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Comparison of recast-layer on die-steel machined with Al powder-mixed distilled water and kerosene dielectric fluid

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Abstract : In this paper, an attempt has been made to compare the effect of Al powder mixed distilled water and kerosene dielectric fluids with respect to white-layer thickness (WLT). The work and tool electrode materials used are W300 die-steel and electrolytic copper respectively. Pulse peak current, pulse on-time and concentration of Al powder are taken as the process parameters to study white-layer thickness. The experiments are planned using face centered central composite design procedure. Empirical models are developed for WLT using response surface methodology. Low WLT of 17.14 μm is obtained at high concentration of Al powder of 4 g/l in distilled water and at low peak current of 6 A, whereas 22.46 μm thickness obtained with 4 g/l Al powder mixed kerosene at 18 A.
Keywords : PMEDM, Distilled water, Kerosene, Al powder, W300 die-steel, white-layer.

Introduction

Manufacturers are aiming to achieve better stability and high economical productivity of the manufacturing process using various advanced machining techniques[1]. In Electrical discharge machining dielectric fluids fulfil an important function on which, productivity, cost and quality of the machined parts depends. In addition to maximizing quality and cost, it is imperative for the manufacturing industries to be concerned to be concerned with minimizing environmental impact[2].To that end, research is continuously being done over three decades to improve the process efficiency using environmental friendly dielectric fluids. Several researchers have attempted to modifythe EDM process to alleviate some of these constraints using powder-mixed hydrocarbon oils (PMEDM).

During the investigation of various powders (Graphite, Al, Si, SiC, Crushed glass, MoS_2), suspended in kerosene, Al powder produced near mirror finish, whereas graphite and Si resulted in glossy finish surfaces on the AISI-O1, SKH54 steels[3]. Increase in the concentration of Ni powder in the kerosene, the recast layer became more uniform and thick during the machining of aluminium-bronze[4]. During machining of inconel718, Si powder produced grey zone beneath the actual white-layer with lower nickel concentration in that area[5].

In addition to the studies on varying electrical parameters[6], investigated the thermo-physical properties of powders. Addition of powders found to reduce white-layer thickness[7]. In order to prevent the agglomeration of powders during machining in PMEDM, surfactant molecules (Polyoxythylene-20-sorbitan monooleate) in dielectric fluid also tried[8].

The CNT suspension in dielectric resulted in reduced micro-cracks and better surface morphology when compared with pure dielectric fluid[9]. Addition of graphite nono-powder (55 nm), machining time reduced by 35%, micro-crack density reduced from 0.03 /cm to 0.004 /cm and R_a value from 1.8 μm to 1.4 μm when compared to pure dielectric fluid[10].

Even though PMEDM having distinctive advantages over EDM, addition of different metallic powders is limited to oil based dielectric fluids only.Investigations on the influence of EDM oil and deionized water dielectric fluids on the composition and the metallographic phases of the white-layer[11]. EDM oil increased the carbon content of the white-layer, which appears as Fe_3C carbide with columnar dendritic structure. Whereas machining with water resulted in decarburization and less micro-cracks on the white-layer.During the investigations of the machining characteristics of Ti-6A-4V, TiC layer formed during machining of Ti-6Al-4V with kerosene and TiO layer with distilled water [12] .During machining with de-ionized water,the intensity of micro-cracks are less in the white-layer than the base material[13]. Whilst, carbon-based dielectric fluid resulted in white-layer composed of cementite. Further studies reveals that, the amount of retained austenite for samples machined with kerosene was found to be less when compared to de-ionized water [14].

In addition to the organic compounds, the effect of SiC powder in PMEDM using water dielectric fluid were also done[15]. Al powder mixed distilled water produced low surface roughness of 2.08 μm on die-steel[16].B_4C abrasive powder mixed water found to improve the surface quality and reduce the WLT on Ti-6Al-4V when compared to pure water [17]. Eemulsion resulted in higher value of surface roughness, WLT and micro-hardness when compared to kerosene or de-ionized water. Whereas machining with water resulted in micro-cracks with low penetration depths [18].

PMEDM with hydrocarbon oils proved their capabilities during machining of different die-steel materials. Among these, W300 is commonly used die-steel having wide range of applications in tool and die industry due to its low cost. In present research an attempt was made to compare the performance of Al powder-mixed distilled water with that of Al powder-mixed kerosene with reference to white-layer thickness and surface integrity during PMEDM.

1.Experimentation

A separate dielectric recirculation system was fabricated and attached to the machine to perform experiments using Al powder-mixed water dielectric fluid. W300 die-steel material chosen for the present study. The workpieces were wire-cut to the required size and the top and bottom surfaces were ground to maintain similar R_a values and flatness. The tool electrode is a solid rod of 9.5 mm diameter made of Electrolytic copper.

In PMEDM, process parameters are classified into various groups such as electrical, non-electrical, powder, dielectric fluid and electrode parameters, and dielectric fluid. The most influencing parameters such as peak current (I), pulse on-time (T_{on}), duty factor (DF), gap voltage (V), Polarity (P), concentration of the powder (C) and size of the powder (S) are identified for the present work.

The levels of the process parameters were selected by conducting pilot experiments, literature survey and from the machine manual. Negative polarity (NP) was selected for kerosene and positive polarity (PP) for distilled water which resulted in high MRR. Peak current is varied from 6 - 18 A. A gap voltage of 40 V was selected for the experiments for stable machining condition.From the machine manual the pulse on-time (T_{on}) and pulse off-time (T_{off}) were selected to maintain a constant duty factor of 65-75%.Pilot experiments conducted to study the influence of size of Al powder on MRR for three different particle sizes 7, 27 and 36 μm mixed with distilled water and kerosene. From the results, it is found that Al powder of particle size 27 μm produces relatively higher MRR for distilled. Hence Al powder of particle size 27 μm was chosen.It was found that MRR increases with the increase in concentration up to 1 g/l for both the dielectric fluids and then decreases gradually with further increase in the concentration. The concentration level more than 6 g/l causes frequent short circuits and makes machining process unstable. Hence, a maximum concentration of 4 g/l was selected. The coded and the actual values of these process parameters are shown in the Table 1. The process parameters maintained at a fixed value are shown in the Table 2.

Table 1 Process Parameters (FCCCD).

Process parameters	**Unit**	**Levels**		
		-1	**0**	**1**
Peak current (*I*)	A	6	12	18
Pulse on-time (T_{on})	µs	120	220	320
Concentration of powder (*C*)	g/l	0	2	4

Table 2 Values of the Fixed Process Parameters.

Fixed process parameter	**Value**
Voltage (V)	40 V
Duty factor (DF)	65%
Powder size (S)	27 μm
Flushing pressure	70(kPa)
Polarity (P)	Distilled water – PP Kerosene - NP

2.Results and Discussion

Experiments were designed using face centered central composite design (FCCCD) for distilled water and kerosene dielectric fluids. The controllable process parameters chosen for the experimentation were peak current (I), pulse on-time (T_{on}), concentration of the powder (C). For the selected three process parameters the design consists of each 20 (cube points-8, center points in the cube-6, axial points-6) experiments using Al powder-mixed with distilled water and kerosene dielectric fluids. Empirical equations for the responses were developed using response surface methodology (RSM). Finally, the performance of powder-mixed distilled water and kerosene dielectric fluids were compared with respect to WLT and surface integrity.

The regression models for WLT were developed from the regression model coefficients. ANOVA was performed to check the adequacy of the regression model. The process parameters such as *I*, T_{on}, *C*, interaction parameters such as $C \times I$ and $T_{on} \times C$ have significant contribution in WLT model, since these P-values are less than the significance level, β = 0.05. The calculated F-values for WLT are 6.43 and 26.45 for distilled water and kerosene respectively. Further, the computed F-value is greater than the F-critical ($F_{0.05,9,10}$ = 3.02) for a significance level of β = 0.05. It indicates that the models are adequate for 95% confidence level.The values of WLT for the given input parameters can be obtained from the Eqs. (1)and (2) for distilled water and kerosene respectively.

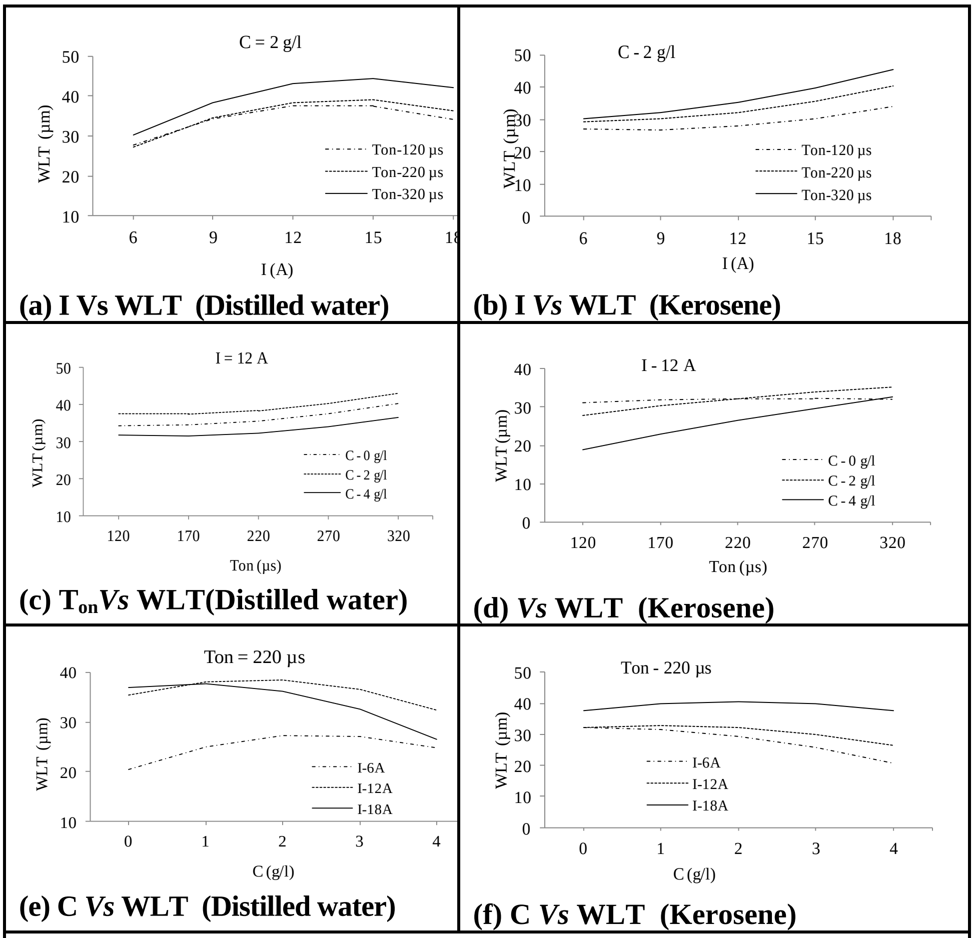
$$WLT\ (\mu m) = 32.26 + 5.57\,I + 3.67\,T_{on} - 2.89\,C + 2.67\,I \times I - 0.69\,T_{on} \times T_{on} - 2.94\,C \times C + 1.99\,I \times T_{on} + 2.91\,C \times I + 3.19\,T_{on} \times C \quad (1)$$

$$WLT\ (\mu m) = 38.41 + 4.53\,I + 2.68\,T_{on} - 1.57\,C - 6.71\,I \times I + 1.91\,T_{on} \times T_{on} - 4.52\,C \times C + 1.37\,I \times T_{on} - 3.69\,C \times I - 0.32\,T_{on} \times C \quad (2)$$

2.1 Effect of Process Parameters on WLT

Effect of peak current(distilled water)

From the trend of WLT at different levels of the process parameters for distilled water dielectric, it is evident from Figure 1(a) that, the thickness of the white-layer increases with increase in peak current for any value of the pulse on-time. The minimum thickness of the white-layer is obtained at low peak current of 6 A, and low pulse on-time of 120 μs. This is due to the fact that, increase in the pulse current leads to an increase in the pulse energy which increases the rate of melting and evaporation of electrodes. This causes higher volume of molten material and the dielectric fluid unable to flush away all the molten material and causing it to build upon the surface of the parent material. During pulse-off time, this molten material resolidifies to form white-layer. The observations are consistent with the results reported by [18].



(a) I Vs WLT (Distilled water) **(b) I *Vs* WLT (Kerosene)**

(c) T_{on} *Vs* WLT(Distilled water) **(d) *Vs* WLT (Kerosene)**

(e) C *Vs* WLT (Distilled water) **(f) C *Vs* WLT (Kerosene)**

Figure 1 Effect of process parameters on WLT

Effect of peak current (kerosene)

From the trend of white-layer thickness at different levels of the process parameters, it can be observed from Figure 1(b), the white-layer thickness increases gradually with increase in peak current for any value of the pulse on-time. The minimum white-layer thickness is obtained at low peak current of 6A and smaller pulse on-time of 120 μs.Increase in the pulse current at a constant concentration of the powder increases the energy of thepulse and ultimately gives a high thickness of white-layer.

Effect of pulse on-time (distilled water)

From the Figure 1(c) it is evident that, the increase in T_{on} value increases the tendency of formation of white-layer. In EDM metal is primarily removed in the liquid and vapour phase. At low pulse on-time the short pulses may cause less vaporization of the work material, whereas long pulse duration causes the plasma channel to expand and this expansion causes less energy density on the workpiece, which is insufficient to melt and/or vaporize the workpiece material, which ultimately results in thick white-layer. The minimum thickness of white-layer is obtained at low pulse on-time of 120 μs and high concentration of powder 4 g/l. A similar effect found on the samples when machined with kerosene dielectric fluid using graphite electrode due to the desire infiltration of recast layer [14].

Effect of pulse on-time (kerosene)

From the figure1(d), it is evident that an increase in the pulse on-time, increases the tendency of formation of white-layer. In EDM metal is primarily removed in the liquid and vapour phase. At low pulse on-time the short pulses may cause less vaporization of the work material, whereas long pulse duration causes the plasma channel to expand and this expansion causes less energy density on the workpiece, which is insufficient to melt and/or vaporize the workpiece material, which ultimately results in a thick white-layer. The minimum recast layer is obtained at low pulse on-time of 120 μs and high concentration of powder 4g/l. The white-layer thickness is gradually starts to increase at the value of 220 μs. The thickness of the white-layer found to be non-uniform high pulse on-time 320 μs for the samples machined with Al powder-mixed kerosene dielectric fluid. The piled re-solidified material resulted in a multi-layer structure as shown in the figure2. A similar effect found on the samples when machined with kerosene dielectric fluid using graphite electrode due to the desire infiltration of recast layer [14].

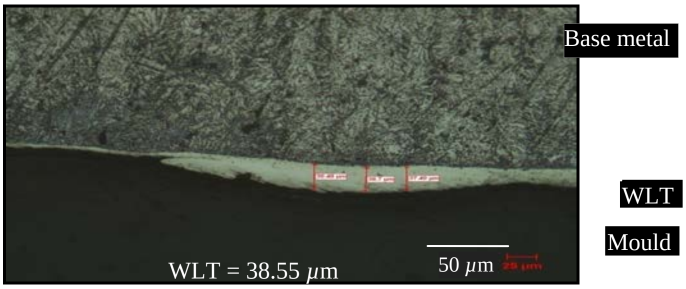


Figure2Recast layer at I - 18A, T_{on} - 320 μs, C - 4 g/l, kerosene.

Effect of concentration of powder (distilled water)

Figure 1(e) depicts the influence of concentration of powder suspended in the distilled water on WLT. With increase in the concentration of the aluminium powder, the white-layer thickness tends to decrease for low value of peak current 6 A more effectively. This is because the conductive powder particles cause the bridging effect between the electrodes which increase discharging rate. This improves the process stability and reduces the impulsive forces [19] which results in uniform and thin white-layer. The minimum thickness of white-layer 17.14 μm is obtained at high concentration of powder of 4 g/l and low peak current of 6 A, which is shown the Figure 3 (a). Whereas low concentration of 0 g/l at peak current of 12 A, and pulse on-time of 220 μs resulted in high thickness of white-layer 27.92 μm which is shown in the figure3 (b).

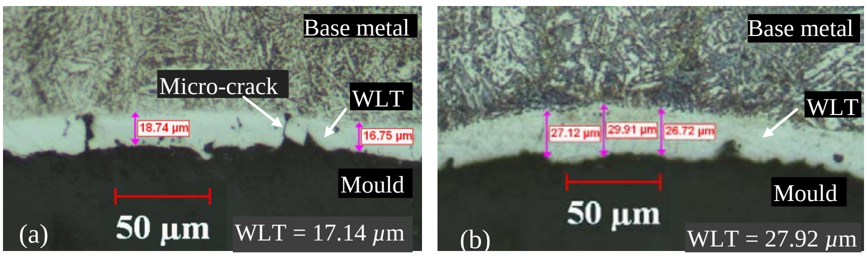
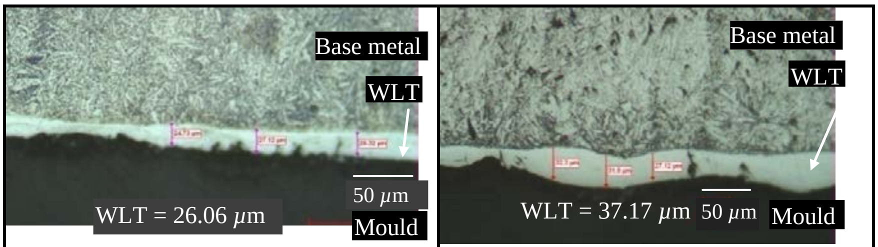


Figure 3 Effect of concentration of powder (kerosene)

Figure 1(f) depicts the influence of concentration of aluminium powder on recast layer thickness. Low thickness of white-layer is obtained at different conditions of the dielectric fluid. Pure kerosene at low current of 6 A and 120 μs pulse duration produces low thickness of white-layer of 19.14 μm. Whereas similar thickness of 22.46 μm is obtained at high current of 18 A, 120μs and an addition of high concentration of aluminium powder of 4 g/l. The white-layer thickness tends to decrease for medium and high peak current of 18 A in presence of aluminium powder in the dielectric. This is because the conductive powder particles cause the bridging effect between the electrodes which increase discharging rate particularly at high pulse currents.

From the experimental results, it is observed that, the thickness of the white-layer obtained with distilled water dielectric fluid is lower than that obtained with kerosene for the similar machining. This can be observed from the figure 4 that, distilled water and kerosene resulted in WLT of 26.06 μm and 37.17 μm respectively at pulse current of 12 A, pulse on-time of 220 μm and concentration of 2 g/l.



(a) Dielectric - distilled water. **(b) Dielectric - kerosene.**

Figure 4 white-layer (I - 12 A, T_{on} - 220 μs, C - 2 g/l, NP)

3.Conclusion

The factors peak current, pulse on-time and concentration have significant contribution in WLT model. The parametric study shows that the thickness of the white-layer increases with increase in peak current and pulse on-time. Hence low values of peak current and pulse on-time, and high concentration of powder should be selected for minimum WLT (17.14 µm) with distilled water dielectric fluid.

Kerosene dielectric fluid results in minimum WLT (19.14 µm) at low pulse current of 6 A, low pulse on-time of 120 µs and low concentration of powder. It is noted that minimum WLT (22.46 µm) is also obtained at high current of 18 A, low pulse on-time of 120 µs at high concentration of aluminium powder of 4 g/l. This could be due the strong interaction effect between the pulse current and powder concentration.

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