Studies on Recast-layer in EDM using Aluminium Powder Mixed Distilled Water Dielectric Fluid

Khalid Hussain Syed [1], P. Kuppan [2]
School of Mechanical & Building Sciences, VIT University, Vellore
Tamil Nadu, India, 632014
[1] khalidhussains@gmail.com
[2] pkuppan@vit.ac.in

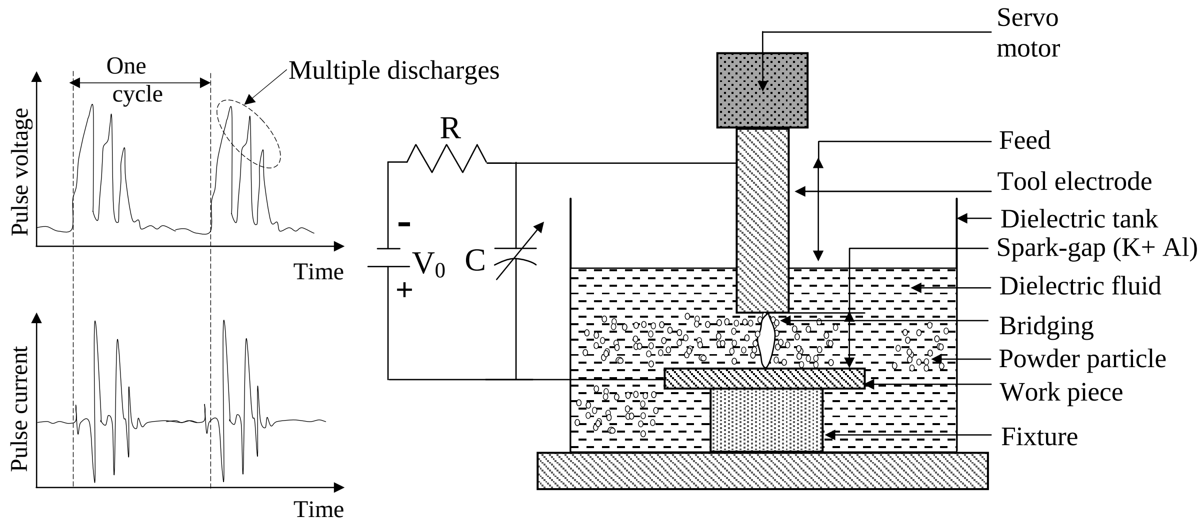
***Abstract*—In this paper, an attempt has been made to study the effect of aluminium powder when mixed in the distilled water dielectric fluid. The work and tool electrode materials used are W300 die-steel and electrolytic copper respectively. Pulse peak current, pulse on-time and concentration of aluminium powder are taken as the process parameters. The output response considered is white layer thickness (WLT). The experiments are planned using face centered central composite design procedure. Empirical model is developed for WLT using response surface methodology (RSM) to study the effect of process parameters. Optical microscopy results show that low 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.**

Keyword-PMEDM, Distilled water, Al powder, W300 die-steel, white-layer

I. BACKGROUND

Powder Mixed Electric Discharge Machining (PMEDM) is one of the techniques used in EDM to improve the machining efficiency and surface finish in the presence of powder suspended dielectric fluid. Electrically conductive powder suspended in the dielectric fluid reduces the insulating strength of the dielectric and increases the spark gap between the tool and workpiece. As a result, the process becomes more stable, increases machining efficiency and reduces the surface defects.

The working principle of PMEDM is different from conventional EDM. A series of voltage pulses of magnitude about 20-120 V and frequency on the order of 5 kHz is applied between the two electrodes, which are separated by a spark gap typically 10-200 μm. The spark gap filled up with powder particles suspended in the dielectric fluid, get energized due to the electric field. These charged particles are accelerated by the developed electrical field and act as conductors. The powder particles arrange themselves under the sparking area and gather in clusters. The chain formation of particles helps in bridging the gap (Fig. 1b) between the electrodes and decreases the insulating strength of the dielectric fluid. This results in several discharging paths creating multiple discharges within a single input pulse [1].Thus a single input pulse creates several discharging



(a) Voltage and current wave form

(b) Schematic diagram of PMEDM setup

Fig. 1 PMEDM principle

craters causing faster metal removal from the work surface. At the same time, shallow craters create smaller debris and will be flushed away easily from the spark gap, which results in improved surface finish. Due to the multiple discharges, modified wave of the voltage pulse is entirely different from the pure dielectric fluid which is shown in Fig. 1(a).

Environmentally friendly dielectric fluids such as pure water and organic compound mixed deionized water were tried by several researchers as an alternative for hydrocarbon based dielectric fluids [2]. Water-based dielectrics can replace hydrocarbon oils as have better performance and environmentally suitable due to the non-toxic emissions when compared to other hydrocarbon oils [3]. Some advantages of using pure water are owing to its higher thermal conductivity, which is about four times that of kerosene [4], a low viscosity coefficient, and a high flowing rate. Further, pure water temperature not affected by longer machining time leads to high MRR. Extensive comparative studies have been done on recast layers of a surface machined by EDM using de-ionized water, kerosene and W/K emulsion [5].

Aluminium bronze machined with nickel powder mixed kerosene dielectric fluid has a smaller surface roughness than that in conventional EDM with pure kerosene. Recast layer contained nickel richly and the thickness of white-layer became larger and uniform with an increase in the concentration of nickel powder. Further, the hardness of the white-layer is higher and the surface is smoother than that with pure kerosene [6].

In micro-EDM using graphite nano-powder in suspended kerosene as dielectric fluid Prihandana et al. [7] found that, machining time reduces by 35%, and improves the surface quality by reducing micro-crack density from 0.03 /cm to 0.004 /cm. and R_a reduces from 1.8 μm to 1.4 μm.

Prabhu and Vinayagam [8] conducted experiments by suspending Carbon Nano-Tubes (CNT) in to the kerosene and found, reduced micro cracks and better surface morphology as compared with specimens sparked without CNTs.

During machining of Inconel718 using tungsten wire of diameter 1 mm, suspended Al powder leads to thinnest rim zone and highest MRR, where as Si powder produces grey zone beneath the actual white zone with lower Ni concentration in that area [9].

Kibria et al. [10] studied the effect of addition of B_4C to the de-ionized water during the machining of Ti-6Al-4V and found to improve metal removal rate (MRR), lower tool wear rate (TWR), higher over cut, higher surface quality and less WLT than pure water.

Kruth et al. [11] investigated the influence of type of dielectric fluid and electrode material (Cu, Al, Graphite) on the composition and the metallographic phases of the white-layer formed on the workpiece C35 and Armco iron. The results show that machining in oil increases the carbon content of the white-layer which appears as Fe_3C carbide with columnar dendritic and increases micro-hardness. Whereas machining in water causes decarburization and less micro-cracks on the white-layer.

Metal powder suspension in dielectric fluids improves the MRR and surface quality. Most of the research works on PMEDM are on powder suspension in oil-based dielectric fluids. There appears to be hardly any published report on metal powder suspension in water based dielectric fluids. Further, important die steel materials such as oil hardened non-shrinking steels (OHNS), high speed tool steels (HSS) and water-hardening die steels (W-series) have not been investigated using PMEDM [12]. It is found that, Al powder attracted many researchers as it's thermo-physical properties contributing for improving the performance of EDM [13].

In the present work, WLT and surface morphology of W300 sampled machined with Al powder suspended distilled water in EDM are investigated.

II. Experimentation

A. Experimental set-up

The experiments were conducted on a die sinking EDM machine with a separate dielectric re-circulating system. The work material chosen for the present study is W300 die-steel (0.32% C, 0.8 % Si, 4.5 % Cr, 1% Mn, 0.3% V and remaining Fe), which is extensively used in the fabrication of tools and dies. The required sizes of workpieces were wire-cut from a blank. Electrolytic copper of diameter 9.5 mm was chosen as a tool electrode material. The experiments were conducted with powder mixed distilled water as dielectric fluid. External jet flushing with a pressure of 0.75 kPa was used for all the experiments. The metal powder selected was aluminium with average particle size of 27 μm. Pilot experiments were conducted with three different sizes of Al powder of average particle size 7, 27 and 36 μm and selected 27 μm based on higher MRR (Fig. 2) for further experimentations. The average particle size measured using laser diffraction particle size analyzer CILAS 920.

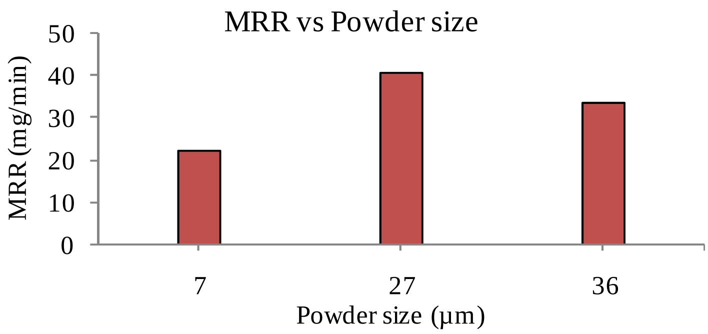


Fig. 2 MRR Vs powder size

B. Design of Experiments

Design of experiments (DOE) is a structured, organized method for determining the relationship between factors, which affect the process and the output of that process by conducting only minimum number of experiments[14]. In this study face cantered central composite design (FCCCD) was selected. FCCCD designs comprise a set of two-level factorial points, axial points and center runs. The factorial points contribute to the estimation of linear terms and two-factor interactions. The axial points contribute to the estimation of quadratic terms.

The controllable variables chosen for the experimentation were peak current (I), pulse on-time (T_{on}), concentration of the powder (C). Other factors such as gap voltage (35 V), machine servo sensitivity, lift time and flushing pressure were kept constant. The range of input parameters were fixed from the pilot experiments and the literature[15]. The experimental conditions are shown in the Table I. White layer thickness (WLT) is the response parameters measured using Carlzeiss optical microscope with image analysis software. For the selected three input process parameters the design consists of each 20 experiments using Al powder mixed with distilled water as dielectric fluid.

TABLE I
Experimental Conditions

Workpiece	W300 Die-steel
Workpiece size	20 mm×40 mm×6 mm
Electrode	Electrolytic copper Ø 9.5 mm
Voltage (V)	35
Dielectric fluid	Al powder + distilled water
Polarity	Positive
Peak current(A)	6, 12, 18
Pulse-on time (μs)	120, 220, 320
Powder concentration (g/l)	0, 2, 4
Duty factor (%)	75
Flushing pressure (kPa)	70

C. Empirical modeling

Response Surface Methodology (RSM) was used to develop the quadratic regression equations for the output response. RSM is a method which uses quantitative data from the experiments to determine and simultaneously solve multi variant equations.

TABLE II
Regression Analysis for WLT with Distilled Water

Term	Coefficient	P-value
Constant	32.2606	0.000**
I	5.5670	0.001**
T_{on}	3.6650	0.009**
C	-2.8860	0.029*
I x I	2.6701	0.245
T_{on} x T_{on}	-0.6891	0.757
C x C	-2.9441	0.203
I x T_{on}	1.9912	0.147
C x I	2.9137	0.044*
T_{on} x C	3.1888	0.031*
S = 3.58571	R-Sq = 85.26%	

** highly significant

* significant

The regression model coefficients are shown in the Table II for distilled water dielectric fluid. ANOVA was performed to check the adequacy of the regression model. The values of correlation coefficients, R-Sq for WLT for water is over 0.85. The fit summary recommended that the quadratic model is statistically significant for analysis of WLT. The associated *p*-value for the models are lower than 0.05 (i.e. α = 0.05, or 95% confidence) indicates that the developed empirical model is statistically significant. WLT values for the given input parameters can be obtained from the equation (1) for distilled water dielectric fluid.

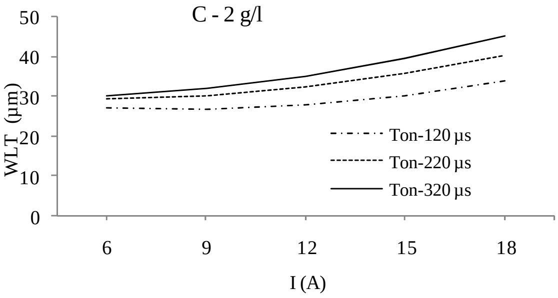
$$WLT\ (\mu m) = 32.2606 + 5.5670\ I + 3.665\ \mathrm{T}_{on} - 2.886\ C + 2.6701\ I \times I - 0.6891\ T_{on} \times T_{on} - 2.9441\ C \times C + 1.9912\ I \times T_{on} + 2.9137\ C \times I + 3.1888\ T_{on} \times C \quad (1)$$

III. RESULTS AND DISCUSSION

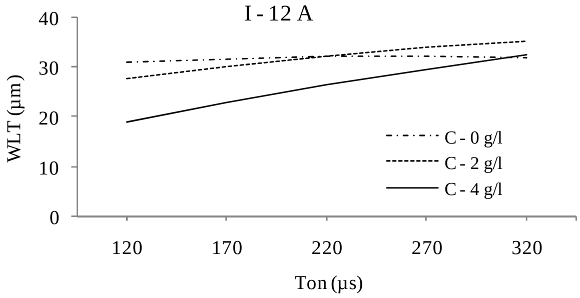
A. Effect of process parameters on WLT for distilled Water

1) *Effect of peak current*: From the trend of WLT at different levels of the process parameters, it is evident from Fig. 3(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 Zhang et al. [5].

2) *Effect of pulse on-time:* From the Fig. 3(b) 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 4g/l.



(a)



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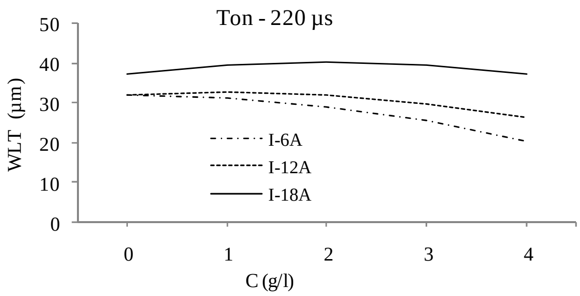
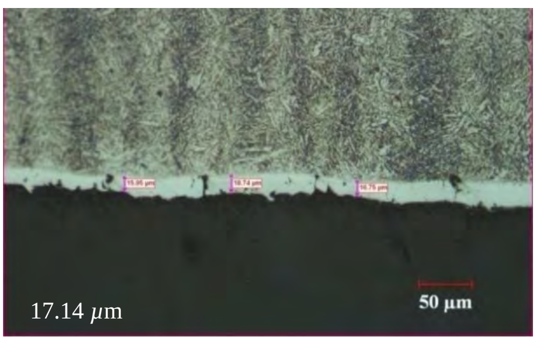


(c)

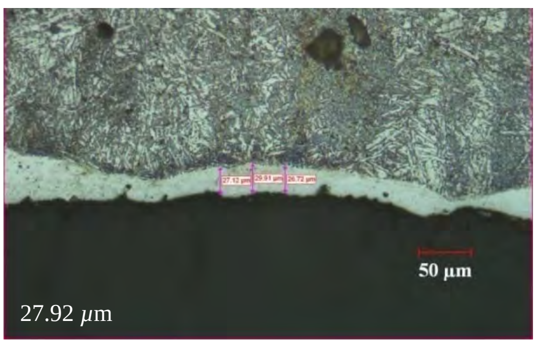
(a) I Vs WLT (b) T_{on} Vs WLT (c) C Vs WLT

Fig. 3 Effect of process parameters on WLT

3) *Effect of concentration of the powder:* Fig. 3(c) depicts the influence of concentration of powder suspended in the distilled water on WLT. With increase in the concentration of the aluminium powder, the WLT tends to decrease for any value of peak current and for lower value of 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 [16]. Peak current of 6 A, and concentration of the powder of 4 g/l in the positive polarity resulted in uniform and thin white-layer of 17.14 μm which is shown in the Fig. 4(a). Further, high concentration of Al powder leads to deeper cracks and voids on the white-layer. Whereas medium peak current of 12 A, and pulse on-time of 220 μs with pure distilled water in positive polarity resulted in dense high thickness of white-layer 27.92 μm which is shown in the Fig. 4(b). Further lowest thickness of white-layer is reported by the author 11 μm in the negative polarity of the electrode [17].



(a) 6A - 120 μs - 4 g/l in positive polarity



(b) 12A - 220 μs - 0 g/l in positive polarity

Fig. 4 WLT on W 300 die steel machined with distilled water

IV. CONCLUSION

From the experimental results it is found that, Al powder mixed distilled water can be used to reduce the white layer thickness formed on W300 di-steel material. The other conclusions drawn are as follows:

- The parametric study shows that, the WLT increases with increase in peak current for any value of the pulse on-time.
- With the increase in T_{on} value, the tendency of formation of white-layer increases.
- With increase in the concentration of the aluminium powder, the WLT tends to decrease for any value of peak current.
- Low peak current of 6 A, high concentration of Al powder of 4 g/l suspended in the distilled water produces, minimum thickness of white-layer 17.14 μm on the machined surface with positive polarity.
- Empirical equations are developed to predict the WLT at various machining conditions within the range of investigation.
- Pure distilled water produces dense and high thickness white-layer with less cracks on the machined surface.
- Higher concentration of aluminium powder in the distilled water produces thin white-layer consisting more cracks and voids on the machined surface.

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