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Characterization of EDM Surface Morphology of Al-6061using different dielectrics

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Abstract-The effect of discharge current and pulse duration during the electric discharge machining of Aluminum alloy 6061 T6 is studied using copper electrode with paraffin oil and distilled water as a dielectric medium. The electric discharge machined surface is characterized by surface roughness (Ra), crack intensity, and average white layer thickness (AWLT). The behavior of material removal rate (MRR) and electrode wear rate (EWR) is also considered under varying conditions of EDM. AWLT and surface roughness is found to be dependent on the orientation of surface, pulse current, pulse duration, dielectric medium and electrode material. A new method of AWLT and surface roughness measurement through optical microscope is described. The results of surface roughness by this method are verified by conventional roughness tester.

Keywords-EDM, AWLT, Surface Roughness, Heat Affected Zone, MRR, Cracks Formation

I. INTRODUCTION

Electrical discharge machine (EDM) is a non-conventional machining process uses thermal energy to remove material through erosion process of electrically conductive materials [i-ii]. Erosive properties of electric discharge were invented by English chemist Joseph Priestly in 1770 and in 1943,Lazarenko used damaging properties of electric discharge for productive purpose [iii]. In 1950 and later such properties were used for successive development EDM models [iv]. This type of material removal produces different heat effected zones which typically categorized as white layer, heat effected zone and parent metal surface. Some part of molten material left during flushing process of EDM and re-solidified on machined part of specimen. During formation of recast/re-solidified/ white layer (WL) composition is changed so this layer has different mechanical properties as compared to base material [v-vi]. So study ofWL and surface roughness is most important because after EDM this layer has direct affect the service life of component.

Surface morphology directly affected with EDM parameters such as pulse duration (Pon), peak current(I), open gap voltage, electrode material, electrode geometry and dielectric medium used for EDM [vii,viii]. It is known that AWLT is associated with EDM parameters and it is harder than base metal. Peak current/pulse current and pulse duration is directly related to AWLT, surface roughness and material removal rate and inversely related to surface crack density [ix-xiv]. However the thickness of white layer increases with increasing pulse current but higher pulse current the thickness of layer decrease due to breakdown of white layer [xv-xvi]. AWLT is affected by electrode material, work material grain size, dielectric medium and pulse duration. Ultra-fined grain size of aluminum has greater effect on recast layer, heat effected zone surface crack density as compared to coarse grains[xvii-xviii]. EDM with distilled water has high WLT and MRR and more dense packed with less cracks and as compared to aluminum powder mixed with water [xi] . At lower pulse duration WLT using distilled water as a dielectric medium is lower as compared to paraffin oil and at high pulse duration only water oil emulsion has high thickness. Distilled water produced high MRR, lower tool wear ratio, better surface finish at higher pulse energy then paraffin oil. Although distilled water has lower machining accuracy. Distilled water form oxide layer on work piece while paraffin form carbide layer. Carbon and oxygen in oxide and carbide layers comes from dielectric mediums respectively[xix-xxiii].

EWR is almost zero and MRR is high when EDM is done with gas as dielectric and with the increase of oxygen concentration in air, the MRR increased [xxiv]. EWR can also be achieved to using tap water and copper electrode with negative polarity [xxv]. MRR depends on thermal properties of work material and it is also measured of productivity [xxvi]. Geometry of electrode material has great influence on MRR, irrespective the EDM processing parameters and processing variables. [xxvii-xxix]. High strength aluminum alloys has lot of application in aerospace and automobile industry because of high strength to weight ratio. EDM is preferred for machining of complex shapes on aluminum alloy. Therefore current study is performed to explore the altered characteristics of the aluminum alloy after EDM under different conditions.

II. Experimental Setup and Methodology

The Experiments are performed using NEUAR sinking EDM with thick hollow copper electrode. EDM with distilled water is performed in separate tank with water pumping system so that paraffin oil should contaminate with distilled water as shown in Fig.1.

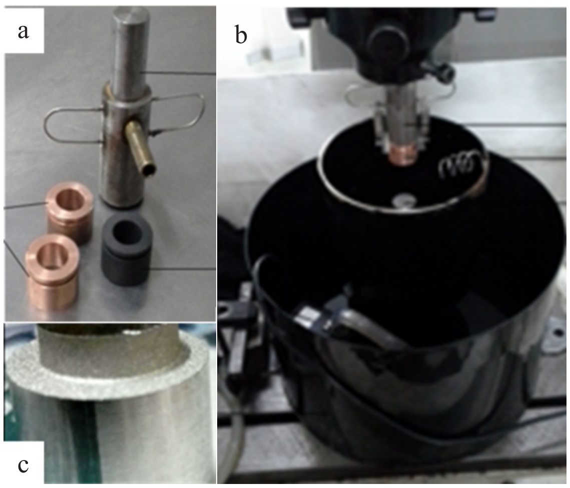

Fig 1. (a)Electrodes with holding fixture,(b) separate tank for machining with distilled water, and (c)sample obtained after machining which contained HS, VS and CS surfaces.

EDM is performed with processing parameter of pulse current and pulse duration keeping all other electrical parameter constant. Aluminum specimens are machined with copper electrode in the presence of kerosene dielectric and distilled water respectively. Thirty samples of work material Al-6061 are machined and hallow electrode produce the horizontal, vertical and corner between horizontal and vertical surface and design of experiment for machining sample is given in Table II.

TABLE I
Experimental Conditions in EDM

Work piece	Al 6061 (diameter= 22mm)
Dielectrics	Paraffin oil and distilled water
Pulse current (A)	6, 9, and 12
Electrode material	Copper
Gap (mil)	2
Pulse duration (µs)	15, 20, 30, 45,and 60
Pulse off time (µs)	7

TABLE II
Design of Experiment for EDM

Pulse Current (A)	Copper electrode with paraffin oil	Copper electrode with distilled water
	Pon (µs)	Pon (µs)
Level (1) = **6amp**	15	15
	20	20
	30	30
	45	45
	60	60
Level (2) = **9amp**	15	15
	20	20
	30	30
	45	45
	60	60
Level (3) =**12amp**	15	15
	20	20
	30	30
	45	45
	60	60

Steps for sample preparation are shown in schematic diagram 2.

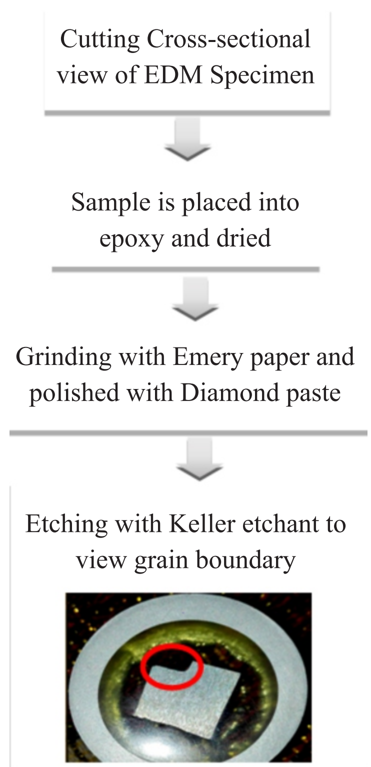

Fig. 2. Schematic procedure for sample preparation for optical microscope

After etching recast surface is observed under optical microscope OLYMPUS BX51 at 50X and 20 µm resolution, and10-15pictures of each sample including horizontal (HS) and vertical surface (VS)and the corner surface (CS) region between horizontal and vertical surface is also consider because it is important region for service life of EDM machined components. AWLT calculation using image processing technique, module Image J, by calculating area of white layer by selecting the recast layer. AWLT is calculated dividing area of white layer to its length. For each sample 6-10 values of AWLT are taken at different machined surface including horizontal and vertical and curved surface between these two. Finally mean value of both horizontal and vertical surfaces is taken. Surface roughness is measured by selecting surface profile using Engauge Digitizer 2.12 module. In Engauge Digitizer we defined scale and the coordinate system and marking the set of data points on the curve profile as shown in Fig. 3.

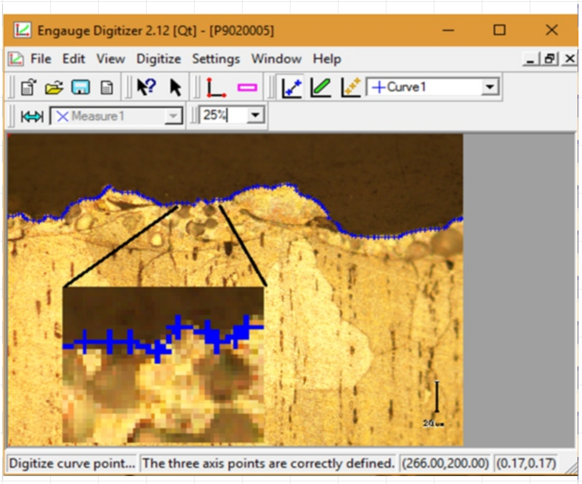

Fig. 3. Surface roughness calculation using Engauge Digitizer

These set of data points are imported into Microsoft Excel and the surface roughness (Ra) is calculated by formula

$$\mathbf{Ra} = \frac{1}{n}\sum_{i=1}^{n}|yi - m| \quad (1)$$

Where;

y = height of crest/trough from reference line

m = height of mean line from reference line

n = total no. of data points

For each sample 10 times surface roughness are measured 5 times for horizontal surface and 5 times for vertical surface at different position of machined surface and finally mean value of Ra is taken for each horizontal and vertical surfaces. These values of surface roughness are compared with the conventional portable surface roughness tester Mitutoyo SJ-410.

III. Results and Discussion

For varying condition of pulse current and pulse duration, the results are categorized into two groups.

A. *Copper Electrode and Paraffin Oil as a Dielectric*

The behavior of white layer and surface roughness at varying condition of pulse current and pulse duration is observed simultaneously using copper electrode with positive polarity and Al 6061 work piece with negative polarity and paraffin oil is used as working fluid. Fig.4 shows that the AWLT increases with the increase of pulse current at same pulse duration. It is also observed in fig.4that with the increase of pulse duration at same current the thickness of white layer increase. So AWLT increases with the increase of both pulse current and pulse duration. It has been seen that horizontally machined surface has slightly greater thickness value as compared to vertical surface, and corner surfaces show irregularities with increasing trend. It has also been observed that at higher current of 12A and pulse duration 60 µs the AWLT is decreased.

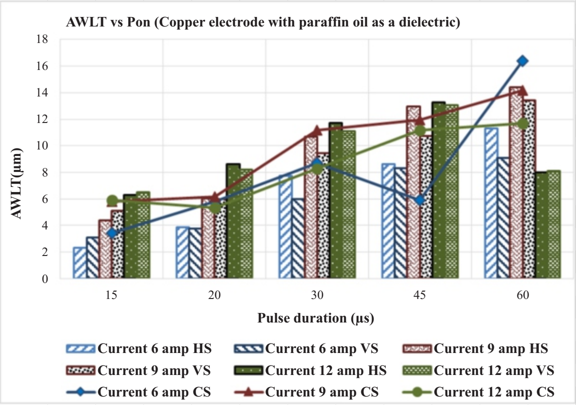

Fig. 4. AWLT variation with respect to pulse current and pulse duration

Cross-sectional view of Fig. 5(b)shows discontinuity in white layer thickness is so much. It can be thebreakdown of white layer. Fig 3(b) also shows that heat affected zone (HAZ) is slightly visible andwhite layer cross sectional area has large quantity of porosity like in the surface. Sharp break of WL, Cavities and globules with cavities formation is also observed. Fig 5(a) shows that at low pulse current 6A and low pulse duration 15 µs, the visibility of WL is seen at some place of EDM surface and at some point ofmachined surface, WL is invisible.

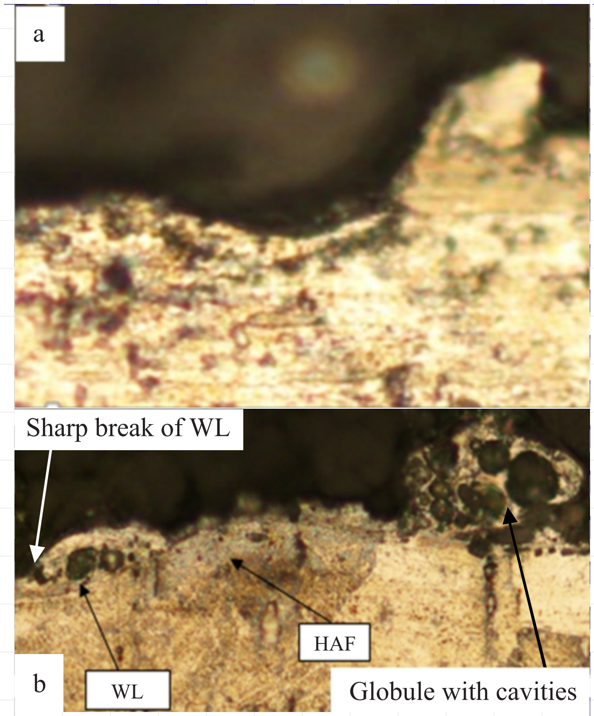

Fig. 5. White layer surface with paraffin oil at, (a) 6A with 15μs and (b) 12A with 60μs (50X+crop)

Surface roughness measured through digital image process analysis (DIP)is compared with conventional roughness testing machine. Table 3 shows that in most values, the variation is about one micron that may be vibrational effect of environment. The overall percentage error from roughness tester measured value is 9 %.

TABLE III
COMPARISON OF HORIZONTAL SURFACE ROUGHNESS DATA OBTAINED BETWEEN DIGITAL IMAGE PROCESSING METHOD AND CONVENTIONAL ROUGHNESS TESTING MACHINE

Pulse Current (A)	Copper with paraffin oil			Copper with distilled water		
	Pon (μs)	Ra (DIP) (μm)	Ra (μm)	Pon (μs)	Ra (DIP) (μm)	Ra (μm)
Level (1) = 6A	15	5.898	5.15	15	3.961	3.42
	20	5.065	5.20	20	6.806	3.79
	30	6.216	7.07	30	4.984	4.34
	45	6.869	7.00	45	4.980	4.11
	60	10.63	7.66	60	5.100	4.74
Level (2) = 9A	15	3.517	3.43	15	5.486	5.03
	20	6.043	6.17	20	5.776	5.57
	30	6.608	6.01	30	5.822	6.15
	45	8.355	8.61	45	6.847	6.62
	60	7.284	7.00	60	6.452	5.98
Level (3) =12A	15	5.954	5.83	15	4.981	4.68
	20	5.989	6.07	20	6.022	5.68
	30	6.900	7.53	30	6.851	6.35
	45	8.432	8.50	45	7.044	6.97
	60	9.040	9.98	60	5.569	5.68

Fig. 6. shows that surface roughness value increases with the increase of pulse current and pulse duration. It is also observed that at 6A current horizontal surface roughness values are slightly higher than 9A pulse current at various pulse duration. It is observe that at 12A vertical surface roughness has slightly straight line which indicate vertical surface roughness has not much variation with pulse duration. It can be seen from Fig. 6 that the overall surface roughness slightly increased with increase of both pulse current and pulse duration.

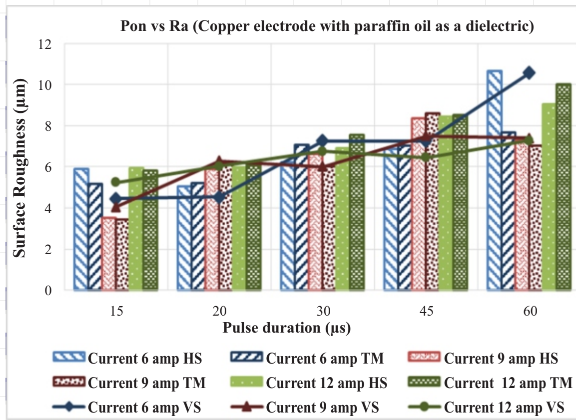

Fig. 6. Surface roughness behavior at different condition of pulse current and pulse duration

B. Copper Electrode with Distilled Water as Dielectric

Using same EDM parameters as used for copper elelectrode by replacing distilled water from paraffin oil as a dielectric medium. The over all AWLT trend is similar as described above for copper electrode with paraffin oil, however few exceptions have been seen. The magnitude of AWLT values is greater then the paraffin oil as shown in Fig 7. AWLT values of corner surface at 12A current shows decreasing behavior with inreasing pulse duration. AWLT of corner suface at 6A show zigzage behavior with increasing pulse duration. Similarly at 12A pulse current and 60μs pulse duration the value of AWLT decreased to much even decreased from 15μs pulse duration and 12A current which indicate the disintigration of white due higher pulse energy and pulse duration.

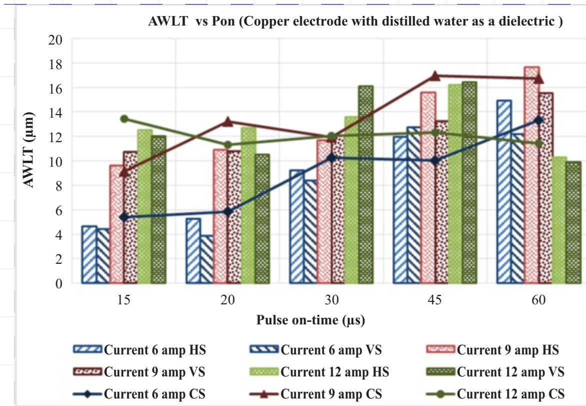

Fig. 7. AWLT variation, using copper electrode and distilled water as dielectric

Dense nature of AWLT is observe using distilled water as compared to paraffin oil which means not too much cavities and air bubbles entrapped in white layer and very less globule formation is observed as represented in fig.8. It has been observe that with increasing pulse duration and pulse current, heat affected zone and micro cracks also visible. It can also be observed from fig.8 and Fig. 5(b) that micro cracks generated in white layer are penetrating into heat affected zone and intensity of these micro crack is much greater then cracks generated using paraffin oil

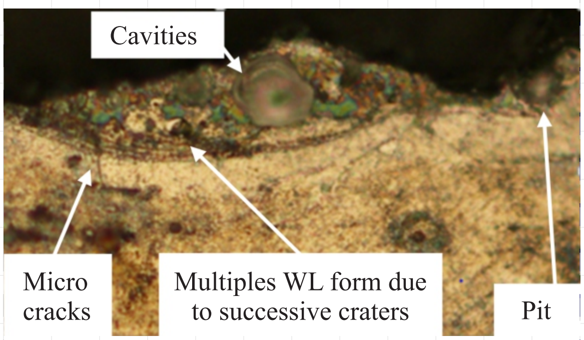

Fig. 8. White layer at 6 amp I and 60µs Pon with distilled water (50X+ crop)

Surface roughness measured with the variation of pulse current and pulse duration using distilled water is shown in Fig 9. It is observed that at 15µs and 60µs pulse duration, the value of surface roughness of 9A pulse current is greater then 12A. The surface roughness at 20µs Pon with 6A current is much greater, which can be improrper flushing. It is also observed that surface roughness values for 9A and 12A pulse current at pulse duration 60µs and 45µ are almost equal. However over all trend of surface roughess is increansing with enhancing the pulse current and pulse duration. But the surface roughness obtained using distilled water as a dielectric is lower than the surface roughness obtained using paraffin oil as a dielectric.

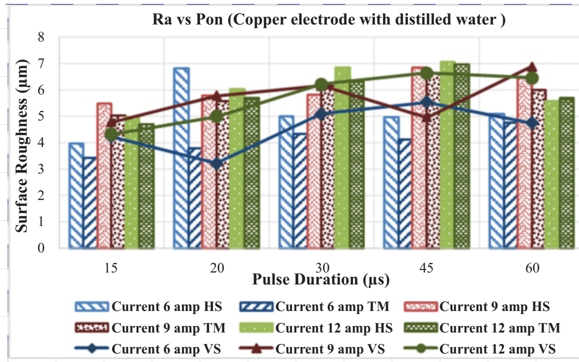

Fig. 9. Surface roughness behavior at different condition of pulse current and pulse duration

C. Material Removal Rate and Electrode Wear Rate Using Copper Electrode

Weight difference in the before and after machining of specimen and electrode determines MRR and EWR as shown in Table IV and Table V respectively.

TABLE IV
MRR (MM^3/MIN) OF AL-6061

PON	Kerosene			Distilled water		
µs	6A	9A	12A	6A	9A	12A
15	32.6	53.6	84.4	30.1	43.2	45.7
20	55.6	80.7	119	33.3	60	67.8
30	71.9	103	147	35.3	78.5	75.3
45	71.1	119	181	37	54.8	61.5
60	72.2	124	199	32.8	54.1	48.1

TABLE V
EWR (MM^3/MIN) OF COPPER ELECTRODE

PON	Kerosene			Distilled water		
	6A	9A	12A	6A	9A	12A
15	0.749	1.7	2.81	0.524	1.87	3.6
20	0.524	1.7	2.25	0.75	1.27	4.04
30	0.674	1.6	1.35	0.45	1.5	3.18
45	0.449	1	0.899	0.75	1.69	2.25
60	0.225	0.4	0.674	0.524	1.24	2.02

MRR of Al alloy is observed using copper electrode with paraffin oil and distilled water as a dielectric as shown in Fig.10.

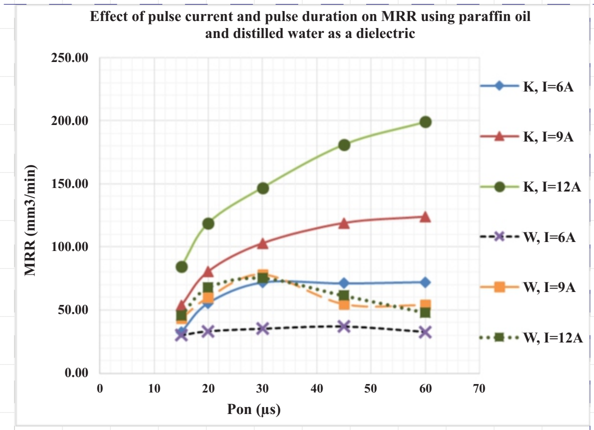

Fig. 10. MRR vs Pon at various current

It is observed that MRR increased with the increase of pulse current and pulse duration using copper electrode and paraffin oil as dielectric. But in case of distilled water as a dielectric the MRR is increased with increase of pulse duration up to 30µs, then it start to decrease with the further increase of pulse duration. It also shows that material removal rate is higher when paraffin oil used as dielectric as compared to distilled water as a dielectric. It is already observed that the AWLT is greater when distilled water used as a dielectric as compared to paraffin oil. So MRR and AWLT have relationship with each other when copper electrode is used. Fig.11 shows EWR of copper electrode, which shows the reverse behavior of MRR. It shows that EWR of copper electrode with distilled water at 12A current is much higher and decreased with increase of pulse duration. Overall decreasing trend is observed with the increase of pulse duration. In case of copper electrode, EWR increases with increasing current. As higher currents produce more thermal energy thus it removes more material from electrode. So paraffin oil has greater MMR and lesser EWR as compared to distilled water with increase of pulse current and pulse duration because the thermal conductivity of paraffin oil is grater then distilled water.

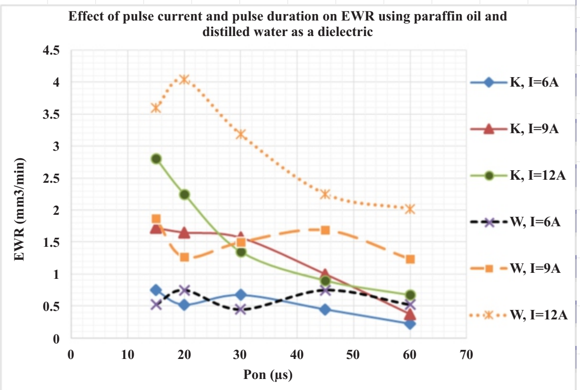

Fig. 11. EWR using copper electrode with paraffin oil and distilled water as dielectric

IV. Conclusion

The EDM of Al 6061 is done under varying condition of pulse current and pulse duration using copper with paraffin oil and distilled water as dielectrics. MRR, EWR, AWLT, and surface roughness are characterized under varying the EDM processing parameters.

AWLT increases with the increase of pulse current and pulse duration. At higher pulse current and pulse duration breakdown of white layer occurs. Dielectric medium also affect the magnitude of AWLT. Thicker white layer is obtained using distilled water as a dielectric medium as compared to paraffin oil.

Surface roughness behavior is not much varied, however with the increase of pulse duration and pulse current slight increase in surface roughness is observed. Magnitude of surface roughness is greater in paraffin oil as compared to distilled water. Similarly better surface finish and dense-packed nature of surface is observed using distilled water as dielectric. Surface crack intensity and heat affected zone increases with increasing pulse current and pulse duration. Surface cracks intensity and their penetration into HAZ using distilled water is greater than paraffin oil. Similarly HAZ is greater using distilled water.

MRR is more using paraffin oil than the distilled water. MRR also increased with the increase of pulse current and pulse duration. EWR using distilled water is higher than paraffin oil.

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