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Performance Parameters Characteristics of PMEDM: A Review

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Abstract

Electrical Discharge Machining is a non-conventional Machining process used for machining of very hard and complex geometrical shapes of conductive material which cannot be machined by conventional machining process. Electrical discharge machining (EDM) is an Electro-thermal process with a complex metal-removal mechanism, involving the formation of a plasma channel between the tool and work piece in a dielectric fluid. For several decades, EDM has been an important manufacturing process for the tool and die industry. To improve the performance of EDM, dielectric fluid suspended with different powders was attempted by several investigators. Further researches in this area found that if electrically conductive powder mixed in the dielectric fluid it reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and work piece. Due to this, the process becomes more stable and its improve MRR and surface finish of work piece. In this review paper an attempt has been made to find effect of different powder mixed in dielectric and performance parameter of PMEDM. Authors have also identified the research gap for further research and scope in this area.

Keywords: EDM, MRR, TWR, Dielectric Fluid, PMEDM

INTRODUCTION

Electrical discharge machining (EDM) has ability to machine the high strength temperature resistant alloys and difficult-to-machine materials having very complex and sophisticated shapes. Powder mixed electro-discharge machining (PMEDM) is a new technique which overcomes the limitations and improves the machining capabilities of EDM. In this process, a suitable material in the powder form is mixed into the dielectric fluid. For better circulation of the powder mixed dielectric, a stirring system is employed [1]. Various powders particle that can be added into the dielectric fluid are Aluminum (Al), Graphite, Copper (Cu), Chromium (Cr), Silicon, Tungsten etc. The voltage is applied to both the electrodes. An electric field is generated in the spark gap. The spark gap is filled up with powdered particles and the gap distance setup between tool and the work piece increases [13]. The set up is immersed under a dielectric fluid. The electric field energizes the powder particles and they move in a zigzag manner. They arrange to form chains at different places during sparking, which bridge the gap between the electrode and work piece. Thus, the gap voltage and insulating strength of the dielectric fluid decreases. Short circuit occurs easily and the series of discharge starts under the electrode. With an increase in frequency of discharging, the quicker sparking within the discharge takes place which causes erosion at a higher rate on the work piece surface [2]. Researches in this area reported that addition of different materials powder in the EDM dielectric increases MRR and reduces surface roughness as compared to normal EDM [3].

The process variables of PMEDM play a considerable role in material removal mechanism. Performance of the PMEDM process depends upon characteristics like powder type, concentration, particle size, dielectric type, pulse on time, pulse of time, peak voltage, electrode material and work piece constituents.

PROCESS PARAMETER OF PMEDM

Following are the process parameters which are taken into consideration.

1. Powder Material
2. Powder Size
3. Powder Concentration
4. Dielectric type
5. Peak Voltage
6. Peak current
7. Pulse on time
8. Pulse off time
9. Polarity
10. Inter electrode gap (IEG)

Powder type:

The powder added into the dielectric fluid could increase the MRR and decrease the tool wear rate (TWR) and improve the surface quality of the work quite clearly. But the different powders would have different impact on the output characteristics of the EDM process. A powder which can be suspended into dielectric fluid of EDM must have following properties:-

1. It should be electrical conductive in nature.
2. It must be non-magnetic in nature.
3. It must have good suspension capabilities.
4. It should have good thermal conductivities.
5. It should be non toxic and odorless.

Powder Size:

Micro to nano particle size of powders are used in PMEDM.

Powder concentration:

Generally Powder concentration of about 1g/l to 40 g/l of dielectric is used.

Dielectric Fluid:

Dielectric fluid carries out three important tasks in EDM.

1. It insulate the inter electrode gap and after breaking down at the appropriate applied voltage, conducting the flow of current.
2. It flushes away the debris from the machined area.
3. It also acts as a coolant to assist in heat transfer from the electrodes.

Most commonly used dielectric fluids are hydrocarbon compounds, like light transformer oil and kerosene.

Table 1. Commonly used powder in PMEDM and their physical properties are shown.

Material	**Density (g/cm^3)**	**Electrical resistivity (μΩ-cm)**	**Thermal conductivity (W/m-K)**
Aluminum (Al)	2.70	2.89	236
Graphite C	1.26	103	3000
Chromium (Cr)	7.16	2.6	95
Copper (Cu)	8.96	1.71	401
Silicon (Si)	2.33	2325	168
Nickel (Ni)	8.91	9.5	94
Silicon Carbide (SiC)	3.22	1013	300
Titanium (Ti)	4.72	47	22
Tungsten (W)	19.25	5.3	182
Alumina (Al_2O_3)	3.98	103	25.1
Bron Caride (B_4C)	2.52	5.5×10^5	27.9
Carbon nano tubes (CNTs)	2.0	50	4000
Molybdenum Disulfide (MoS_2)	5.06	106	138

Table 2. Properties of typical dielectrics used in PMEDM are given in the table [4].

Dielectric Name	**Specific heat (J/kg-K)**	**Thermal conductivity (W/m-K)**	**Breakdown strength (kV/mm)**	**Flash point (ºC)**
Deionized water	4200	0.62	65-70	Not applicable
Kerosene	2100	0.14	24	37-65
Mineral oil	1860	0.13	10-15	160
Silicon oil	1510	0.15	10-15	300

Peak current (*Ip*):

During each pulse-on time, current rises until it attains a certain predetermined level that is termed as discharge current or peak current. It is governed by the surface area of cut. Higher currents produce high MRR, but at the cost of surface finish and tool wear. Accuracy of the machining also depends on peak current, as it directly influences the tool wear.

Discharge voltage (*V*):

Open circuit voltage between the two electrodes builds up before any current starts flowing between them. Once the current flow starts through plasma channel, open circuit voltage drops and

It is a vital factor that influences the spark energy, which is responsible for the higher MRR, higher tool wear rate and rough surfaces.

Pulse-on time or pulse duration (T_{on}):

It is the duration of time (µs), the current is allowed to flow per cycle. Dielectric ionizes and sparking takes place during this period. It is the productive regime of the spark cycle during which current flows and machining is performed. The amount of material removal is directly proportional to the amount of energy applied during this on-time. Though MRR increases with Ton, rough surfaces are produced due to high spark energy.

Pulse-off time or pulse interval (T_{off}):

It is the duration of time between two consecutive pulse-on times. The supply voltage is cut off during pulse-off time. Dielectric de-ionizes and regains its strength in this period. This time allows the molten material to solidify and to be washed out of the arc gap. Pulse-off time should be minimized as no machining takes place during this period. However, too short T_{off} leads to process instability.

Polarity:

Polarity refers to the potential of the workpiece with respect to the tool. In straight or positive polarity the workpiece is positive, whereas in reverse polarity workpiece is negative. In straight polarity, quick reaction of electrons produces more energy at anode (workpiece) resulting in significant material removal. However, high tool wear takes place with long pulse durations and positive polarity, due to higher mass of ions. In general, selection of polarity is experimentally determined depending on the combination of workpiece material, tool material, current density and pulse duration.

Inter electrode gap (IEG):

The inter electrode gap is a vital factor for spark stability and proper flushing. The most important requirements for good performance are gap stability and the reaction speed of the system; the presence of backlash is particularly undesirable. The reaction speed must be high in order to respond to short circuits or open gap conditions. Gap width is not measurable directly, but can be inferred from the average gap voltage. The tool servo mechanism is responsible for maintaining working gap at a set value. Mostly electro mechanical (DC or stepper motors) and electro hydraulic systems are used, and are normally designed to respond to average gap voltage.

Table 3. Spark gap under different powder suspension conditions Table 3 [5].

Dielectric Condition	Spark gap distance (µm)
Without powder	10- 15
Graphite	45- 50
Silicon	27- 33
Aluminium	120- 160
Crushed Glass	10- 15
Silicon Carbide	80- 90

PERFORMANCE PARAMETERS

Performance of PMEDM can be measured by following parameters.

1. Material Removel Rate (MRR)
2. Tool Wear Rate (TWR)
3. Wear Ratio (WR)
4. Surface Roughness (SR)

Material Removel Rate (MRR):

The MRR is expressed as the weight of material removed from workpiece over a period of machining time in minutes.

$$\text{MRR (mm}^3\text{/min)} = \frac{\text{Workpiece weight loss (g)} \times 1000}{\text{Density (g/cm}^3\text{)} \times \text{machining time (min)}}$$

Tool Wear Rate (TWR):

The TWR is calculated by using the weight loss from the tool divided by the time of machining.

$$\text{TWR (mm}^3\text{/min)} = \frac{\text{Tool weight loss (g)} \times 1000}{\text{Density (g/cm}^3\text{)} \times \text{machining time (min)}}$$

Wear Ratio (WR):

WR is the ratio of TWR to MRR and is used as a performance measure for quantifying tool work piece material combination pairs since different material combinations gives rise to different TWR and MRR values. A material combination pair with the lowest WR indicates that the tool-work piece material combination gives the optimal TWR and MRR condition.

Surface Roughness (SR):

The SR of the workpiece can be expressed in different ways like, arithmetic average (R_a), average peak to valley height (R_Z), or peak roughness (R_P), etc. Generally, the SR is measured in terms of arithmetic mean (R_a) which according to the ISO 4987: 1999 is defined as the arithmetic average roughness of the deviations of the roughness profile from the central line. The Surface Roughness is the measure of the texture of the surface. It is measured in µm. If the value is high then the surface is rough and if low then the surface is smooth. It is denoted by R_a. The values are measured using Portable style type profilometer.

LITERATURE REVIEW

Table 4. Research Literature available in the field of PMEDM using different powders and effect of different parameters are given in the following Table.

Powder Type	**Author/Year**	**Process Parameters**	**Tool Electrode**	**Workpiece**	**Research Finding**
Aluminium Chromium Copper & Silicon Carbide powders concentration	Tzeng, Y. F. & Lee C. Y. (2001)[6]	MRR,TWR, Surface Roughness	Copper	SKD-11	1. The discharge gap distance and material removal rate increased as powder granularity was increased. 2. Of the powder materials capable of remaining in suspension during machining, Aluminium produced the largest discharge gap enlargement and Silicon Carbide produced the smallest.
Al	Jhao W.S., Meng Q. G. & Wang Z. L. (2002) [1]	Pulse on time, Peak current, Discharge gap, Pulse width, Concentration of Al Powder.	Copper	Steel	1. PMEDM was applied to improving the efficiency of rough machining. 2. PMEDM enabled a 70% improvement in machining efficiency over EDM in powder-free dielectric while achieving similar machined surface roughness.
Si	Pecas P. et al (2003) [7]	Peak current, Duty Cycle, Polarity, Flushing, Concentration of Si powder, Electrolyte.	Copper	AISI H13	1. The positive influence of the Si powder in the reduction of the operating time, achieve a specific SQ, and in the decrease of the SR, allowing the generation of mirror-like surfaces.
Al, Si	Klocke, F. et al (2004) [8]	Polarity, Voltage, Pulse duration, Duty Cycle, Concentration of Al, & Si Powder.	Tungsten Electrodes	Inconel 718 superalloy	1. The powder additives caused greater expansion of plasma channel compared to a powder-free dielectric. 2. The powder additives changed the thermal material removal mechanism and affected the composition and morphology of the recast layer.
Al, Cr, Cu, Si.	Tzeng, Y.F. et al (2005) [9]	Peak Current, Pulse on time, Duty Cycle, Powder size, Powder Concentration of Al, Cr, Cu, Si.	Copper	SKD-11	1. The presence of powder additives reduced the recast layer thickness. 2. The surface roughness decreased when aluminum powder granularity was decreased. 3. The RLT decreased when aluminum powder granularity was increased. 4.Aluminium powder material produced the smallest surface roughness and thinner recast layer.
Si	Kansal et al (2005) [10]	Pulse on time, Duty cycle, Peak current, Concentration of the added Si powder.	Copper	EN 31 tool steel	1. MRR increased with the increase in the concentration of silicon powder. 2. Surface roughness improves with increased concentration of silicon powder.
Si	Kansal H. K. et al (2006) [11]	Peak Current, Pulse Duration, Duty cycle, Concentration of Silicon powder.	Copper	H-11 Die Steel	1 The concentration of Added silicon powder, pulse duration, & peak current significantly affect the material removal rate & Surface roughness in powder mix Electrical Discharge Machining. 2. Addition Of appropriate quantity of

					silicon powder into dielectric fluid of EDM enhances the material erosion rate.
Si	Kansal H. K. et al (2007) [12]	Peak Current, Pulse on time, Pulse-off time, Concentration of Powder gain, Nozzle Flushing	Copper	AISI D2 Die Steel	1. The concentration of Si powder into the dielectric fluid of EDM appreciably enhances MRR. 2. Peak current, concentration of the Si powder, pulse-on time, pulse-off time, & gains significantly affect the MRR in PMEDM. 3. The nozzle flushing when applied at the interface of tool electrode and workpiece does not significantly affect the MRR.
Titanium Powder	Furutani, K., et al (2009) [13]	Discharge Current, Pulse Duration, Concentration of Titanium Powder.	Copper	Titanium carbide	1.PMD-EDM was applied to accretion process. 2. Deposition of TiC was possible at discharge energies below 5 mJ under certain discharge current and pulse on time combinations. 3. There existed a maximum discharge current for deposition. 4. The larger the discharge current, the smaller the range of pulse on time durations available for deposition.
Al	Sharma s. et al. (2010) [14]	Concentration of Al powder and the Grain Size of the Powder particles, Reverse Polarity Current, Voltage, Pulse on time, Duty Cycle.	Copper	Hastelloy	1. The surface roughness of the work material continuously decreases with the increase in the concentration of aluminium powder and with change in the grain size of the powder particles. 2. With the increase in the concentration of the powder, percentage wear rate decreases sharply. 3. With change in the grain size of the powder, the percentage wear rate decreases continuously. 4. With the increase in the concentration of additive powder in the dielectric fluid, the tools wear increases. 5. With the addition of aluminium powder in the dielectric fluid of EDM, the material removal rate increases.
Al	Singh P. et al. (2010) [15]	Concentration of Aluminum Powder and Grain size of Powder.	Copper	Hastelloy	1. The addition of Al powder in dielectric fluid increases MRR, decreases TWR and improves surface finish of Hastelloy.

Cr	Ojha et Al. (2011) [16]	Peak current, Pulse on time, Diameter of electrode, Concentration of Cr Powder.	Copper	EN-8 Steel	Current powder concentration & electrode diameter are significant factor affecting both MRR & TWR. MRR shows increasing trend for increase in powder concentration. TWR increases with lower range of powder concentration but then decrease.
Aluminium Powder	Singh G. et al. (2012) [17]	Polarity, Peak Current, Pulse on time, Duty Cycle, Gap Voltage, Concentration of Abrasive Powder.	Copper	H 13 steel	1. Negative polarity of tool electrode is desirable lowering of SR 2. Increasing pulse on time leads to produce more rough surfaces. 3. Addition of powder particles in dielectric fluid decreases SR of specimen in EDM process. 4. Higher peak currents produce more rough surfaces in EDM process.
Aluminium Powder	Khalid Hussain Syed, Kuppan Palaniyandi (2012) [18]	Peak current, Pulse on-time, Concentration of the Powder, Polarity.	Copper	W300 Die Steel	1.Uses distilled water mixed with aluminium powder improve the performance of MRR, SR & WLT. 2. High MRR, is obtained in positive polarity, whereas better surface quality (surface roughness and white layer thickness) is achieved in negative polarity. Hence for rough machining positive polarity can be selected to achieve higher MRR and during finishing a better surface is achieved by changing the polarity.
Silicon Powder	Soumakant Padhee, Niharranjan Nayak, S K Panda, R Dhal and SS Mahapatra (2012) [19]	Pulse on time, Duty cycle, Peak Current.	Copper	EN 31 Steel	1. A large number of experiments have been conducted at different levels of factors viz., pulse on time, duty factor, peak current, and concentration of abrasive. 2. The MRR and SR roughness have been measured for each setting. The use of powder mixed dielectric promotes the reduction of surface roughness and enhances MRR.
Aluminium Powder	Gurule N. B., Nandurkar K. N. (2012) [20]	Tool material, Peak Current, Pulse on time, Pulse off time, Duty Cycle, Gap Voltage, Powder Concentration, Tool RPM, Flushing Pressure.	Copper, Brass, Al	D2 Die Steel	1. Current, on time, tool material, tool rpm and powder concentration significantly affect MRR. 2. The suspension of Al powder into dielectric enhances MRR. 3. The maximum MRR is produced at 4 g/l of Al powder, 900 tool rpm with Cu tool. 4. Flushing shows least effect on MRR.
Aluminium Powder	Junaid Mohd. Mir, Khalid Sheikh, Singh Balbir, and Malhotra Navdeep (2012) [21]	Current, Pulse on time, Powder Concentration.	Copper	AISI H-11	1. The EDM process has been successfully modeled in terms of SR using Response Surface Methodology. Results showed that central composite design is a powerful tool for providing experimental diagrams and statistical mathematical models, to perform the

					experiments efficiently and economically. 2. There is improvement in surface roughness of the work surface after using the Aluminium powder into the dielectric fluid of EDM. 3. The analysis of variance revealed that the factors peak current and concentration are most influential parameters on SR. 4. The error between experimental and predicted values at the optimal combination of parameters setting for SR is 6.98%. Obviously, this confirms excellent producibility of the experimental conclusion.
Graphite & Cr Powder	Mathapathi U. et al. (2013) [22]	Pulse on time, Pulse off time, Peak current, Tool electrode lift time, Concentration of Graphite & Cr powder.	Copper	ASI D3/HCHCR	1. TWR in PMEDM is smaller as compared with the conventional EDM. 2. MRR has increased by adding the powder in dielectric fluid as compared with conventional EDM. 3. MRR is maximum effected by the increase of peak current. 4. MRR has been decreased by increasing the pulse off time. 5. As the tool electrode lift time has increased, the MRR.
Copper, Diatomite, Aluminium	Muniu J.M. et al. (2013) [23]	Concentration of Copper, Diatomite, Aluminium.	Graphite	Mild steel	1. MRR for copper, aluminium and diatomite powder increases to maximum and then decreases with further increase in powder concentration.
Silicon Powder	Nimo Singh Khundrakpam, Harmeet Singh, Som Kumar and Gurinder Singh Brar, (2014) [24]	Peak Current, Powder Concentration, & Tool Diameter.	Copper	EN 8	1. It is found that powder concentration have more significant effect on MRR. 2. The adequacy of the developed models was checked by performing confirmation runs. The variation in prediction errors for MRR was found within ±5.5%.
Aluminium Powder	Goyal Shivam, Singh Rakesh Kumar, (2014) [25]	Grain Size & Al Concentration. Rest all parameters Constant	Copper	AISI 1045 Steel	1. Too low and too high concentration of aluminium powder & Grain Size in EDM oil reduces MRR of AISI 1045 Steel. 2. If we consider MRR and Surface roughness equally important then with the increase in concentration of aluminium powder & Grain size MRR and surface finish of AISI 1045 Steel increases.
Silicon Powder	Razak M. A., Abdul-Rani M. A., Nanimina A. M., (2014) [26]	Powder Concentration, Grain size of Powder	Graphite and Copper	Stavax	1. The influence of PMEDM in machining Stavax® material in terms of MRR,TWR and Ra. 2. The reduction machining time of EDM process with PMEDM.

					3. The optimum powder concentration and size of powder particles to achieve the highest efficiency of EDM process.
Aluminium Powder	Jamadar M. M., Kavade M.V. (2014) [27]	Peak Current, Pulse on-time.	Copper	AISI D3 Die Steel	1. Maximum MRR is obtained at a high peak current of 14Amp, higher Ton of 150µs, and high concentration of Al powder 6g/l. 2. Low TWR is achieved with low peak current of 2Amp, lower Ton of 50µs and higher concentration of Al powder of 6g/l. 3. Low surface roughness is achieved with a low peak current of 2Amp, a higher Ton of 150 µs and higher concentration of Al powder of 6g/l.
Cr	Abrol Abhishek, Sharma Sunil, (2015) [28]	Peak current, Pulse on time, Pulse off time, Powder Concentration.	Copper	AISI D2 Die steel	1. MRR is mainly affected by current, pulse-on time and powder concentration. With the increase in current and pulse-on time, MRR increases. But it is also observed that with the increased concentration of chromium powder, MRR tends to decrease. 2. TWR is mainly affected by current. With the increase in current, TWR increases. Also, TWR tends to decrease with the increase in chromium powder concentration. 3. Current is the most dominant factor affecting both MRR and TWR. Both the performance data show an increasing pattern with increase in current for any other parameter. 4. Surface roughness is mainly affected by the pulse-off time as per the main effects plot for SR. Surface Roughness is higher with the increase in pulse-off time.

LITERATURE GAP

Over the last two decades, work has been done in the field of PMEDM (Powder Mixed Electric Discharge Machining) on the process performance such as MRR, TWR and SR. However, the data is insufficient about variability of process parameter for a particular powder to a known workpiece and electrode. Also, the critical size of powder and its variation with other process parameters is yet to be determined. This can be accomplished by conclusive experimental work. By taking different powders, varying workpiece and electrode material in experimental work, researchers can find out optimum value of various process parameters. In the past, various researchers have used powders like silicon, silicon carbide, aluminum mixed in dielectric for the machining of workpiece material. Nickel, chromium, graphite, copper etc., are the powdered materials which can be mixed in dielectric. Tool steel and alloy steel has been commonly used as workpiece by various researchers. These materials have been selected due to their hardness, resistance to abrasion, their ability to hold a cutting edge and their resistance to deformation at elevated temperatures (red-hardness). Materials like water hardened die steel, molybdenum high speed tool steel have not been tried yet as work material. Copper electrode has been most frequently used as electrode.

CURRENT PROBLEMS IN PMEDM

Number of issues need to be addressed in future for implementation of this modified process of machining. Few of them are discussed here. Many researchers have shown that powder suspended EDM machining can distinctly improve the SR and surface quality in the finish machining phase and obtain nearly mirror surface effects. Despite the promising results, PMEDM process is used in industry at very slow pace.

One of the key reasons is that many fundamental issues of this new development, including the machining mechanism are still not well understood. The complexity of this process, particularly in context with thermo physical properties of the suspended particles deserves a thorough investigation. Secondly, the difficulty in operation of dielectric interchange, the high amounts of powder consumption, the environmental requirements of fluid disposal and its higher initial cost (two to three times higher than the one required for a conventional EDM system) have restricted its frequent use [32]. The optimization of powder characteristics (type, shape, size concentration, etc.) also urgently needs a thorough study.

The other problems associated with the PMEDM are:

(1) Cost effectiveness/working life of powders,

(2) Concentration of the working fluid,

(3) Circulation of mixture of additives and working fluid,

(4) Filtration of additives from debris,

(5) Agglomeration and

(6) Arcing.

Moreover, very little research has been reported on the application of PMEDM in rough machining phase

CONCLUSIONS AND FUTURE SCOPE

This paper presents a detailed summary of research results reported in the area of powder mixed EDM. It can be concluded from this review that PMEDM holds a bright promise in application of EDM, particularly with regard to process productivity and surface quality of workpiece. As such, extensive study is required to understand mechanics of machining and other aspects of PMEDM.

REFERENCES

[1] Zhao,W.S., Meng, Q.G., Wang, Z.L.: The Application of Research on Powder Mixed EDM in Rough Machining. J. Mater. Process. Technol. 129, 30–33 (2002)

[2] Yeo, S.H., Tan, P.C., Kurnia, W.: Effect of Powder Additives Suspended on Dielectric on Crater Characteristics for Micro Electrical Discharge Machining. Journal of Micromechanics and Microengineering 17, 91–98 (2007)

[3] Chow, H.M., Yang, L.D., Lin, C.T., Chen, Y.F.: The Use of SiC Powder in Water as Dielectric for Micro-slit EDM Machining. Journal of Materials Processing Technology 195, 160–170 (2008)

[4] Zhang, Y., Liu, Y., Shen, Y., Ji, R., Li Z., Zheng, C.: Investigation on the Influence of the Dielectrics on the Material Removal Characteristics of EDM. J. Mater. Process. Technol. 214, 1052–1061 (2014)

[5] Wong, Y. S., Lim, L. C., Rahuman Iqbal, Tee, W. M.: Near Mirror Finish Phenomenon in EDM Using Powder Mixed Dielectric. Journal of Material Processing Technology 79, 30-40 (1998)

[6] Tzeng, Y. F., Lee, C.Y.: Effects of Powder Characteristics on Electro Discharge Machining Efficiency. International Journal of Advanced Manufacturing Technology 17(8), 586-92 (2001)

[7] Peças, P., Henriques, E.: Influence of Silicon Powder-Mixed Dielectric on Conventional Electrical Discharge Machining. Int. J. Mach. Tools Manuf. 43(14), 1465–1471 (2003)

[8] Klocke, F., Lung, D., Antonoglou, G., Thomaidis, D.: The Effects of Powder Suspended Dielectrics on the Thermal Influenced Zone by Electro Discharge Machining with Small Discharge Energies. 14th International Symposium on Electromachining (ISEM XIV) J. Mater. Process. Technol., Elsevier, 149, pp. 191-7 (Edinburgh, Scotland, UK, 30 Mar-1 Apr 2004)

[9] Tzeng Yih-Fong, Chen Fu-Chen: Investigation into Some Surface Characteristics of Electrical Discharge Machined SKD-11 using Powder-Suspension Dielectric Oil. Journal of Materials Processing Technology 170, 385–391(2005)

[10] Kansal, H.K., Singh, S., Kumar, P.: Parametric Optimization of Powder Mixed Electrical Discharge Machining by Response Surface Methodology. Journal of Materials Processing Technology 169, 427–436 (2005)

[11] Kansal, H.K., Singh, S., Kumar, P.: Performance Parameters Optimization (Multi Characteristics) of Powder Mixed Electric Discharge Machining (PMEDM) through Taguchi’s Method Utility Concept. Indian Journal Of Engineering & Material Science, 13, .209-216 (2006)

[12] Kansal, H.K., Singh, S., Kumar, P.: Effect of Silicon Powder Mixed EDM on Machining Rate of AISI D2 Die Steel. Journal of Manufacturing Processes 9 (1), 13-22 (2007)

[13] Furutani, K., Sato, H., Suzuki M.: Influence of Electrical Conditions on Performance of Electrical Discharge Machining with Powder Suspended in Working Oil for Titanium Carbide Deposition Process. International Journal Of Advanced Manufacturing Technology 40(11), 1093- 1101 (2009)

[14] Sharma, S., Kumar, A., Beri, N., Kumar, D.: Effect of Aluminium Powder Addition in Dielectric During Electric Discharge Machining of Hastelloy on Machining Performance Using Reverse Polarity. International Journal of Advanced Engineering Technology 1(3), pp. 13-24 (2010)

[15] Singh, P., Kumar, A., Beri, N., Kumar, V.: Some Experimental Investigation on Aluminum Powder Mixed EDM on Machining Performance of Hastelloy

Steel. International Journal of Advanced Engineering Technology 11(2), pp. 28-45(2010)

[16] Ojha Kuldeep, Garg, R. K., Singh, K.K.: Parametric Optimization of PMEDM Process Using Chromium Powder Mixed Dielectric and Triangular Shape Electrodes. Journal of Minerals & Materials Characterization & Engineering 10(11), pp. 1087-1102 (2011)

[17] Singh Gurtej, Singh Paramjeet, Tejpal Gaurav, Singh Baljinder.: Effect of Machining Parameters on Surface Roughness of H 13 Steel in EDM Process Using Powder Mixed Fluid. International Journal of Advanced Engineering Research and Studies 2 (1), 148-150 (2012)

[18] Hussain, Khalid S., Kuppan, P.: Performance of Electrical Discharge Machining using Aluminium Powder Suspended Distilled Water. Turkish J. Eng. Env. Sci., 1-13 (2012)

[19] Padhee, S., Nayak, N., Panda, S. K., Dhal, P. R., Mahapatra S. S.: Multi-Objective Parametric Optimization of Powder Mixed Electro-Discharge Machining using Response Surface Methodology and Non-Dominated Sorting Genetic Algorithm. Sadhana - Acad. Proc. Eng. Sci. 37, 223–240 (2012)

[20] Gurule, N. B., Nandurkar, K. N.: Effect of Tool Rotation on Material Removal Rate During Powder Mixed Electric Discharge Machining of Die Steel. International Journal Of Emerging Technology and Advanced Engineering 2, pp. 328-332 (2012)

[21] Mir, Mohd. J., Khalid, S., Singh Balbir, Malhotra, N.: Modeling and Analysis of Machining Parameters for Surface Roughness in Powder Mixed EDM Using RSM Approach. International Journal of Engineering, Science And Technology Vol. 4 No. 3, pp. 45-52 (2012)

[22] Mathpathi, U., Jeevraj, S. K., Ramola, I. C.: Analysis of Material Removal Rate with Powder Mixed Dielectric. IJCAE 4(3), pp. 316-332 (2013)

[23] Muniu, J. M., Ikua, B.W., Nyaanga, D.M., Gicharu, S.N.: Study on Effects of Powder-Mixed Dielectric Fluids on Electrical Discharge Machining Processes. International Journal of Engineering Research & Technology 2 (10), pp. 2449-2456 (2013)

[24] Khundrakpam, N. S., Singh, H., Brar, G. S.: Investigation and Modeling of Silicon Powder Mixed EDM Using Response Surface Method. Int. J. Curr. Eng. Technol. 4 (2), 1022–1026 (2014)

[25] Goyal, S., Singh, R. K.: Parametric Study of Powder Mixed EDM and Optimization of MRR & Surface Roughness. International Journal of Scientific Engineering And Technology 3 (1), 56-62 (2014)

[26] Razak, M. A., Abdul-Rani, A. M., Nanimina,A. M.: Improving EDM Efficiency with Silicon Carbide Powder-Mixed Dielectric Fluid. Int. J. Mater. Mech. Manuf. 3 (1), 40–43 (2015)

[27] Jamadar, M. M., Kavade M. V.: Effect of Aluminum Powder Mixed EDM on Machining Characteristics of Die Steel (AISI D3). Proceedings of 10th IRF International Conference, Jun. p. 121–3 (2014)

[28] Abrol Abhishek, Sharma Sunil.: Effect Of Chromium Powder Mixed Dielectric on Performance Characteristics of AISI D2 Die Steel Using EDM. International Journal of Research in Engineering And Technology, Volume 04 Issue 01, 232-246 (Jan-2015)