International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Experimental Investigation on Process Performance of Powder Mixed Electric Discharge Machining of AISI D3 steel and EN-31 steel

G. Bharath Reddy[Ȧ*], G.Naveen Kumar[Ȧ] and K. Chandrashekar[Ȧ]

[Ȧ]Department of Mechanical Engineering, CVR College of Engineering, Hyderabad, India

Accepted 02 May 2014, Available online 01 June 2014, **Vol.4, No.3 (June 2014)**

Abstract

In this paper, an effort has been made to study the effect of fine metal powders such as aluminium(Al) and copper(Cu) are mixed to the dielectric fluid, during Electric Discharge Machining (EDM) of AISI D3 Steel (a variant of high carbon high chromium steel) and EN-31 steel. The work piece material, peak current, pulse on time, duty factor, gap voltage and mixing of fine metal powders in dielectric fluid are taken as process input parameters. Material removal rate and Surface Roughness are taken as output parameters to measure the process performance. 18 experiments have been performed on the newly designed experimental set up and by using electrolytic copper electrode. Taguchi design of experiments is used to conduct experiments. The obtained outcomes of experiments indicate that the addition of metal powders in dielectric fluid increases the material removal rate and improves the surface quality.

Keywords: *Metal powders, Dielectric-fluid, EDM, Material removal rate, surface roughness*

1. Introduction

Scientifically highly advanced industries like automotive, aerospace, defense, micro-electronic, nuclear power, steam turbine, metallic moulds and dies requires materials of high strength high temperature resistant alloys like stainless steels, titanium alloys, carbides, super alloys, hastealloys etc. These materials are difficult to machine by traditional machining processes. With rapid expansion in the field of materials it has become essential to develop cutting tool materials and processes which can safely and conveniently machine such latest materials for sustained production and high precision. Accordingly, non-traditional machining processes are providing effective solutions to the problem imposed by the increasing demand for high strength high temperature resistant alloys, the requirement of parts with complicated shapes. In non-traditional machining processes, there is no direct contact between the tool and work piece; hence the cutting tool need not to be harder than work piece.

Electric discharge machining is one of the most widely used non-traditional material removal process for machining of any material, which is electrically conductive, irrespective of its hardness and strength. In spite of remarkable advantages of the process, limitations like poor surface finish and low volumetric material removal are connected with EDM. In the recent years, Powder Mixed Electric Discharge Machining (PMEDM) has evolved as an advanced technique to improve the process efficiency of EDM. In PMEDM, a suitable material (aluminum, graphite, copper, chromium etc.) in powder form is mixed into the dielectric fluid used in EDM. In this process, the metal powder is mixed into the dielectric fluid. When a suitable potential difference is applied between the tool and work electrodes, an electric field is established. The inter electrode spark gap is filled up with fine metal powder particles, and the gap distance between tool and the work piece increases. The powder particles get energized and the grains come close to each other under the sparking area and form clusters. Under the influence of electrostatic forces, the powder particles arrange themselves in the form of chains at different places under the sparking. The chain formation helps in bridging the gap between both the electrodes. Due to the bridging effect, the gap voltage and insulating strength of the dielectric fluid decreases (H.K. Kansal, *et al*, 2005). The easy short-circuit takes place, which results premature explosion in the gap. Thus a series of discharges starts under the electrode area. Due to the increase in the frequency of discharging, the faster sparking within a discharge takes place, which causes faster material removal from the work piece surface. At the same instance, the mixed powder alters the plasma channel. The plasma channel gets enlarged. The electric density decreases; hence, sparking is uniformly spread among the powder particles. Hence even and more uniform distribution of the discharge takes place, which causes uniform material removal from the work piece. This results in improvement in dimensional accuracy.

2. Experimental Details

2.1 Selection of work piece materials

*Corresponding author: **G. Bharath Reddy**

The work materials chosen for the present study are AISI D3 Steel and EN-31 steel. EDM is capable of machining of hard tool steels, super alloys, carbides, heat resistant steels etc. AISI D3 Steel is developed for applications requiring high resistance to wear or to abrasion and for resistance to heavy pressure rather than sudden shocks. Because of these qualities and its non-deforming properties, AISI D3 steel is used to manufacture blanking, stamping and cold forming dies, bending, forming, and seaming rolls etc. EN-31 steel finds wide applications in roller bearing components such as brakes, cylindrical, conical & needle rollers.

Table 1 Chemical composition of Work materials

S.No	Element	AISI D3 steel % Wt.	EN-31 steel % Wt.
1	C	2.55	1.07
2	Si	0.26	0.32
3	Mn	0.47	0.58
4	P	0.038	0.04
5	S	0.056	0.03
6	Cr	13	1.12
7	Mo	0.08	---
8	Fe	balance	balance

Table 2 Thermo physical properties of work materials

S.No	Work Material	AISI D3 steel	EN-31 steel
1	Thermal conductivity (w/mk)	20	46.6
2	Density (g/cc)	7.67	7.81
3	Electrical resistivity (Ω-cm)	0.0000720	0.0000218
4	Specific heat capacity (J/g °C)	0.5	0.475

2.2 Selection of micro size metal powders

In this experimentation aluminium and copper metal powders are used as additives to the dielectric fluid.

Table 3 Thermo physical properties of metal powders

S.No	Type of Powder	Aluminium	Copper
1	Thermal conductivity (w/cm k)	2.38	4.16
2	Density (g/cm^3)	2.70	8.96
3	Electrical resistivity (μΩ-cm)	2.45	1.59
4	Specific heat capacity (cal/g °C)	0.215	0.092
5	Melting point (°C)	660	1083

2.3 Selection of tool material

The tool electrode does not undergo much surface wear when it is impinged by the positive ions in the process. The localized heat rise at the surface of the tool has to be less. It should have higher thermal conductivity, higher density, higher melting point and easily machinable. In this study the electrolytic copper is selected as tool electrode material because it possesses the above characteristics efficiently. The properties of Copper electrode are summarized as follows:

Table 4 Thermo physical properties of electrolytic copper

S.No	Material	Copper
1	Thermal conductivity	391.1W/m K at 100^{0}C
2	Density	8.94×10^3 kg/m^3
3	Modulus of Elasticity	117 Gpa
4	Melting point	1356 K
5	Latent heat of fusion	134 J/g
6	Thermal expansion	16.9×10^{-6}/K at 100°C

2.3 Selection of Dielectric fluid

The Dielectric fluid should provide an oxygen free machining environment to avoid layers formation on the work surface which results poor surface finish. Further it should have strong dielectric resistance so that it does not breakdown electrically too easily until the required breakdown voltage is reached. The dielectric fluid used for experimentation was commercial grade kerosene.

Table 5 Properties of Kerosene

Dielectric constant	Electrical conductivity	Density	Dynamic viscosity
1.8	1.6×10^{-14} S/m	730 kg/m^3	0.94 m Pas

3. Experimental set up

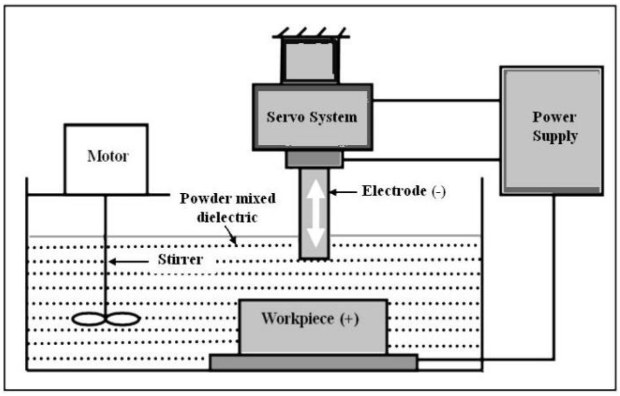

Fig.1 Schematic Diagram of Experimental Setup

Experiments are performed on Electra EMS-5535 EDM machine. The working tank of EDM machine has the dimensions of 800mm×500mm×350mm.It requires great amount of metal powders for mixing in such a large tank of EDM to obtain desired powder concentration in dielectric fluid for experimentation. Furthermore, filter of machine might choke due to presence of fine powder particles and debris when using existing circulation system of machine itself. Therefore, a new experimental container was fabricated of size 450mm×200mm×180mm, which is filled with 7 liters of dielectric fluid. The container is made up of sheet metal, is called the machining container. It is placed in the existing working tank of EDM machine and experiments were performed in this machining container. The work piece is mounted on the magnetic V-block which is placed in the machining container. The tool is placed on the tool holder and its alignment is checked with the help of dial gauge. A stirrer assembly is used to stir the dielectric continuously to prevent settling of the powder in the machining tank.

4. Experimental Procedure

The electric discharge machine is of die sinking type, with servo-head and straight polarity is used to conduct the experiments. The following steps have been followed during the experimentation work:

- Place the separately manufactured mild steel container (machining container) in the actual working tank of EDM machine and clamp firmly to the T-slots.
- Attach the Motor-stirrer assembly to the machining container at desired location, which is running at a speed of 1000 rpm.
- Fix the copper tool electrode in the servo feed tool holder of EDM machine.
- Ground the work pieces on top and bottom faces to a good level of surface finish with the help of surface grinder.
- Measure the initial mass of the work piece with the help of Electronic weighing balance.
- Clamp the work material on the magnetic V-block, which is placed in the machining tank and check its alignment with the help of the dial indicator and fill the machining tank with 7 liters of dielectric fluid.
- Set the parameters of the experiment according to the experimental setting finally, switch 'ON' the machine.
- After machining operation, the work pieces are taken out and measure the mass once again on electronic weighing balance.
- The same experiment was repeated with and without addition of fine metal powders in dielectric on various types of work materials.
- The Material Removal Rate (MRR) is calculated by:

$$\mathrm{MRR} = \frac{W_i - W_f}{\rho t} \times 1000\ \mathrm{mm^3/min}$$

Where, W_i = Initial weight of work piece material (gm)
W_f = Final weight of work piece material (gm)
t = Time period of trial in minutes
ρ = Density of work piece in gm/cc

- The instrument Taly-Surf has been used to determine the surface roughness of the work piece after conducting each experiment.

5. Experimental Design

As the intention of this research work is to study the effect of powder mixed in the dielectric fluid upon MRR and Surface roughness, by changing the various input machining process parameters, the design variables can be summarized as follows:

Table 6 Process Parameters and their Levels

Parameters	Levels		
	1	2	3
Work Piece	AISI D3 Steel	EN-31 Steel	----
Peak Current	6	9	12
Pulse on time	20	50	100
Duty factor	7	8	9
Gap Voltage	40	60	80
Powder	Aluminium	Copper	----

The machining parameters that have been kept fixed throughout the experimentation are as follows:

Table 7 Constant machining parameters

S.No	Machining Parameter	Fixed Value
1	Open Circuit Voltage	135 ± 5% Volts
2	Polarity	Straight
3	Machining Time	15 min.
4	Type of Di-electric	Kerosene
5	Powder size	325 mesh
6	Powder Concentration in dielectric	4g/liter

For conducting the experiments, it has been decided to follow the Taguchi design of experiments and a suitable orthogonal array is to be selected after taking into concern the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for six design variables(namely work piece material, peak current, pulse on-time, duty factor, gap voltage and metal powder) which would constitute the orthogonal array. The effects of process parameters on material removal rate and surface roughness are analyzed by using statistical software MINITAB16.

6. Result and Discussions

From the experimental result, it is observed that the material removal rate is superior in AISI D3 Steel compared to EN-31 Steel. This is probably due to lower thermal conductivity and lower density of AISI D3 steel, results in bulk heating of work surface there by additional material is melted and evaporated.

The experimental result shows that by increasing the peak current and pulse on time increases the material removal rate. In EDM process, the material removal rate is a function of electrical discharge energy. The increase of peak current produces high energy intensity spark, which produces high temperature, causing more material to melt and vaporize from the work piece. Thus material removal rate increases with increase of peak current. In general, the power of the spark and frequency defined by the number of pulses per second to decide the process performance. The low frequency and high power combination results in high metal removal. As pulse on time increases the frequency reduces and therefore the long pulse duration increases material removal.

Table 8 Experimental Settings and output responses

Exp. No.	Work Piece	Peak Current (Amps)	Pulse on time (µs)	Duty factor	Gap voltage (volts)	Powder	MRR (mm³/min)	SR (µm)
1	AISI D3 Steel	6	20	7	40	Al	0.312	2.78
2	AISI D3 Steel	6	50	8	60	Cu	0.521	2.96
3	AISI D3 Steel	6	100	9	80	----	0.834	3.44
4	AISI D3 Steel	9	20	7	60	Cu	0.365	2.78
5	AISI D3 Steel	9	50	8	80	----	0.312	3.16
6	AISI D3 Steel	9	100	9	40	Al	0.990	2.88
7	AISI D3 Steel	12	20	8	40	----	0.208	3.18
8	AISI D3 Steel	12	50	9	60	Al	1.929	3.22
9	AISI D3 Steel	12	100	7	80	Cu	2.816	3.24
10	EN-31 Steel	6	20	9	80	Cu	0.563	2.68
11	EN-31 Steel	6	50	7	40	----	0.204	2.70
12	EN-31 Steel	6	100	8	60	Al	0.563	2.86
13	EN-31 Steel	9	20	8	80	Al	0.102	3.28
14	EN-31 Steel	9	50	9	40	Cu	0.612	3.32
15	EN-31 Steel	9	100	7	60	----	0.665	2.92
16	EN-31 Steel	12	20	9	60	----	0.609	3.44
17	EN-31 Steel	12	50	7	80	Al	1.382	2.96
18	EN-31 Steel	12	100	8	40	Cu	1.485	3.22

By increasing the voltage causes higher energy to discharge i.e., larger impulsive force of discharge on the work piece results in higher MRR.

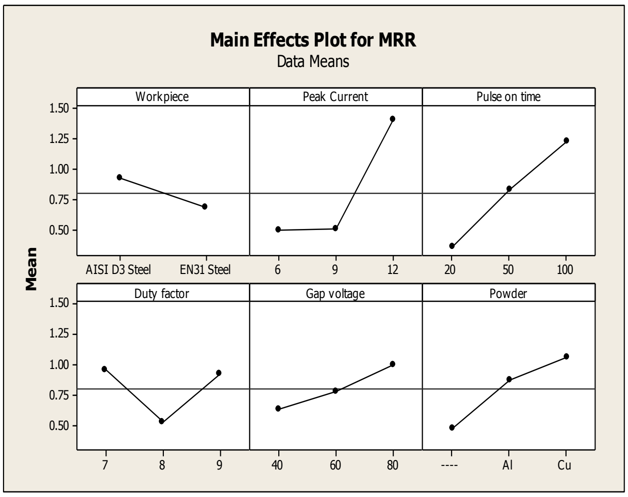

Fig.2 Effect of process parameters on MRR

Material removal rate is higher with copper powder as an additive in comparison to that of aluminium powder. Reason for this is may be due to higher thermal conductivity and lower electrical resistivity of copper powder, electrode material is not allowed to absorb more amount of heat and most of the heat is used to remove material. As a result, material removal rate will be higher.

The Surface roughness of the AISI D3 steel is more compared to EN-31 steel. This can be possibly due to more MRR on the AISI D3 results in deeper craters.

The peak current was the most important factor that influences the surface roughness. At higher current, the impact of the discharge on the surface of the work piece becomes more intense and the resulting erosion led to the increase in the deterioration of the surface roughness. Heating and cooling effect during machining process resulted in heat affected layer to form on the surface of the work piece hence affected the surface roughness value. At higher value of current causes the more surface roughness.

Increase in pulse on time led to an increase in the surface roughness. This can be possibly due to more discharge bombards the work surface and forms deeper depression.

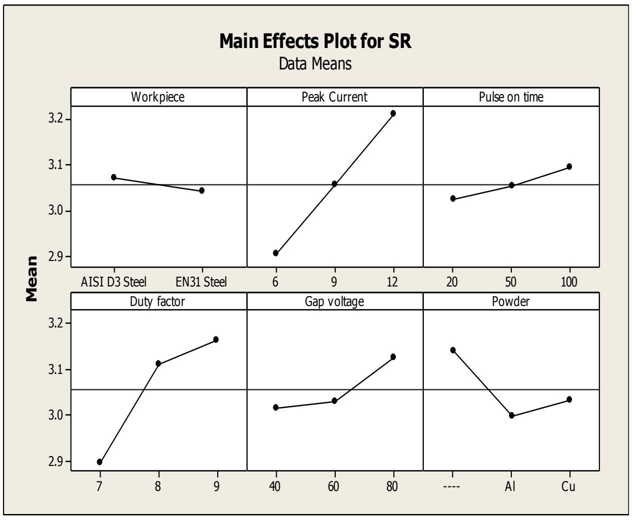

Fig.3 Effect of process parameters on surface roughness

The Surface roughness generated by adding copper powder is more as compared to aluminium powder. Reason for this is may be the higher density of copper powder overwhelms the suspension ability of the dielectric fluid.

Conclusions

Mixing of fine metal powders into the dielectric fluid is one of the recent progresses in EDM that ensures better material removal rates at preferred surface excellence. From the current research work, for the selected process parameters the following conclusions are drawn:

1) PMEDM makes discharge breakdown easier, increases the discharge gaps and widens the discharge passage, the plasma channel gets enlarged and lastly forms evenly distributed large and shallow cavities on the work piece.
2) Additive metal powder can lower the discharge voltage; increase the discharge gap and make the discharge current further even. The addition of metal powders in dielectric fluid increases the material removal rate than that of without addition of powders.
3) The most vital characteristics of work materials are affecting the EDM performance has been identified as the density and the thermal conductivity.
4) MRR also mainly affected by Peak current and pulse on time, and type of metal powder addition. At the higher value of Peak current larger is the MRR.
5) The Surface roughness of the AISI D3 steel is more compared to EN-31 steel. The addition of aluminium powder in dielectric fluid produces better surface finish than that of copper powder and without powder.

Nomenclature

PMEDM Powder Mixed Electric Discharge Machining
MRR Material Removal Rate
SR Surface Roughness

References

Kansal H.K., Singh S., Kumar P.,(2005), Parametric optimization of powder mixed electrical discharge machining by response surface methodology, *Journal of Materials Processing Technology*, Vol. 169, pp. 427-436.

Wu K.L., Yan B.H., Huang F.Y., Chen S.C., (2005), Improvement of surface finish on SKD steel using electro-discharge machining with aluminum and surfactant added dielectric, *International Journal of Machine Tools & Manufacture*, Vol. 45, pp. 1195-1201.

Zhao W.S., Meng Q.G., Wang Z.L., (2002), The application of research on powder mixed EDM in rough machining, *Journal of Material Processing Technology*, Vol. 129, pp.30-33.

Kansal H.K., Singh S., Kumar P., (2007), Effect of silicon powder mixed EDM on machining rate of AISI D2 die steel, *Journal of Manufacturing processes*, Vol. 9, pp 13-21.

Kumar S., Singh R., Singh T.P., Sethi B.L. (2009), Surface modification by electrical discharge machining: A review, *Journal of Material Processing Technology*, Vol. 209, pp 3675-3687.

Wong Y. S, Lim L.C, Rahuman I., Tee W. M, (1998), Near-mirror-finish phenomena in EDM using powder-mixed dielectric, *Journal of Material Processing Technology*, Vol. 79, pp. 30-40.