PARAMETRIC ANALYSIS ON POWDER MIXED ELECTRIC DISCHARGE MACHINING OF VARIOUS STEELS USING TAGUCHI METHOD

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ABSTRACT

This paper presents the outcomes of an experimental analysis carried out to study the effect of micro-sized metal powders, when they are mixed to the dielectric fluid, during Electric Discharge Machining (EDM) of different steels. The work piece material, peak current, pulse on time, duty factor, gap voltage and mixing of fine metal powders(copper and aluminium) in dielectric fluid are taken as process input parameters. Material removal rate and Surface Roughness are taken as output parameters to measure the process efficiency. A newly designed experimental set up has been used to perform the task. Taguchi design of experiments is used to conduct experiments. The achieved results of this work indicate that the addition of fine metal powders in dielectric increases the material removal rate and reduces the surface roughness.

Keywords: Dielectric, EDM, Steels, Micro-Sized Metal Powders, Material Removal Rate, Surface Roughness

I INTRODUCTION

Scientifically emerging industries like automotive, defense, aerospace, electronics, nuclear power, metallic moulds and dies requires materials of high strength, high temperature resistant alloys like carbides, super alloys, haste-alloys etc. These materials are difficult to machine by conventional machining processes. With the drastic improvement 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 constant production and high precision [1]. Thus, non-conventional 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 intricate shapes.

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 associated with EDM. In the recent past, Powder Mixed Electric Discharge Machining (PMEDM) has emerged as an innovative method to improve the process effectiveness of EDM [1]. In PMEDM, the micro-sized metal powder is mixed into the dielectric used in EDM. When a suitable voltage 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 groups. Under the influence of electrostatic forces, the powder particles arrange themselves in the form of chains at various places under the spark area. 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. 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 enhancement in dimensional accuracy [2].

II EXPERIMENTAL PARTICULARS

2.1 Selection of work piece materials

The work piece materials selected for the current study are High carbon high chromium steel (HCHCr Steel) and EN-31 steel.The HCHCr steel work materials of size 50mm×20mm×12mm of 9 specimens are prepared by using power hacksaw, shaper and surface grinder. HCHCr 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, HCHCr steel is used to manufacture blanking, stamping and cold forming dies, bending, forming, and seaming rolls etc.

Table 1 Chemical Composition of HCHCr Steel

Elements	C	Si	Mn	P	S	Cr	Mo	Fe
Composition (wt. %)	2.55	0.26	0.47	0.038	0.056	13	0.08	Balance

EN-31 steel finds wide applications in roller bearing components such as brakes, cylindrical, conical & needle rollers. The EN-31 steel work materials of size 40mm×20mm×10mm of 9 specimens are prepared by using power hacksaw, shaper and surface grinder.

Table 2 Chemical Composition of EN-31 Steel

Elements	C	Si	Mn	P	S	Cr	Fe
Composition (wt. %)	1.07	0.32	0.58	0.04	0.03	1.12	Balance

Table 3 Properties of HCHCr steel and EN-31 steel

Material	Thermal Conductivity	Density	Electrical Resistivity	Specific heat capacity

	(W/mK)	(g/cc)	(Ω-cm)	(J/g. ^{O}C)
HCHCr steel	20	7.67	0.0000720	0.5
EN-31 steel	46.6	7.81	0.0000218	0.475

2.2 Selection of tool electrode material

The tool electrode does not undergo much surface wear when it is strike by the positive ions in the process. The local heat rise at the surface of the tool electrode has to be less. It must have higher thermal conductivity, higher density, and higher melting point and can be machined without any difficulty. In this study the electrolytic copper is selected as tool electrode material because it possesses the above features efficiently. The electrode has a cross-section of 10mm×12mm.

Table 4 Properties of Copper electrode

Material	**Copper**
Thermal conductivity	391.1W/m K at 100^{0}C
Density	8.94×10^{3} kg/m^{3}
Modulus of Elasticity	117 Gpa
Melting point	1356 K
Latent heat of fusion	134 J/g
Thermal expansion	16.9×10^{-6}/K at 100^{o}C

III EXPERIMENTAL SET-UP

Experiments are performed on Electra EMS-5535 EDM machine. The working tank of EDM machine has the dimensions of 800mm×500mm×350mm.It requires rich 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 clog due to existence of fine powder particles and debris when using existing circulation system of machine itself. Therefore, a new experimental tank was made-up of size 450mm×200mm×180mm, which is filled with 7 liters of dielectric fluid. The experimental tank 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 [4]. 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 settle down of the powder in the machining tank.

Fig.1 Experimental setup

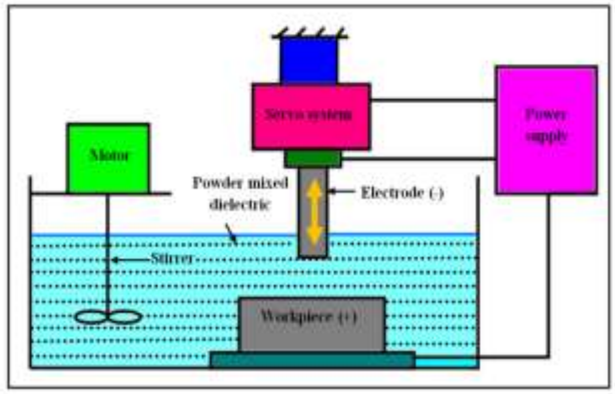

Fig.2 Schematic Diagram of Experimental Setup

IV 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 machining container in the actual working tank of EDM machine and fasten firmly to the T-slots.

•Attach the stirrer assembly to the machining container at chosen position, which is running at a speed of 800 rpm.

•Fix the copper 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 weighing balance.

•Clamp the work piece on the magnetic V-block, which is placed in the machining tank and check its alignment by using dial indicator and fill the machining tank with seven liters of kerosene (dielectric fluid).

•Set the parameters of the experiment according to the experimental setting finally, switch 'ON' the machine.

•Once machining operation is completed, the work pieces are taken out and measure the mass again on weighing balance.

•The same experiment was repeated with and without addition of fine metal powders in dielectric on different types of work pieces.

•The Material Removal Rate (MRR) is calculated by:

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

Where, Wi = Initial weight of work piece material (gm),

Wf = 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 pieces after conducting each experiment.

Fig.3 Work pieces before machining

Fig.4 Work pieces after machining

V EXPERIMENTAL DESIGN

In this investigational work, to study the effect of fine metal powder mixed in the dielectric, upon Material removal rate (MRR) and Surface roughness (SR), by changing the various input machining parameters and some parameters have been kept fixed throughout the testing. The design variables can be summarized as follows:

Table 5 Process Parameters and their Levels

Parameters	**Levels**		
	1	2	3
Work piece	HCHCr 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	----

Table 6 Fixed 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 Dielectric	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 selected after considering the above design variables. The effects of process parameters on material removal rate and surface roughness are analyzed by using statistical software MINITAB16.

Table 7 Experimental Settings and output responses

Exp. No.	Work Piece	Peak Current (Amps)	Pulse on time (µs)	Duty factor	Gap voltage (volts)	Powder	MRR (mm^3/min)	SR (µm)
1	HCHCr Steel	6	20	7	40	Al	0.312	2.78
2	HCHCr Steel	6	50	8	60	Cu	0.521	2.96
3	HCHCr Steel	6	100	9	80	----	0.834	3.44
4	HCHCr Steel	9	20	7	60	Cu	0.365	2.78
5	HCHCr Steel	9	50	8	80	----	0.312	3.16
6	HCHCr Steel	9	100	9	40	Al	0.990	2.88
7	HCHCr Steel	12	20	8	40	----	0.208	3.18
8	HCHCr Steel	12	50	9	60	Al	1.929	3.22
9	HCHCr 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

VI RESULT AND DISCUSSIONS

From the test results shown in Fig.5, the material removal rate is greater with the addition of copper powder in comparison to that of aluminium powder. This is may be due to higher thermal conductivity and lower electrical resistivity of copper powder, electrode material is not permissible to absorb more amount of heat and most of the heat is used to eradicate material. As a result, material removal rate will be higher. The experimental result shows that by increase in 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.

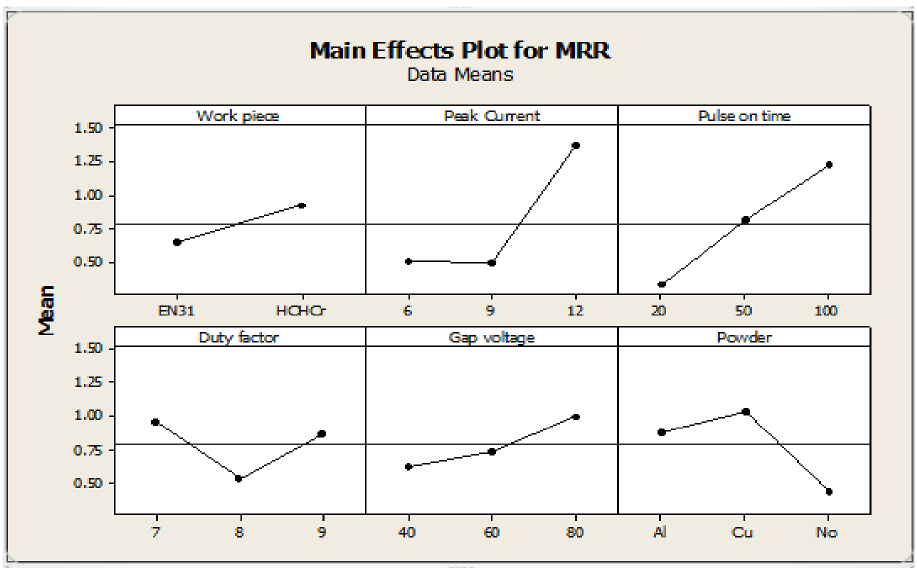

Fig.5 Effect of process parameters on Material Removal Rate

As pulse on time increases the frequency reduces and therefore the long pulse duration increases material removal. By increasing the voltage causes higher energy to discharge i.e., larger impulsive force of discharge on the work piece results in higher MRR. From the investigational result, it is detected that the material removal rate is greater in HCHCr steel compared to EN-31 Steel. This is possibly due to lower density and lower thermal conductivity of HCHCr steel, results in bulk heating of work surface there by extra material is melted and evaporated.

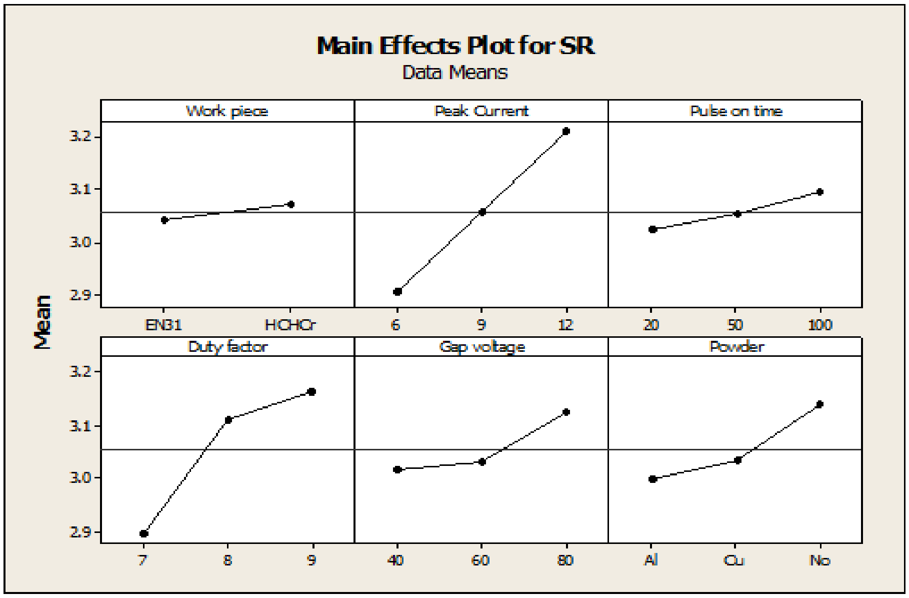

Fig.6 Effect of process parameters on surface roughness

From the experimental results shown in Fig.6, The Surface roughness obtained by the addition of copper powder is greater as compared to aluminium powder. The reason for this may be the higher density of copper metal powder overwhelms the suspension capability of the dielectric fluid. The Surface roughness of the HCHCr steel is more related to EN-31 steel. This can be probably due to more material removal rate on the HCHCr results in deeper cavities. The peak current is the utmost significant factor that affects the surface roughness. At higher current, the impact of the discharge on the surface of the work piece become more powerful and results more erosion led to the increase in the surface roughness. Increase in the pulse on time results to an increase in the surface roughness, that can be feasibly due to more discharge impinges the work piece surface and forms deeper cavities.

VII CONCLUSIONS

Addition of micro-sized metal powders into the dielectric fluid is one of the modern progresses in EDM that confirms better material removal rates at chosen surface quality. From the current investigation, for the selected process parameters the following conclusions were made:

1) Adding aluminium metal powder in dielectric fluid generates superior surface finish than that of the addition of copper metal powder and without the addition of metal powder.

2) The material removal rate is mainly affected by Peak current and pulse on time, and type of metal powder as additive. At the higher value of peak current, greater is the MRR.

3) Powder Mixed EDM makes discharge collapse easier, increases the discharge gaps and expands the discharge channel, and finally forms uniformly distributed large and shallow craters on the work piece.

4) The Surface roughness of the HCHCr steel is superior compared to EN-31 steel.

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