Influence of Electrode Geometry in Parameters of Electrical Discharge Machining Process of AISID2 Tool Steel

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Abstract: ***The Electrical Discharge Machining (EDM) is a nontraditional cutting process for metals removing based upon the fundamental fact that negligible tool force is generated during the machining process. Also, EDM is employed in producing very hard materials that are electrically conductive. In this paper, we will study and investigation of the effects of electrode geometry (tip radius and tip angles) with input parameters of EDM machining process such as (pulse current and pulse on time) on the output parameters like Metal Removal Rate (MRR), Electrode Wear Ratio (EWR), thickness of Heat Affected Zone (HAZ) of machining of AISI D2 tool steel were investigated. The results of the experimental study are discussed in this paper. It is revealed that conical electrode with radius 1 mm gives highest MRR and the lowest EWR was with conical electrode with radius 0mm as compared with the other electrodes, the results have indicated that the White Layer Thickness (WLT) increases with increase in electrode tip angle.***

Keywords: Electrical Discharge Machining, Material Removal Rate, Electrode Wear Ratio, White Layer Thickness

1. Introduction

The Electrical Discharge Machining (EDM) is one of the nontraditional machining processes which have been widely used to produce dies and molds, finishing parts for aerospace, automotive industry and surgical components. Figure 1 which shows principal of metal removal processes in EDM. In this process the material is removed by means of series of electrical charges between tool called electrode and the workpiece in the presence of dielectric fluid. The electrode is moved toward the workpiece until the gap is becomes a small enough so that the applied voltage is great enough to ionize the dielectric. The material is removed due to erosion. EDM does not make direct contact between workpiece and tool. Material of any hardnesscan be cut if material can conduct electricity.

The temperatures of the electrodes can be raised more than their normal boiling points [1]. EDM is a method for material removal which is suitable for all kinds of electro conductive materials, regardless of their physical and metallurgical properties. It is used for machining complex geometry workpieces and difficult-to-machine materials, for which conventional methods are not applicable. Theuse of EDM is especially essential for the accurate productionof forming tools, prototype parts, micro parts andother highly specialized products [2]. The technology required manufacturing and machining of high hardness and strength of materials, new machiningprocesses, machining is replacing the traditional process. One of the most important and most useful of these processes, Electrical Discharge Machining (EDM). Electrical Discharge Machining is a process wherebyapplying a voltage pulse and the pulse between the tools and workpiece, and material removal machining operation is performed. Cold work tool DIN 1.2379 tool steel having good wear resistance at high temperatures, high hardnessand high toughness, such as the manufacture of molds, forging molds, extrusion, casting is used [3].

In Electrical Discharge Machining (EDM), a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectricmedium. A gap is maintained between the tool and the workpiece. Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. If the work function or the bonding energy of the electrons is less, electrons would beemitted from the tool (assuming it to be connected to the negative terminal). Such emission of electrons is called or termed as cold emission. The "cold emitted" electrons are then accelerated towards the job through the dielectric medium. As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionization of the dielectric molecule depending upon the work function or ionization energy of the dielectric molecule and the energy of the electron.

This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap. The concentration would be so high that the matter existing in that channel could be characterized as "plasma". The high-speed electrons then impinge on the job and ions on the tool. The kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux. Such intense localized heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000C such localized extreme rises in temperature leads to material removal. Material removal

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occurs due to instant vaporization of the material as well as due to melting.Thus, to summarize, the material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to discontinuation of applied potential difference, as shown in Fig. (1).

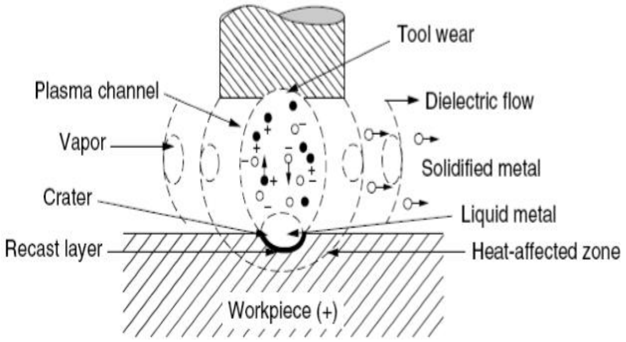

Figure 1: EDM spark description [1]

The Die sinking electrical discharge machining (EDM) is one of the most widely used techniques for the fabrication of die and mold cavities which are finally used for mass production of metals and polymer products by replication such as die casting, injection molding, etc. In any replication process, it is expected that the quality mold will faithfully duplicate its shape and surface texture. In accurate duplications cause problems in assemblies, operations as well as lower the aesthetic view. In die sinking EDM the electrode produces exactly its opposite shape on the work material EDM does not make direct contact between tool and workpiece where it can eliminate the mechanical stresses, vibration during machining. Material of any hardness can be cut as long as the material can conduct electricity. EDM techniques have developed in many areas. The trends on activity carried out by researcher depend on the interest of and the availability of technology. This is achieved by the development of different types of spark generation and optimizing production parameter. Although due to a great number of variable and a variety of products, an optimal machining process performance is very difficult to achieve [4]. In this paper, influence of process parameters and effect of geometry of electrodes (tip radius and tip angles) on out parameters including material removal rate, electrode wear ratio and white layer thickness were studied to explain the electrode that gives highest MRR, lowest EWR and thinner white layer.

2. Literature Review

A review of the available literature related to EDM shows the type and extent of work done earlier. N. Pelliceretal. (2009) [5] presented the influence of various geometric shapes on the basic performance measures of the process. Variable parameters such as the pulse currents, open voltages, pulse-on time and pulse-off time are permitted in H13 steel using different geometric shapes of copper electrode. In addition, MRR, Ra, different dimensional and geometrical micro-accuracies have been investigated by statistical methods. The result shows that MRR and Ra increase with the increase of discharge currents.-Pulse-off time has different effects on MRR. Yet, its performance is not direct because of interactions with other process parameters. The geometrical shapes (rectangle and square) electrodes provided the best radial and axial erosion ratios. Thus, these geometric shapes are expected to be the best choice for a flexible electrode design. A. Khan et al. (2009) [6] examined the effect of the electrode shapes on the (MRR) and Electrodes Wear Ratio (EWR) for mild steel in EDM. The ultimate values of MRR were located in the circular electrode,square shape comes in second position, thereafter the triangle and at last the diamond electrode. Yet, maximum EWR has been found in the diamond electrode. They conducted the simulation of the process and found the distance between the workpiece, electrode (gap) and discharge location that depends on the distribution of focus of debris reported to yield a widely true representation of the EDM phenomenon.

Z. S. Shuker, M. A. Rijab (2011) [7] researched in effect of the parameters of EDM on the recast layer thickness. The parameters pulse duration, dielectric pressure and electrode tip angle were studied. The results revealed that the recast layer thickness increases with pulse duration and electrode tip angle increase. M. Rahman et al. (2011) [8] investigated the machine properties of the Austenitic Stainless Steel (AISI 304) through EDM. The EDM operation was estimated by the MRR, SR, and EWR from producer of the workpiece. Experimental work has been performed utilizing Die Sinking Electro Discharge Machine which used Copper electrodes. Through the test outcome, no wear situation was observed for the copper (Cu) toolat a long pulse-on time (Ton) with reverse polarity. The optimum (Ton) has been varied with the higher amp.

S. Rajesha et al. (2012) [9] studied the EDM process using Inconel 718 workpiece. The copper electrode with 99.9% purity, which has a tubular shape, has been employee with 20 mm height and 12 mm diameter. Five of main process parameters (IP, duty factor, gaps control, sensibility control, and flushing pressure) were discussed on MRR and SR. Examination shows essential interactionalimpact of IP and duty factor on the MRR with a varied zone from (14.4 mm3/ min, to 22.6 mm3/ min), whereas IP stays the most participate factor with approximate changes in MRR and, SR of about 48% and 37%, respectively. A. Singh, P. Kumar and I. Singh (2013) [10] investigated the effect of electrode geometry in electric discharge drilling process on MRR using copper electrodes with four bottom shapes (solid cylindrical, chamfered, conical and helical) on Al6063/10% SiC composite workpiece. The experimental results showed that the conical electrode produced the highest MRR, the chamfered and solid cylindrical electrodes produced nearly the same MRR, and the helical electrode produced the lowest MRR. M. Manohar et al. (2014) [11] investigated the experimental study to assess the effect of electrode bottom profiles while machiningInconel 718 through EDM Process. Electrodes of different bottom profiles were used, and the machined surfaces were analyzed in terms of recast layer, surface topology, form tolerance and MRR. Electrodes having Convex, Concave and Flat profile at their bottom surface were chosen for the experimental study and the results shows that the con convex profile electrodes produce machined surfaces of better quality in terms of higher surface finish, thinner recast-layer and closer geometry, in addition to higher MRR compared to flat profile or concave profile electrodes. Sanjay et al. (2014) [12] analyses the

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influence of machined parameters such as (Ton), (Toff) and (Ip) on MRR, EWR and (SR) of the (AISI D2) tool steel. Through experimentation, the authors have used "grey relational analysis, and entropy measurements methods based upon the responses surfaces methods". The tests indicate that the parameters Ton, Toff, and Ip, have the direct effect upon (MRR), and with their increase, MRR, will increase as well. With an increase in pulse-off time, (EWR) decreases. Surface roughness analysis results show that pulse-on time and pulse-off time have the highest effect on surface roughness in the AISI D2 tool.

S. Dhanabalan et al. (2015) [13] studied the effect of (IP), (Ton) and (Toff) on the (Ra). The experiments wereconducted according to the Taguchi method. The authorsconduct a valuation on the Ti alloy using copper, brass,and Al electrodes during the process of EDM. Mostly,the IP has the important effect on the Ra as long as thealloy that was machined by the electrodes possesses theminimal of Ra. A. Singh, C. S. Kalra (2016)[14] investigated the experimental investigation to assess the effectof electrode bottom profiles during machining Monel 400through EDM Process,The metal removal rate and Surfaceroughness has been measured for each experimentto study the effects of tool profile such as Flat, Convex,and Concave shape, peak current, pulse on time and pulseoff time on performance during machining.

The optimum combination parameters for machining of Monel 400 alloy using EDM for lower surface roughness are concave shape of tool. Eshraq A. (2016) [15] studied the effect of electrode type such as (solid and tube) in EDM process. The experimental work used Tool steel H13 depending on Taguchi method and three parameters have been chosen such as pulse current (I), pulse on time (Ton) and pulse off time (Toff) of three levels.-Nine experiments (L9) for each type of electrodes were conducted.ANOVA (analysis of variance) software was used to choose the most activeinfluence of input parameters on the outputs. The succeeding outputs were (MRR), (EWR), (SR), (WLT) and (HAZ). The results displayed that an increase in MRR was achieved by 78.40%, a decrease in each of EWR up to 76.60%, SR 42.40%, WLT 31.50% and HAZ 8.50% when using the tube electrode compared with the solid one.

S. Yadav&Manoj. K. Gaur (2016) [16] showed thatTaguchi method of L9 orthogonal array was used to optimize input parameters based upon the input parameters like: TON, TOFF, IP, and voltage and how these factors affect the MRR and EWR. Using ANOVA method is to determine the variance analysis of the factors at each level.

The investigation result indicated that the optimum performance of the IP, TON and voltage has been seen at 12A, 7_, and 55V, respectively for MRR. Also, for EWR, the optimum performance can be patterned for the IP, TON and V which are: 12A, 7_, and 55V respectively. Therefore, these are the above analysis based on the S/N ratios for MRR as well as TWR. Thus, it can be said that the higher the S/N ratio, the better the result at the optimal machining level. N. G. Ghazey, S. H. Aghdeab (2017) [17] investigated the effect of the machining parameters for different electrodes shape (flat, conical, and round) bottoms on electrode wear rate in EDM, The relationship between machining parameters (current, pulse duration,and pulse interval) and electrode wear rate (EWR) wasfound for each electrode shape and a comparison between electrodes shape was done to know which electrode shape gives lowest EWR ,it is revealed that for most of runs conical electrode gives lowest EWR as compared with flat and round electrodes. Ali T. Bozdana& Nazar.K.AL-Karkhi (2017) [18] examined the effect of the electrode geometry on the perforation and debris process by electricaldischarge drilling(EDD) on 304 stainless steel and the resulting properties of MRR, EWR, TWR, the dimensional characteristics, the surface quality of the holes based on the overcut OC, the depth of the hole and also the surface roughness. Two types of electrodes, cylindrical and the side-cut electrode have been used. In addition, the ANSYS Fluent program (CFD) was used to model the flow at thegap between the electrodes. The results showed that the side-cut profile was superior to the rest of the electrodes, which in turn produced holes with good dimensional accuracy and good surface quality. L. Selvarajan et al. (2018) [19] studied the effect of the Pentagon copper electrode shape on output properties such as MRR, TWR, WR, and EDM machining time on an EN29 alloy in the process of producing pentagonal holes. Input parameters such as IP, Ton, Toff, and dielectric pressure were used.

In addition, L9 Orthogonal Array (OA) based on the Design of Experiments (DOE) program by the Minitab software was used to study the output parameters independently. The results showed that MRR increased up to the 8th hole and that the TWR was reduced at the 4th hole, while the machining time was reduced to the 8th hole, and for the Angularity was reduced at the 4^{th} hole.

3. Availability of Data and Materials

3.1 Workpiece Details

Workpieces (12 specimens) were cut by wire electrical discharge machining process (WEDM) of AISI D2 tool steel material with dimensions (20x20x10mm), as shown in figure 2. The chemical composition in weight percentage (wt.%) of the elements that form AISI D2 tool steel was obtained in the laboratories of the high vocational center of casting, as shown in Table 1.

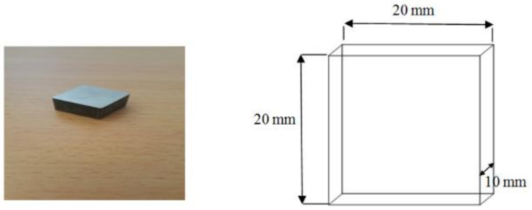

Figure 2: The dimensions of specimen of AISI D2 tool steel

Table 1: The chemical composition (wt. %) of D2 tool steel specimen

Cr%	Mo%	C%	Cu%	Mn%	P%	S%	Ni%	Fe%
12.4	0.69	1.54	0.132	0.375	0.0128	0.003	0.24	84.2

The workpiece hardening to 1050°C then quenching in oil path and tempering to treatment at100°C, the average hardness obtained was 58 HRC, as shown in Table 2.

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Table 2: The Heat treatment cycle

Material	D2
Hardening temperature	1050^0C
Quenching media	Oil
Tempering temperature	100^0C

The workpiece hardening to 1050_C then quenching in oil path and tempering totreatmentat100_C, the average hardness obtained was 58 HRC, as shown in Table 2. The twelve samples machining on RoboForm 2-LC spark EDM manufactured by charmless technologies as in Fig.3 with spark current 4A, pulse on time duration and pulse of time was 100µs other machine parameters as indicated in -table3. Each machining time test was performed for 15min.

Figure 3: RoboForm 2-LC spark EDM Machine

Table 3: The experimental test conditions

Parameters	Description
Machine Type	RopoForm 2-LC
Pulse current (A)	4
Pulse on time (µs)	100
Pulse off time (µs)	100
Voltage (V)	120
W/P material	AISI D2 tool steel
Electrode material	Copper
Electrode shape tips	Cone round
Dielectric	Kerosene
Polarity	Positive
Working time	15 min

The machined specimens sectioned transversely by wire electrical discharge machine, the specimens were grinded and polished to achieve a smooth and clean surface; afterwards, they were etched with 2%Nitalreagent for about 60 seconds. Then the specimens were evaluated at various magnifications by using optical microscope (Nikon Opti-phot) to examine the microstructure and to identify the effect of different parameters on the microstructure behavior and to measure the thickness of the white layer. The amount of white layer thickness (WLT) was measured using an image analyzer (Microscope Digital Camera Figure 4).

Figure 4: The Optical Microscope

3.2 Electrode Details

As shown in Table 4, the twelve electrodes were used of copper rods (10 mm diameter and 50 mm length). The pure copper metal electrode, which has high conductivity specifications is selected to the operation as a negative pole. A conical and round bottom shapes were selected. The electrodes were designed by turning process using Al- Pin 180 N Turning Machines.

Table 4: Electrode Geometry

Electrode Shape	Tip Angles	Tip radius
Conical with sharp tip	45^0, 60^0, 75^0, 90^0	(0) mm
Conical with round tip	45^0, 60^0, 75^0, 90^0	(0.5 & 1) mm

The selected bottom shapes of electrodes were shown in Figure 5.

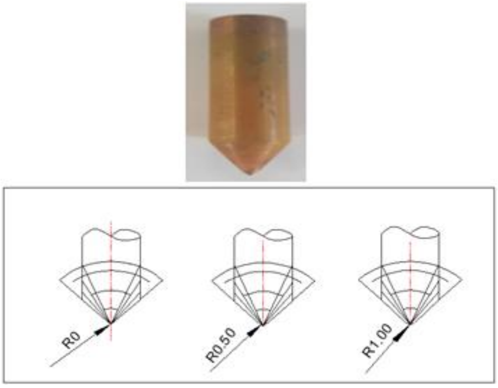

Figure 5: The copper electrode

3.3 Experimental Process

The study was carried out on Spark Discharge Charmless 2l Machine, to perform the experiments on ROBOFORM 2-LCmodel to making a hole in the center of workpieces in advanced center of technology, Tripoli Libya.

The two variable parameters have been considered (shape and tip of electrodes) with constant current to calculate the electrode wear ratio (EWR) and material removal rate (MRR) of workpieces.

The electrodes and work pieces were weighed before and after processing using adigital scale with accuracy 0.0001gm. The weight of the electrode before and after the machining process was measuredto calculate the ***EWR*** and ***MRR*** from the followingequations:

$$EWR = \frac{(EB - EA)}{T \times \rho E} \text{......}(1)$$

Where:
EWR: Electrode wear rate (mm3/min).
EB: Electrode weight before machining (g).
EA: Electrode weight after machining (g).
T: Machining time (min).
ρE: Density of electrode material (g/mm3).

$$MRR = \frac{(WB - WA)}{T \times \rho w} \text{.....}(2)$$

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Where:
MRR: material removal rate (mm3/min).
WB: weight of w/p material before machining (g).
WA: weight of w/p material after machining (g).
T: Machining time (min).
ρw**:** Density of w/p material (g/mm3).

4. Results and Discussion

4.1 Effect of Electrode Shape on Material Removal Rate

The effect of electrode shape (angle of electrode tip and radius of electrode tip) on the material removal rate (MRR) in electrical discharge machining process has been studied. All 12 experiments and final results of MRR values at constant current, pulse on time and pulse off time are illustrated in Figure 6. That obvious the MRR increased significantly with the sharp tip angle 90° comparatively with the other. A sharp edge of electrode concentrated the current then a spark with higher thermal energy will results more MRR. However, for the shape configuration, the highest MRR was found for sharp tip with 90°, 75°, 60°, and 45°angles of electrode tip relatively.

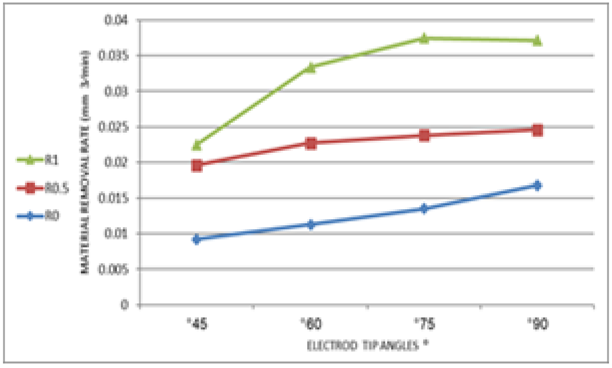


Figure 6: The relationship between the material removal rate and the sharp tip angle of the electrode

4.2 Effect of Electrode Shape on Electrode Wear Rate

As shown in figure 7 for the twelve runs for each electrode shape (conical with sharp and round tips). It is obvious that for most of runs conical electrode with sharp tip (0 mm) produces lowest electrode wear rate (*EWR*) as compared to other electrodes. The reason of this decreasing in conical electrode is due to lowest contact area between the conical electrode and workpiece. Including a point to be sparking area at first leads to low heat energy on surface of electrode [5].

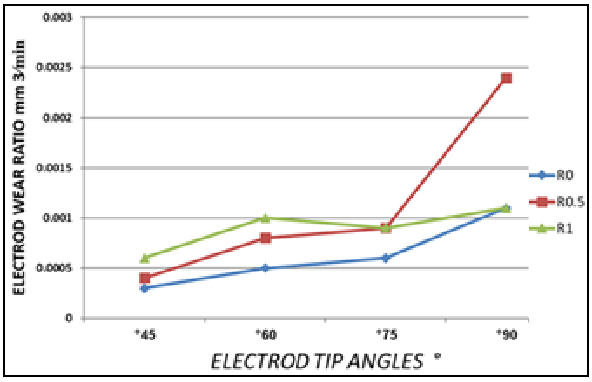


Figure 7: The relationship between the electrode wear rate and the sharp tip angle of the electrode.

4.3 Effect of Electrode Shape on Thickness of White Layer

The white layer (WL) is a thin layer, which appears on the surface of EDMed work pieces, it is mainly composed of martensite and retained austenite with some dissolved carbide [7]. It is a result of the re-solidification of the melted material which was not swept away from the component's surface by the dielectric during the EDM process. WL is known to exhibit high hardness, high surface roughness, and good adherence to the bulk metal and fair resistance to corrosion [8]. Figure (8) shows the effect of electrode shape on thickness of white layer of workpieces, it has been observed that the thickness of white layer increases as the angles of electrode tips increases from 45°,60°to 75°that is due to the increase of surface area exposed to the heating process and expansion of theoperating area, however it was found that increasing the angle of the electrode tip to 90 ° reduces the thickness of the white layer due to the dispersion of the electric spark and its spread over the wider area and then lower temperature on the surface of the operated piece [9,10].Using an image analyzer (Figure 9) it has been confirmed that the thickness of the white layer increased with the increase of the tip radius of electrode due to the expansion of the area.where the increase in the radius of the electrode's tip leads to heat distribution and -their dispersion and lack of focus on the surface of the operator, which in turn works to expose the operating area to more heat and then to refine that area and thus increase the re-layer [2].

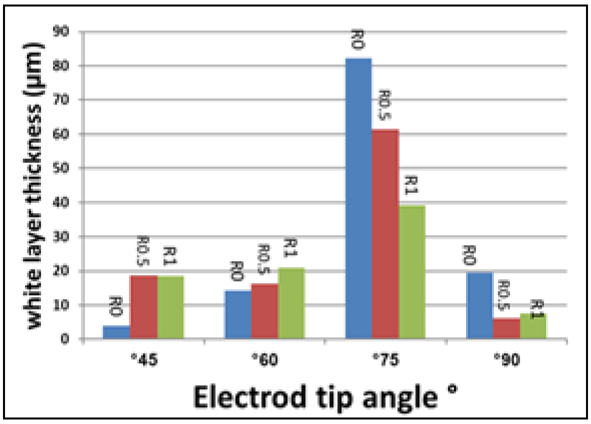
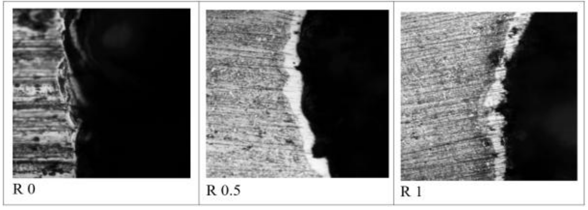


Figure 8: The relationship between the white layer thickness and the electrode tip angle.

The White Layer Thickness with Magnification 400 X with Electrode 45° Tip Angle


R 0
R 0.5
R 1

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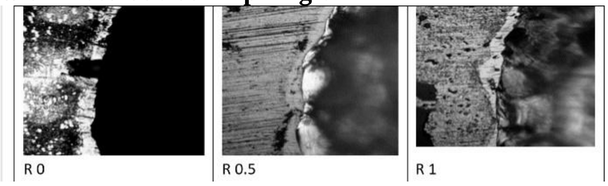
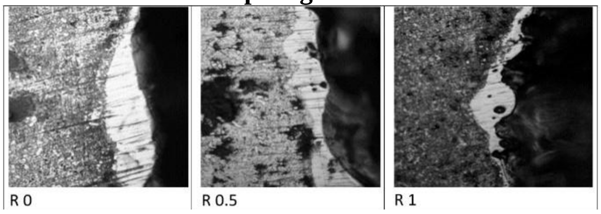
The White Layer Thickness with Magnification 400 X with Electrode 60° Tip Angle



The White Layer Thickness with Magnification 400 X with Electrode 75° Tip Angle



The White Layer Thickness with Magnification 400 X with Electrode 90° Tip Angle

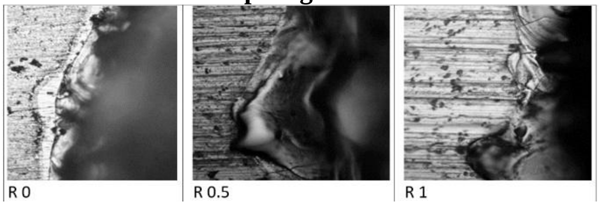


Figure 9: White layer thickness measurements

5. Conclusion

This experimental study was intended to find the optimal electrode geometry for Electrical Discharge Machining process of AISI D2 tool steel as workpiece, the main conclusions of the experimental work could be summarized as following:

1) The maximum values of ***MRR*** were recorded for electrodes tip radius *1mm* for all electrodes tip angles.
2) The ***MRR*** increase with the increase of the angles of electrodes tip form *45°*, *60°*, *75°*,to*90°*.
3) The minimum value of ***EWR***has been recorded forelectrode tip with radius of *0mm* and with electrode tip angle of *45°*.
4) The ***EWR*** decrease with the decrease of the angles of electrodes' tips form *90°*, *75°*, 60°to*45°*.
5) Increasing the angles of electrode tips from*45°* to *60°* then to *75°*has increased the thicknesses of the white layer. However,when using 90° as an angle of the electrode tip,the thickness of the white layer decreased because of the heat distribution was uniformly therefore the re-solidification of the metal was thinner compared with the other angles.

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