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Performance of Environmental Friendly Dielectric Fluid in Powder-Mixed Electrical Discharge Machining

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Abstract: Powder mixed electrical discharge machining is one of the techniques used in EDM to improve the machining performance. In this paper, an attempt has been made to study the effect of aluminium powder when mixed in the distilled water dielectric fluids. 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 surface roughness (R_a). The experiments are planned using face centered central composite design procedure. Empirical models are developed for Ra using response surface methodology (RSM) to study the effect of process parameters. The results show that aluminium powder mixed distilled water produces low surface roughness value of2.08 µm.
Key Words: Powder-Mixed EDM, Distilled water, Ra.

1. Introduction

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 with minimizing environmental impact. To that end, research is continuously being done over three decades to improve the process efficiency by alternative dielectric fluids such as pure water, water mixed with organic compounds and commercial water-based dielectric fluids.

Additions of organic compounds to the dielectric fluid, improved performance of water as the dielectric fluid in EDM during the machining of SK4 die steel[1]. These organic compounds are 10%, 25%, and 50% concentrations of ethylene glycol, glycerine, polyethylene glycol 200-600, dextrose, and sucrose solution in water. The responses studied were MRR, TWR and surface roughness. It was reported that MMR increased with increase in the concentration, and more significantly with increase in the molecular weight. The results suggest that machining characteristics of polyethylene glycols are competitive with conventional EDM oil.

Few researchers [2] compared the performance of dielectric fluids such as glycerine and hydrocarbon oils during electrical discharge machining of 56NiCrMoV7 using Cu electrode. Highly concentrated aqueous solution of glycerine has advantage over hydrocarbon oils for high pulse on-time, high currents, high duty factor and high open circuit voltage during rough machining. Glycerine solution yields high material removal rate, low tool wear and slightly improved surface roughness values as compared to Shell K-60 hydrocarbon dielectric. In a similar study using urea solution in water resulted in the formation of TiN hard layer due to element transfer during machining of Ti alloy[3].

In addition to the organic compounds, few researchers investigated the effect of abrasive powders in PMEDM using water dielectric fluid. SiC powder [4] and B_4C powder [5] mixed with water were investigated during the machining of Ti-6Al-4V alloy. These powders helped in bridging the gap and improved MRR. In addition to MRR, B_4C mixed water found to reduce TWR, improved the surface quality and reduced the WLT when compared to pure water.

Most of the research works on PMEDM are on powder suspension in oil-based dielectric fluids. Literature review of comparative studies reveals that, water-based dielectric fluids results in a better performance due to their low viscosity and less environmental impact. Whereas, hydrocarbon oils are superior in a wide range of machining conditions. There appears to be hardly any published report on metal powder suspension in water based dielectric fluids. PMEDM of water based dielectric fluids are limited to addition of organic compounds only. Further, important die steel materials such as oil hardened non-shrinking steels (OHNS), molybdenum base high speed tool steels (HSS) and water-hardening die-steels (W-series) have not been investigated using PMEDM [6].

Hence, this research work attempts to investigate the effect of aluminium powder-mixed water-based dielectric fluid during machining of W300 die-steel work material.

2. Experimentation

The experiments were conducted on a die sinking EDM machine, manufactured by the Electronica Industries, India. The capacity of the recirculating dielectric tank in the standard machine is 100 litres. Since it is planned to use a fresh dielectric fluid with varying concentrations of Al powder for every experiment, a separate dielectric recirculation system was designed, fabricated and attached to the machine. The recirculation system consists of dielectric tank, pump and delivery devices. Figure 1shows the photographic view of the experimental setup.

The circulation system consists of a 0.25 HP pump. The pump receives the dielectric fluid from the outlet of the conical tank and recirculates to the tool-work inter-electrode gap to flush the debris during machining. The continuous recirculation of the dielectric fluid avoids the settlement of powders in the flushing system.

Effective flushing of dielectric removes debris from the gap, whilst ineffective flushing results in low mrr and poor surface finish. the effective flushing may increase MRR as much as by a factor of 10 or so [7]. The various types of flushing method have been proposed in the literature [8,9]. In this investigation side jet flushing was selected to flush out the debris. The dielectric was flushed at a pressure of 70 kPa by means of flushing tube.

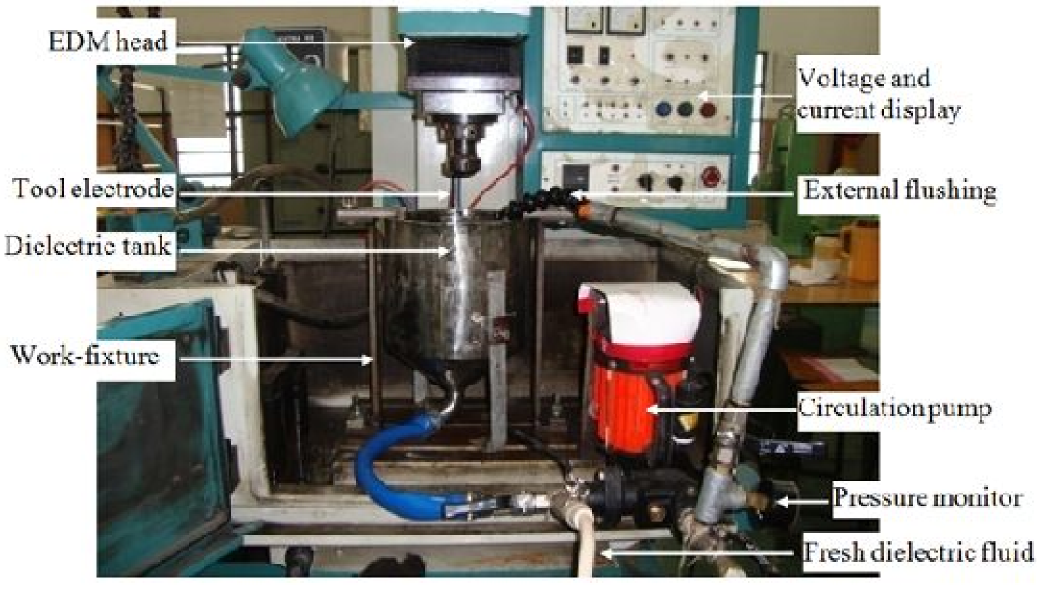


Figure 1 Photograph of experimental setup

Dielectric fluids such as transformer oil, paraffin oil, kerosene, lubricating oils and deionized water could be used as dielectric in EDM. From the literature, it was found that there are two main types of dielectric fluid commonly used namely, deionized water and hydrocarbon oil in PMEDM [10;11; 12]. In this present investigation distilled water is chosen as dielectric fluid. The important characteristics of the dielectric fluids are shown in Table 1.

The work material chosen for the present study is W300 die-steel. It is water hardened die-steel which is essentially a plain carbon and low alloyed steel. This type of tool steel is the most commonly used tool steel because of its low cost. The composition and other physical properties of W300 die-steel are given in Table 2 and Table 3 respectively. The workpieces were wire-cut to the required size from the W300 die-steel block. The top and bottom surfaces of the workpieces were ground by using surface grinding to maintain the flatness.

Metals with a high melting point and good electrical conductivity are usually chosen as tool material for EDM. In this work, electrolytic copper was used for all the experiments. The tool electrode is a solid rod of 9.5 mm diameter.

Table 1 Properties of dielectric fluids [4, 13]

Properties	Distilled water
Thermal conductivity (W/m K)	0.58
Boiling point (^{0}C)	100
Latent heat of vaporization (kJ/kg)	2257
Density (kg/m^3)	1000
Specific heat (kJ/kg.K)	4.22
Dynamic viscosity coefficient, υ (cm/s)	0.852×10^{-2}
Electrical conductivity (10^{-6}S/m)	7.1

Table 2 Chemical composition of W300 die-steel (Wt. %)

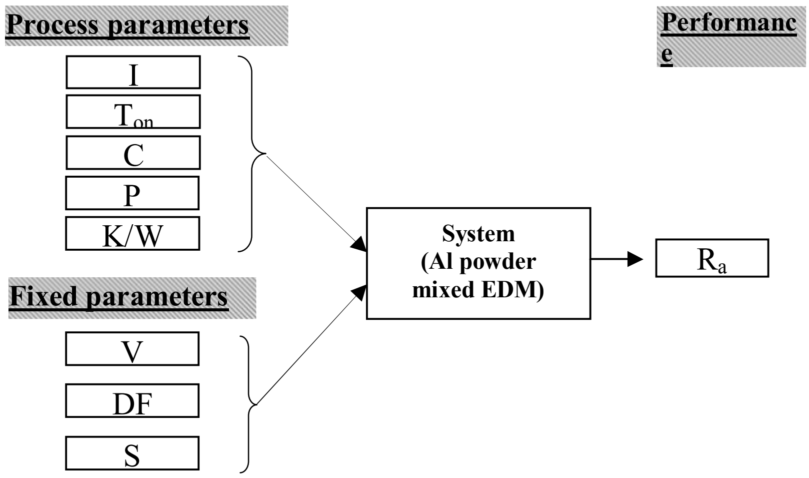
C	Si	Mn	Cr	Mo	V	Fe
0.32-0.42	0.8-1.2	< 0.5	4.5-5.5	1-1.5	0.3-0.5	Balance

Table 3 Properties of W300 die-steel

Properties	Value
Density (g/cm^3)	7.8
Hardness	205 HB
Electrical resistivity (Ω/m)	0.52
Thermal conductivity (W/m K)	26.0
Specific heat (J/kg K)	460
Modulus of elasticity (N/mm^2)	215x10^3

3. Selection of PMEDM Process Parameters

The exhaustive survey of information on technology trend, EDM process parameters selection, electrode material and flushing are given in the EDM handbook[14]. In PMEDM, process parameters are classified into various groups such as electrical, non-electrical, powder, dielectric fluid and electrode parameters, and dielectric fluid. As the number of process parameters are more, 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 from the literature. Figure 2 shows the block diagram of the PMEDM experimental system of the present investigation.



Process Parameters: I = Peak current, T_{on} = Pulse on-time, C = Concentration of powder
P = Polarity, K/W = Kerosene/water, V = Voltage, S = Size of the powder, DF = Duty factor.
Machining Performance: MRR R_a = Surface roughness.

Figure 2 Block diagram of PMEDM experimental

From the literature review it is found that, various powders suspended in the dielectric fluid to improve the process performance. Due to easy of production and also due to the favourable thermo-physical properties (Table 4), many researchers used aluminium powder in PMEDM [15]. In the present work, three different sizes of aluminium powders of average particle size 7, 27 and 36 μm chosen for the experiments. From the results of the pilot experiments, it is found that Al powder of particle size 27 μm produces relatively higher MRR. Hence Al powder of particle size 27 μm was chosen for the experiments. It was found that MRR increases with the increase in concentration up to 1 g/l 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 values and actual values of the process parameters for the experiments are given in Table 5. The process parameters maintained at a fixed value are shown in the Table 6.

Table 4 Thermo-physical properties of Al powder

Powder Type	**Density** (g/cm^3)	**Thermal Conductivity** ($W\ cm^{-1}k^{-1}$)	**Electrical resistivity** ($\mu\Omega$ cm)	**Melting Point** (^0c)	**Specific Heat** ($Cal\ g^{-1}c^{-1}$)
Al	2.7	2.38	2.45	660	0.215

Table 5 Process parameters and their levels

SI. No.	**Process parameters**	**Unit**	**Levels**		
			-1	**-1**	**-1**
1	Peak current (*I*)	A	6	6	6
2	Pulse on-time (T_{on})	μs	120	120	120
3	Concentration of powder (*C*)	g/l	0	0	0

Table 6 Values of the fixed process parameters in phase - I

Fixed process parameter	Value
Voltage (V)	40 V
Duty factor (DF)	65 %
Powder size (S)	27 μm
Flushing pressure	70(kPa)
Polarity (P)	Positive

4. Experimentation

Experiments were designed using face centered central composite design (FCCCD). Empirical equations for the responses were developed using Response Surface Methodology (RSM). 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 20 (cube points-8, center points in the cube-6, axial points-6) experiments using Al powder-mixed with distilled water dielectric fluid. The machining performance of PMEDM has been characterized with surface roughness (R_a). The surface roughness (R_a) is characterized by center line average method (CLA) using Mitutoyo's surftest instrument, SJ-301. In order to measure the surface roughness on the machined surface samples were sectioned using wire-EDM as shown in Figure 3. Sampling length of 0.8 mm in three steps was selected. The measured values are in μm.

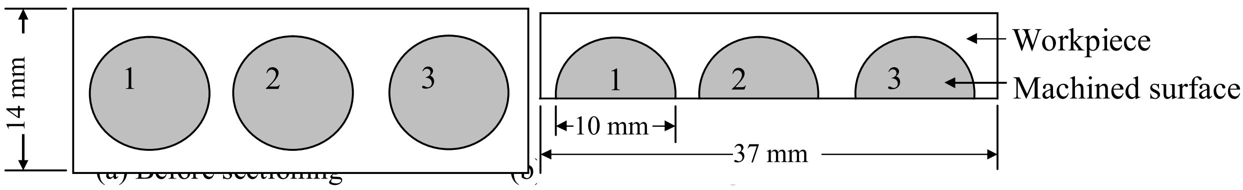


Figure 3 Schematic diagram of machined workpiece

5. Results

The results obtained from powder mixed electrical discharge machining of W300 die-steel using aluminium powder mixed distilled water presented in this section. A quadratic model for the output responses were established from the experimental observation using regression technique. Analysis of variance (ANOVA) was conducted to know the significance of regression equation.

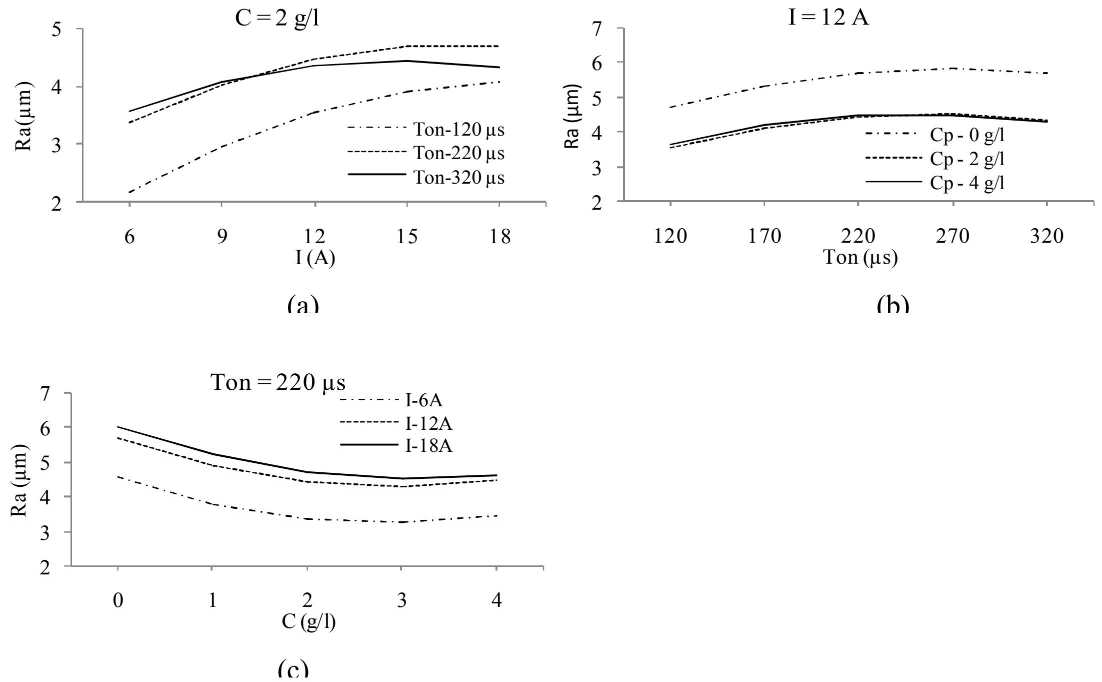
Effect of Process Parameters on R_a

i. Effect of peak current:

It can be seen from this Figure 4(a), R_a tends to increase considerably with increase in the peak current. The value of R_a is also higher for high pulse on-time. This is due to the fact that, high pulse energy at high peak currents removes more molten material creating deeper and wider craters increasing surface roughness [3]. It is clear that the best surface finish is obtainable at the low levels of peak current (6 A) and pulse on-time (120 μs).

ii. Effect of pulse on-time:

The effect of pulse on-time and concentration on R_a is shown in Figure 4(b). This figure displays that the value of R_a increases with increase in pulse on-time up to a level (220 μs) due to the fact that, at constant currents increase in the pulse on-time increases the pulse energy. At the same time R_a value found to be smaller with medium high concentrations of powder for similar pulse on-time. In order to obtain a better surface finish, low values of pulse on-time (120 μs should be used.



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

Figure 4 Effect of process parameters on R_a with powder mixed distilled water

iii. Effect of concentration of powder:

Figure 4(c) depicts the influence of concentration of the powder on R_a. The value of R_a decreases with increase in the concentration of powder up to middle level of 2 g/l. Effect of further increase in the concentration of the powder is limited. The thermo-physical properties of the Al powder cause the better spark distribution, thus producing shallow craters on the machined surface[15]. In this way, low values of peak current of 6 A, at pulse on-time 120 µs and medium to high concentration of Al powder 4 g/l produced a surface of roughness value 2.08 μm. This proves that powder addition to the dielectric fluid plays a significant role in modifying the plasma channel. The widened plasma channel creates several discharging paths causing shallow craters which results in improved surface finish.

6. Conclusion

From the experimental results it is found that, pure distilled water dielectric fluid produced low values of R_a = 2.96 µm during machining at pulse current 6 A, pulse on-time 120 µs. Konig and Jorres[2] also reported low surface roughness using deionized water compared. Eelectrolytic etching of the surface also might have removed peaks and reduced R_a with distilled water dielectric fluid. Addition of 4 g/l of aluminium powder, further reduced the surface roughness to a value of 2.08 µm using distilled water dielectric fluid. The formation of multiple discharges produces shallow craters, which results in low surface roughness values.

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