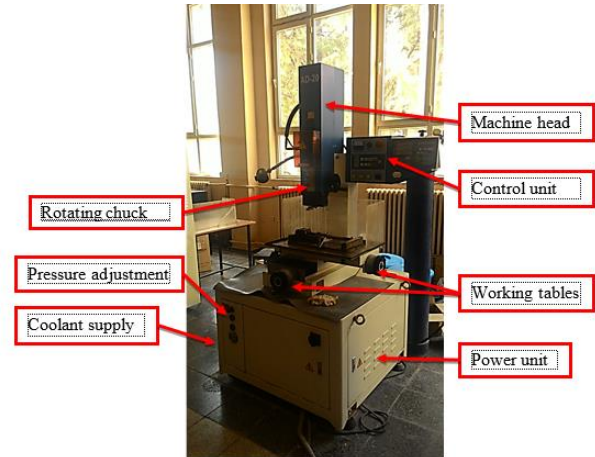


Figure 1. Hole EDM machine

*Corresponding Author

e-mail: gov@gantep.edu.tr

Digital Object Identifier (DOI) : 10.2339/2017.20.2 377-382

Although originally conceived as a method of economically producing small holes with large depth-to-diameter ratios, hole EDM is utilized in many industries where conventional drilling a small hole is normally difficult: Diesel fuel injection nozzles, fibre spinning nozzles, small draw dies, turbine blade cooling holes, silicon masks tool and wire EDM starting holes

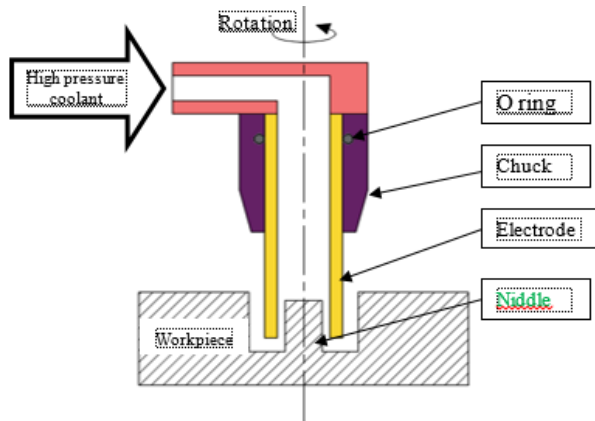


Figure 2. Schematic view of hole EDM process

The tool for hole EDM is the tubular electrode, the electrode material is usually dictated by either the requirements of the machine tool power supply or the workpiece. Hole EDM electrodes are usually made from two materials. Copper electrodes are also the tube of choice when burning carbide and some aerospace alloys. Most copper tubes are made from electrolytic copper. The majority of hole EDM process are designed to utilize brass electrodes for most applications. Brass electrodes made from yellow brass (Cu65:Zn35) and cartridge brass (Cu70:Zn30). Electrodes are available in a variety of configurations (Figure 3) single-channel electrodes are utilized in the majority of Hole EDM applications. Multi-channel electrodes are used in deep hole applications where the needle can cause problems or in blind hole applications where the remaining needle is not acceptable. There are various styles of multi-channel tubes based upon the number of flushing channels required and the construction used to create those channels.

Drilling small holes is one of the difficult machining processes; approximately 35% of all manufacturing time is spent to drill holes. Conventional drilling techniques cannot be employed to produce small in diameter 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 very small in diameter holes for cooling of hot components [2].

Conventional cooling holes have diameter from 2 to 4 mm and have length to diameter ratio from 1 to 200 [3, 4]. 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 [5-7]. The main performance parameters of hole-EDM process are the machining speed, electrode wear, surface quality and the white layer thickness. In all EDM processes, white layer (recast layer) is generated. The workpiece profile, surface quality and the dimensional accuracy are directly related to the white layer characteristic [8]. Gov [4] reported that the effect of EDM parameters is more important than the effect of the other parameters on hole-EDM process. Yilmaz and Okka [9] 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 material removal rate and electrode wear performance than 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. reported that MRR is affected by duty factor, tool rotation and current, while current and pulse on time effect the surface quality [10]. Singh et al. [11] studied the effect of EDM parameters over performance parameters of sink-EDM and they concluded that taper angle, MRR, surface quality and

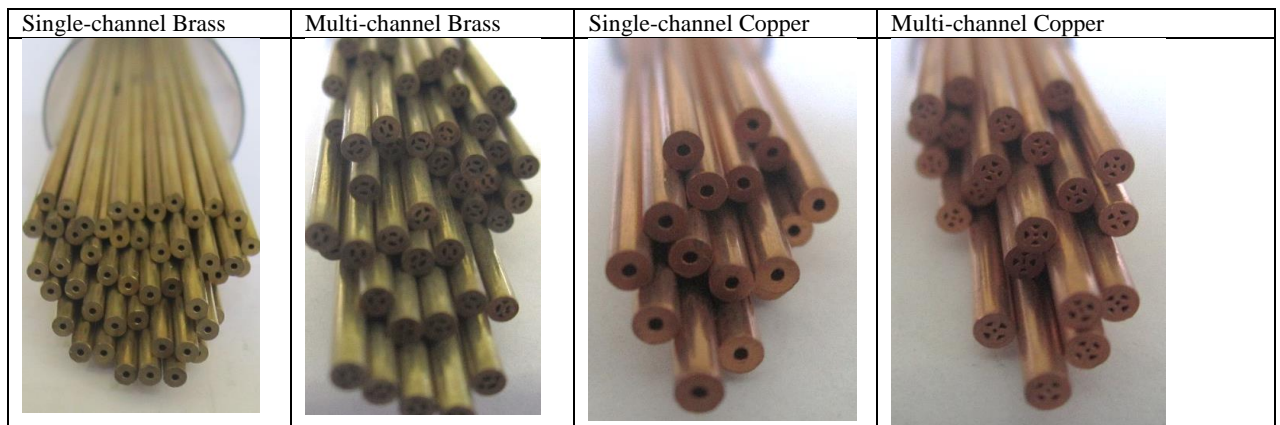


Figure 3. Electrode and channel types

increase whereas the pulse on-time and current were higher. 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. [12]. 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. [13]. Janmanee and Muttamara [14] 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 [15] 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 white layer thickness. The results showed that the increasing in the oxygen dissolution in the coolant, improving the performance parameters. The variations of machining performance outputs were studied with the EDM parameters for metallic powder mixed coolant in EDM by Çogun et al. [16] 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. [17], 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. In this study, electro discharge hole drilling processes (EDHD) was applied to DIN 1.2379 tool steel by using single-channel and multi-channel brass electrodes and single-channel and multi-channel copper electrodes. 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 electrode materials and types on the performance parameters were examined. The performance parameters are chosen as machining speed (MS), electrode wear (EW), surface roughness value (R_a) and white layer thickness (WLT) of the workpiece surface.

2. EXPERIMENTAL PROCEDURE

Experiments were performed by using JS-EDM AD-20 type hole electrical discharge machine which is available in Mechanical Engineering Department of Gaziantep University. The samples were cut by 10x10x40 mm from DIN 1.2379 die steel using wire electro discharge machine. Each face of the samples was ground by using 320 to 3000 size emery papers gradually and polished by using 1 μ m diamond suspension before drilling. 2 mm diameter single and multi-channel brass and copper electrodes were used for drilling the holes which were drilled on the centre of the matched polished faces vertically (Figure 4). The major electrode material properties are given in Table 1. Experiments were performed in 3 repetitions and the performance parameters were calculated by average of these three measurements. The EDM parameters; current, arc on-time, arc off-time, and capacitance were chosen as the

constant values which were proposed previous studies [4]. The list of the EDM parameters are given in Table 2.

Table 1. Electrode Properties

Electrode material	Copper	Brass
Melting point (°C)	1085	900-950
Thermal conductivity (W/m.°K)	390	160
Electrical resistivity (Ω .cm)	1.7	4.71
Specific heat capacity (J/g.°C)	0.385	0.380

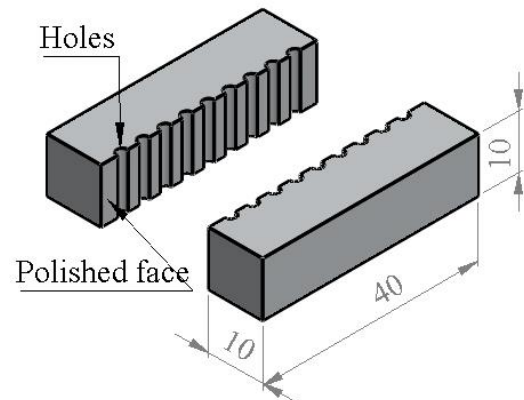


Figure 4. Perspective view of the specimen

Table 2. Experiment Parameters (Deney parametreleri)

Fixed parameters	Value
Time on, T_{on} (μ s)	30
Time off, T_{off} (μ s)	10
Capacitance C (μ F)	1422
Voltage (volt)	30
Electrode rotation (rpm)	200
Coolant pressure (bar)	100
Electrode polarity	Negative (-)
Variable parameters	
Electrode types	Single-ch. Brass, Single-ch. Copper, Multi-ch. Brass, Multi-ch. Copper
Current, I (Ampere)	10,11,12

In the hole EDM drilling process, spark intensity is concentrated on the tip of the electrode. This spark intensity causes high erosion at the tip of the electrode rather than root of the electrode. This high erosion causes the taper on the electrode tip. The electrode is initially flat and sharp edges. Overcut and white layer are created during the hole EDM drilling process due to the high level erosion. The eroded surfaces have the surface roughness related to the EDM parameters, the surface roughness value increased when the current increased [8].

2.1. Performance Parameters

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 and the high machining speed is

proposed. In this study, the specimens were weighed before and after the experiments by using 0.1 mg sensitive Shimadzu AUX220 digital instrument. The machining time was measured by using digital stopwatch. And the machining speed was calculated as the weight loss of workpiece in machining time.

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. The electrode wear was defined as the weight loss of electrode during the machining time in the study.

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 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 the 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 [18]. 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 [18]. In this experimental study, the cross section images were taken by Scanning Electron Microscope (SEM) and the white layer thickness were measured by using these images.

3. EXPERIMENTAL RESULTS

3.1. Machining Speed

In the study, four types of tubular electrodes were used. The effects of electrodes on machining speed for DIN 1.2379 die steel are presented in Figure 5. When machining speed is considered according to the current, the MS is decreased as the current increased for all electrode types. The better MS was obtained at 10 A current value for DIN 1.2379 die steel. When MS compared to the electrode types, brass electrode has the best machining speed than the copper for all current levels. And the single-channel electrodes performed better machining speed compared to the multi-channel electrode types. The lower machining speed of the copper electrode can be explained due to the thermal conductivity difference between the brass and copper electrodes. Lower thermal conductivity decreased the heat energy absorption for the brass electrode. Thus the material removed from the workpiece due to the higher

heat is employed to the workpiece [19]. Single-channel electrodes performed better machining speed due to the higher coolant flow rate. High coolant flow increased the cooling effect, pulverization of the bubbles and material removal rate from the surface. Thus, the single-channel electrode has higher machining speed than the multi-channel one.

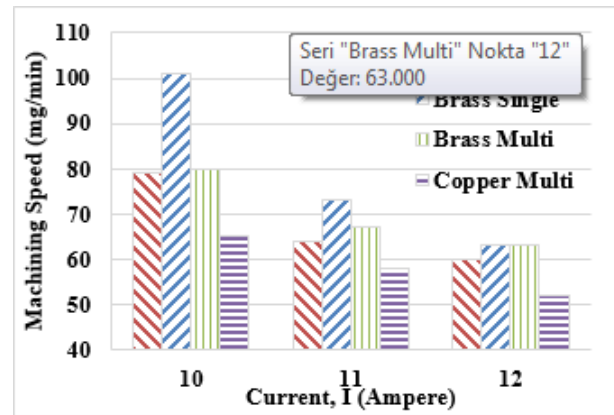


Figure 5. Current versus Machining speed

3.2. Electrode Wear

In EDM process, high energetic electrical spark erodes the workpiece and picks off the particles from the workpiece surface, nonetheless it erodes the electrode and picks off the particles from the electrode respectively. Normally, electrode wear is related to the electrical parameters of the EDM process. In this study, the electrical parameters of T_{on} , T_{off} and capacitance (C) were taken constant and the effect of the current and electrode types on the electrode wear was examined. Electrode wear is generally depending on the EDM parameters and electrode materials [20]. Figure 6 Shows that electrode wear is lower for brass electrodes than copper for all current levels. And the single-channel electrodes have the lower electrode wear compared to the multi-channel electrodes. The thermal properties of the brass cause the lower material removal from the electrode. And higher coolant flow decreased the electrode wear for single-channel electrode compared to the multi-channel ones.

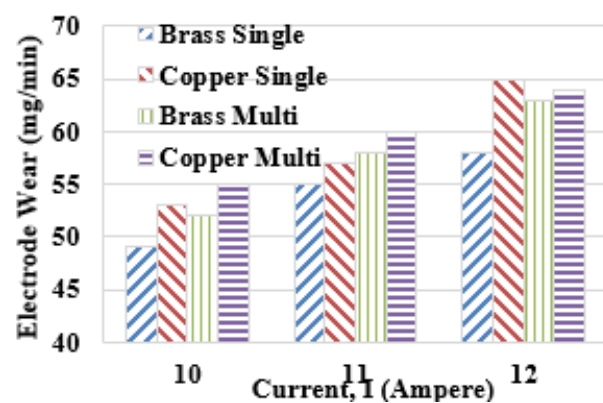


Figure 6. Current versus Electrode wear

3.3. Surface Roughness

Surface roughness (R_a) value was changed according to the reattach particles which was picked off from the workpiece, and also directly affected by the electrical parameters that causes the creation of the debris and craters on the surface of workpiece. In this study, surface roughness measurements were achieved on through holes in each set of experiments. The average surface roughness value was calculated based on surface roughness values obtained from the repeated experiments. The results shown in Figure 7 reveal that use of single-channel brass electrode provides better surface quality, the R_a value was measured as $3,0 \mu\text{m}$ for single-channel brass electrode. The flushing effect in single-channel electrodes were stronger than multi-channel electrodes. This enables the dielectric fluid to pulverize particles in very small size and these very small particles were easily thrown away from machining zone during the EDM drilling. Thus, the machined surface by single-channel brass electrode has smoother surface than the multi-channel electrodes. From the figure, it can be seen that surface roughness value increased when the current is increased.

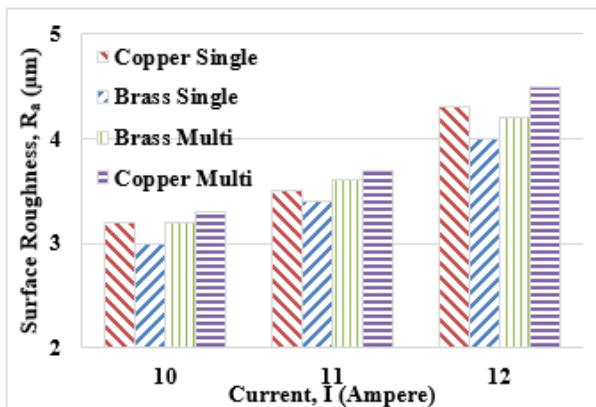


Figure 7. Current versus Surface roughness

3.4. White Layer Thickness

Through the EDM drilling of holes, white layers are created at the side walls of each hole. In this section, the effects of electrodes and current coupled with the hole-EDM drilling process on average white layer thickness were compared. The white layer thickness was not uniform throughout the hole length, so average white layer thickness was determined according to the series of measurements. It is seen in Figure 9, white layer thicknesses of the holes were changing from $10 \mu\text{m}$ to $20 \mu\text{m}$ for all electrodes. Figure 8 shows that the WLT increased when the current increased. The single-channel brass electrode has the lower WLT than the multi-channel brass and copper ones. Single-channel electrodes performed better WLT than multi-channel electrodes. The flushing effect of the single channel electrodes is higher than the multi-channel electrodes. Due to this reason white layer creation is lower for single-channel electrodes.

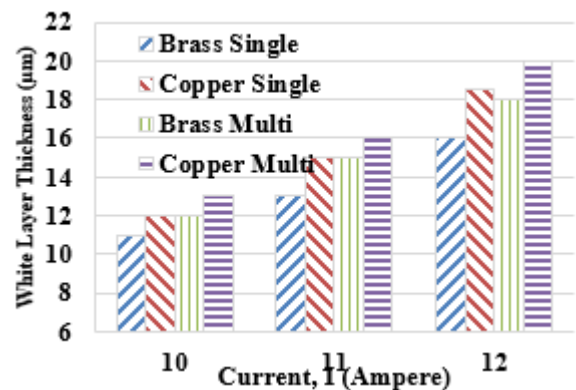


Figure 8. Current versus White layer thickness

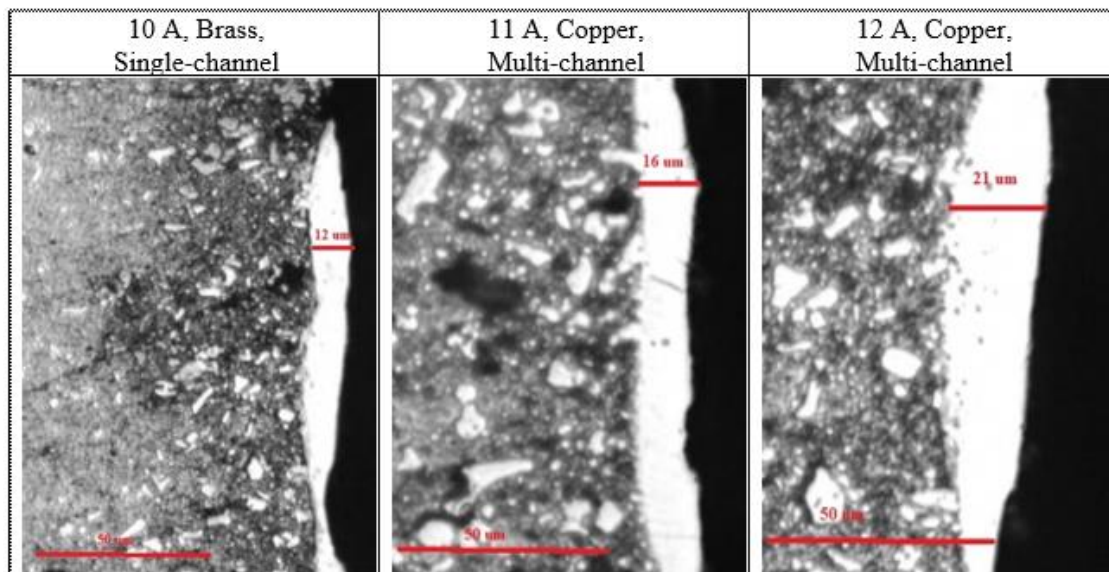


Figure 9. White layer thickness measurements

4. CONCLUSIONS

The outcomes of this study can be concluded as:

- Nearly 50 percent decrease in MS has been achieved by using the single-channel brass electrode compared to the multi-channel copper electrode. This provides a significant improvement of the machining time for EDM drilled deep holes.
- MS is decreased as the current increased for all electrode types. The better MS was obtained at 10 A and single-channel brass electrode.
- Electrode wear rate is reduced approximately 20% by using single-channel brass electrode. This means reduction in electrode cost. (i.e., manufacturing cost).
- EW is decreased as the current increased for all electrodes. The better EW was obtained at 12 A and single-channel brass electrode.
- Surface roughness value is increased as the current increased for all electrodes. The better surface quality was obtained at 10 A and single-channel brass electrode.
- Approximately 30 percent surface improvement has been achieved by using single-channel brass electrode.
- It can be expected that the service life and fatigue strength of the workpiece will be improved by decreasing the white layer thickness.

REFERENCES

1. Sommer, C. and S. Sommer, "Complete EDM handbook". *Advance Pub.*, (2005).
2. Gov, K. "Experimental Investigation of The Effects of The Coolant on The Performance Parameters of Electrical Discharge Drilling of Some Aerospace Materials", *Journal of The Faculty of Engineering and Architecture of Gazi University*, 32(1): (2017).
3. Gov, K. "The effects of the dielectric liquid temperature on the hole geometries drilled by electro erosion", *The International Journal of Advanced Manufacturing Technology*, (2017).
4. Göv, K. "Influence of the Coolant on Performance of Electro Discharge Hole Drilling", *Journal of Polytechnic*, 20(1): 191-196, (2017).
5. Yusuf Keskin, H., H. Selcuk, and K. Mevlut. "An experimental study for determination of the effects of machining parameters on surface roughness in EDM", *International Journal of Advance Manufacturing Technology*, 28: 1118-1121, (2006).
6. Puranik, M.S. and S.S. Joshi. "Analysis of accuracy of high-aspect-ratio holes generated using micro-electric discharge machining drilling", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 222(11): 1453-1464, (2008).
7. Mujumdar, S.S., S.A. Mastud, R.K. Singh, and S.S. Joshi. "Experimental characterization of the reverse micro-electrodischarge machining process for fabrication of high-aspect-ratio micro-rod arrays", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 224(5): 777-794, (2010).
8. Kurnia, W., P.C. Tan, S.H. Yeo, and Q.P. Tan. "Surface roughness model for micro electrical discharge machining", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 223(3): 279-287, (2009).
9. Yilmaz, O. and M.A. Okka. "Effect of single and multi-channel electrodes application on EDM fast hole drilling performance", *The International Journal of Advanced Manufacturing Technology*, 51(1-4): 185-194, (2010).
10. Kuppan, P., A. Rajadurai, and S. Narayanan. "Influence of EDM process parameters in deep hole drilling of Inconel 718", *The International Journal of Advanced Manufacturing Technology*, 38(1-2): 74-84, (2008).
11. Singh, P.N., K. Raghukandan, M. Rathinasabapathi, and B. Pai. "Electric discharge machining of Al-10% SiC p as-cast metal matrix composites", *Journal of materials processing technology*, 155: 1653-1657, (2004).
12. Ekmekci, B., A. Sayar, T.T. Öpöz, and A. Erden. "Geometry and surface damage in micro electrical discharge machining of micro-holes", *Journal of Micromechanics and Microengineering*, 19(10): 105030, (2009).
13. Yadav, U.S. and V. Yadava. "Experimental investigation on electrical discharge diamond drilling of nickel-based superalloy aerospace material", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, (2015).
14. Janmanee, P. and A. Muttamara. "A study of hole drilling on stainless steel AISI 431 by EDM using brass tube electrode", *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, 2(4): 471-481, (2011).
15. Gov, K. "Investigation of the Effects of the Dissolved Oxygen in the Coolant on the Hole Geometries Drilled by Electro Erosion", *Journal of The Faculty of Engineering and Architecture of Gazi University*, 31(2): 231-239, (2016).
16. Çogun, C., B. Özerkan, and T. Karaçay. "An experimental investigation on the effect of powder mixed dielectric on machining performance in electric discharge machining", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 220(7): 1035-1050, (2006).
17. Ekmekci, B., F. Ulusöz, N. Ekmekci, and H. Yaşar. "Suspended SiC particle deposition on plastic mold steel surfaces in powder-mixed electrical discharge machining", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 229(3): 475-486, (2015).
18. Ergün, Z.E. and C. Çoğun. "Elektro Erozyon ile İşleme (EEİ) İş Parçası Yüzey Karakteristiklerinin Deneysel İncelenmesi", *Gazi Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 21(3): (2006).
19. Khan, A.A. "Electrode wear and material removal rate during EDM of aluminum and mild steel using copper and brass electrodes", *The International Journal of Advanced Manufacturing Technology*, 39(5-6): 482-487, (2008).
20. Haşçalık, A. and U. Çaydaş. "Electrical discharge machining of titanium alloy (Ti-6Al-4V)", *Applied Surface Science*, 253(22): 9007-9016, (2007).