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# PERFORMANCE STUDY OF POWDER MIXED ELECTROCHEMICAL DISCHARGE MACHINING (PMECDM) OF CERAMIC MATERIAL

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## ABSTRACT

A new method has been investigated to improve Electro-Chemical Discharge Machining (ECDM) process by use of powder mixed electrolyte. In Electrical Discharge Machining (EDM) processes, which is thermal erosion machining process using spark energy similar to the ECDM, powder-mixed EDM (PM-EDM) fluids have been used to improve machining characteristics. It has been reported that the powder stabilizes discharge current as a result of discharge energy dispersion. Considering the similarity of the ECDM process compared to EDM where electrical sparks are utilized, powder-mixed electrolyte is introduced to create similar effects. This work aims to improve the MRR by adding SiC abrasive to the electrolyte. A mechanism that combines discharge, chemical etching and abrasive cutting is studied. The effects on diametric overcut (DOC) and material removal rate (MRR) are discussed. Experiments on PMECDM have been carried out according to designed experimental plan based on standard orthogonal array ($L_9$) to identify the optimal parametric conditions of PMECDM process using taguchi method of parametric optimisation. Signal to Noise (S/N) ratio is used to measure the quality charactristics deviating from the desired values. Regression analysis is done to determine the best suited equation connecting response with input variables, such as applied voltage, duty factor, electrolyte concentration and SiC concentration in controlling the machining performance, such as material removal rate and diametric overcut of the ECDM process. The chrome alumina is used as workpiece material and aqueous NaOH in

stagnant condition as electrolyte is used. SiC powder of 1200 mesh size (10-15µm) is mixed with electrolyte.

**KEYWORDS:** Powder Mixed Electrochemical Discharge Machining, MRR, DOC, taguchi method, regression analysis.

## INTRODUCTION

**Electrochemical Discharge Machining:** Electrochemical Discharge Machining (ECDM) process is a promising technology to machine electrically non-conducting materials such as ceramics and glass. It is a hybrid technology that combines the electrochemical machining (ECM) and electro-discharge machining (EDM) and can be employed irrespective of the electrical and mechanical properties of materials. It uses two electrodes: one is cathode where tool is generally connected and another is anode having larger area than cathode is used as auxiliary electrode. Cathode (tool) of small size is dipped 2–3mm in an electrolyte. Application of potential (50–80 V) between the electrodes causes the flow of electric current through the electrolytic cell. The hydrogen gas bubbles are generated due to electrochemical reactions and are accumulated at the surroundings of the tool and thereby form a gas bubble layer. If the applied voltage increases beyond the critical limit, sparking is initiated between tool and electrolyte across the gas bubble layers due to electrical discharge and the material is removed at very high temperature from the workpiece, which is placed just below the tool and immersed in an electrolyte solution in a machining chamber. The ECDM process has various advantages such as low heat affected zone, low tool wear, material can be removed from electrically non-conducting materials, no burr at the machined zone etc. The limitations of ECDM process include low machining depth and low material removal rate.

**Powder Mixed Electrochemical Discharge Machining (PMECDM):** In conventional ECDM processes, the generation of fine sparks with uniform energy has been most desired technique to improve the machining efficiency and the surface quality. Untill now graphite and silicon carbide powders are used for PMECDM on glass material. When conductive particles are added to the electrolyte the spark initiation voltage is decreased because of the local electric filed intensification between the tool and workpiece. Silicon Carbide particles are semiconductor in nature. They have very high thermal conductivity (Thermal Conductivity 90-110 W/mK). When a voltage is applied, the powder particles become energized and behave in an erratic fashion. These charged particles are accelerated due to the electric field. The powder particles produce series of spark between the tool and workpiece.

Under the sparking area, these particles come together and arrange themselves in the form of chain like structures. The interlocking between the powder particles occurs in the direction of current flow. The chain formation helps in bridging the discharge gap between the electrodes. This causes early explosion in the gap and series discharge starts under the electrode. The faster sparking within a discharge results in faster erosion of the work piece surface and hence the MRR increases.

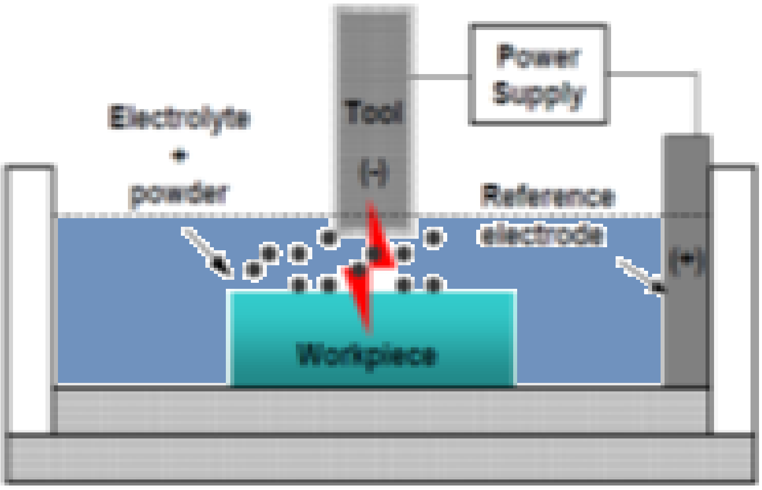


**Figure 1: Schematic of PMECDM.**

**General Investigations:** Rolf Wuthrich and V. Fascio[1] investigated that material removal rate( MRR) increases with increase in voltage and electrolyte concentration. Surface roughness is also influenced by electrolyte concentration. Feeding mechanisms also influences the machining performance. Various feeding mechanisms are gravity feed, stick-slip actuators or maintaining constant force between tool and workpiece. B. Bhattacharyya and B. Doloi[3] reported that NaOH has higher specific conductance than KOH or other electrolytes due to which chemical reaction takes place at faster rate and also generation of gas bubbles is faster. Also tool shape has a significant effect on machining and flat shape is most effective. C.T. Yang, S.L. Song, B.H. Yan, F.Y. Huang[9] investigated the machining performance of wire ECDM on pyrex glass by adding SiC abrasive to electrolyte. They came to the conclusion that adding abrasive to electrolyte increases critical voltage and reduces slit expansion. Surface roughness gets reduced and MRR increases with increase in abrasive concentration. Sanjay K. Chak, P. Venkateswara Rao[10] studied the drilling of $Al_2O_3$ using a pulsed DC supply with rotary abrasive electrode by the electrochemical discharge process. This study has established that the drilling of deep holes in ceramics is possible by using pulsed DC and with the help of an abrasive rotary electrode. It can also be concluded that the pulsed DC has reduced the tendency of cracking at higher supply voltages and improved the volume of material removed to a greater extent during the machining of $Al_2O_3$. Min Seop Han, Byung-Kwon Min, Sang Jo Lee[8] investigated the effect of graphite powder mixed electrolyte during ECDM of glass. Surface roughness reduces and mrr increases and geometrical accuracy increases as smooth surface can be produced. Use of 0.5-1.0 wt. % graphite powder is preferred as micro cracks on glass are significantly reduced.

**ECDM of chrome alumina ceramics**

**Experimental Setup:** As shown in figure 3. the tool is held with a tool holder made of acrylic material. It is guided by sleeve which is fixed to the arm of stand. The tank is made up of acrylic material with a provision to fit an anode. When the process begins, tool holder has sliding movement inside the sleeve because as tool propagates downwards due to self weight and dead weight placed at top of it. The workpiece is clamped from the top. 304 stainless steel has been selected as a tool material because tool material must be good conductor of electricity. Studs of tool material are machined to make them as per the requirement of 0.8 mm diameter and length of 10 mm.

**Figure 2: Stainless steel tool (ø0.8mm).**

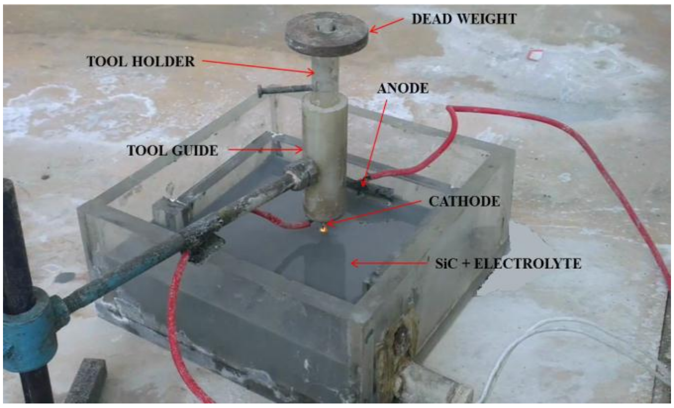


**Figure 3: Gravity feed PMECDM with steady electrolyte setup.**

**Selection of machining parameters:** Based on some pilot experiments following machining parameters and their respective levels are decided.

**Table 1: Machining factors and their levels.**

| **Level→** | **High** | **Medium** | **Low** |
|---|---|---|---|
| **Factors↓** | 1 | 0 | -1 |
| Applied Voltage (v) | 65 | 60 | 55 |
| Duty Cycle | 0.8 | 0.72 | 0.64 |
| Conc.of electrolyte (%) | 50 | 40 | 30 |
| Conc. of SiC (%) | 4 | 3 | 2 |

**Measurement of Machining Performance:** Experiments were conducted as per designed experimental plan and the performance or responses were measured for each experimental run. MRR and DOC were taken as performance criteria or responses. The amount of metal removed (MR) was measured by taking difference in weight of the specimen before ($W_1$) and after machining ($W_2$). The time taken for the experiment was 15 min. The MRR can be evaluated as MR/t or ($W_1$ - W2)/t, where t is the machining time. The outer DOC is computed as (D - d), where D is the diameter of the drilled hole on specimen and d is the diameter of the tool.

**4. Taguchi methodology-based design & analysis of machining parameters:** The present analysis includes Taguchi method based parametric optimisation technique to quantitatively determine the effects of various machining parameters on the quality characteristics of ECDM process and to find the optimum parametric condition for obtaining optimum machining criteria yield. In this analysis, the parametric design of experiment is performed based on the selection of an appropriate standard orthogonal array. The analysis of signal-to-noise (SN) ratio was carried out to study the optimum values of parameters. $L_9$ orthogonal array is used to study the effects of machining parameters on the performance of PMECDM process.

**Table 2: Design of Experiments ($L_9$ OA).**

| Run | VOLTAGE | Duty Factor | CONC.OF Electrolyte | CONC.OF SiC |
|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 |
| 2 | -1 | 0 | 0 | 0 |
| 3 | -1 | 1 | 1 | 1 |
| 4 | 0 | -1 | 0 | 1 |
| 5 | 0 | 0 | 1 | -1 |
| 6 | 0 | 1 | -1 | 0 |
| 7 | 1 | -1 | 1 | 0 |
| 8 | 1 | 0 | -1 | 1 |
| 9 | 1 | 1 | 0 | -1 |

**Analysis of Signal-to-Noise Ratio:** In Taguchi method, S/N ratio is used to measure the quality characteristics deviating from the desired value. The term signal represents the desirable mean value of the output characteristics and the term noise represent the undesirable value (i.e. standard deviation) for the output characteristics. In order to obtain optimal machining performance, the higher the better quality characteristics for MRR is considered. The SN ratio for MRR is defined as.

db = -10 log [ (1/n) * ∑ (1/yi2 )]----------------(1)

Where, db = resultant S/N ratio, n = number of observations y = respective characteristics

Table 3 shows the experimental results for MRR and the corresponding SN ratio using Eqn (1). Since the experimental design is orthogonal, it is possible to sort out the effect of each machining parameter at different levels. The mean SN ratio for the applied voltage (A) at levels 1, 2 and 3 can be calculated by averaging the SN ratios for the experiments 1-3,4-6 and 7-9, respectively. The average S/N ratio for all the levels of all machining parameters (factors) taking MRR as response is graphically exhibited in Fig. 4. The highest average SN ratio gives the maximum MRR. It is clear from the SN ratio response graph that for achieving maximum MRR, the optimum condition of machining is applied voltage of 65 V, duty factor at 0.80 electrolyte concentration of 50 % aqueous NaOH and SiC concentration at 3 %. On the other hand, the lower the better quality characteristics for DOC is taken for obtaining optimal machining performance. The resultant SN ratio is given by.

db = -10 log [ (1/n) * ∑ (yi)2 ]--------------------(2)

Where, db = resultant S/N ratio ,n = number of observations y = respective characteristics

Table 3 shows the experimental results for DOC and the corresponding SN ratio using Eqn (2). The mean SN ratio for DOC for all the factors at different levels is determined. The SN response graph for DOC is shown in Fig. 5. The greater average SN ratio corresponds to the minimum DOC. From the SN response graph (Fig. 3), it is concluded that the optimum parametric combination is voltage at 55v, duty factor at 0.64,concentration of electrolyte at 40 % and SiC concentration at 4 %.

**Table 3: Experimental results for responses and SN ratio For MRR Larger is better.**

| Run | DOC | MRR | SNRA DOC | SNRA MRR |
|---|---|---|---|---|
| 1 | 0.835 | 0.1538 | 1.56627 | -16.2609 |
| 2 | 0.684 | 0.2 | 3.298878 | -13.9794 |
| 3 | 0.725 | 0.2667 | 2.79324 | -11.4795 |
| 4 | 0.5685 | 0.333 | 4.905391 | -9.55112 |
| 5 | 1.2315 | 0.4667 | -1.80869 | -6.61924 |
| 6 | 0.867 | 0.333 | 1.239618 | -9.55112 |
| 7 | 0.9625 | 0.933 | 0.331985 | -0.60237 |
| 8 | 0.943 | 0.5333 | 0.509766 | -5.46057 |
| 9 | 1.2415 | 0.6 | -1.87893 | -4.43697 |

**Table 4: Response table for Signal to Noise Ratio.**

| Level | Voltage | Duty Factor | Conc. of Electrolyte | Conc. of SiC |
|---|---|---|---|---|
| 1 | -13.907 | -8.805 | -10.424 | -9.106 |
| 2 | -8.574 | -8.686 | -9.322 | -8.044 |
| 3 | -3.5 | -8.489 | -6.234 | -8.83 |
| Delta | 10.407 | 0.316 | 4.19 | 1.061 |
| Rank | 1 | 4 | 2 | 3 |

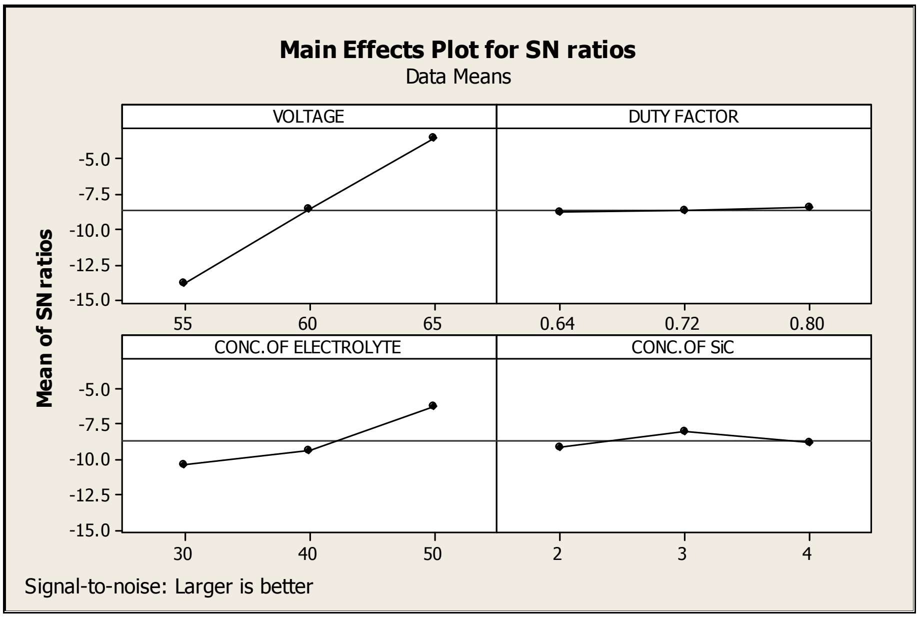


**Figure 4: Signal-to-noise ratio graph for MRR for DOC Smaller is better.**

**Table 5: Response Table for Signal to Noise Ratio.**

| Level | Voltage | Duty Factor | Conc. of Electrolyte | Conc. of SiC |
|---|---|---|---|---|
| 1 | 2.5528 | 2.2679 | 1.1052 | -0.7071 |
| 2 | 1.4454 | 0.6667 | 2.1084 | 1.6235 |
| 3 | -0.3457 | 0.718 | 0.4388 | 3.4432 |
| Delta | 2.8985 | 1.6012 | 1.6696 | 3.4432 |
| Rank | 2 | 4 | 3 | 1 |

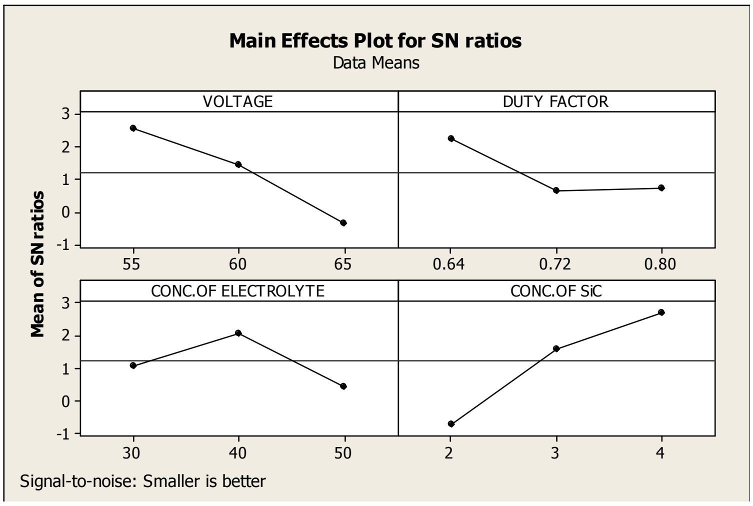


**Figure 5: Signal-to-noise ratio graph for DOC.**

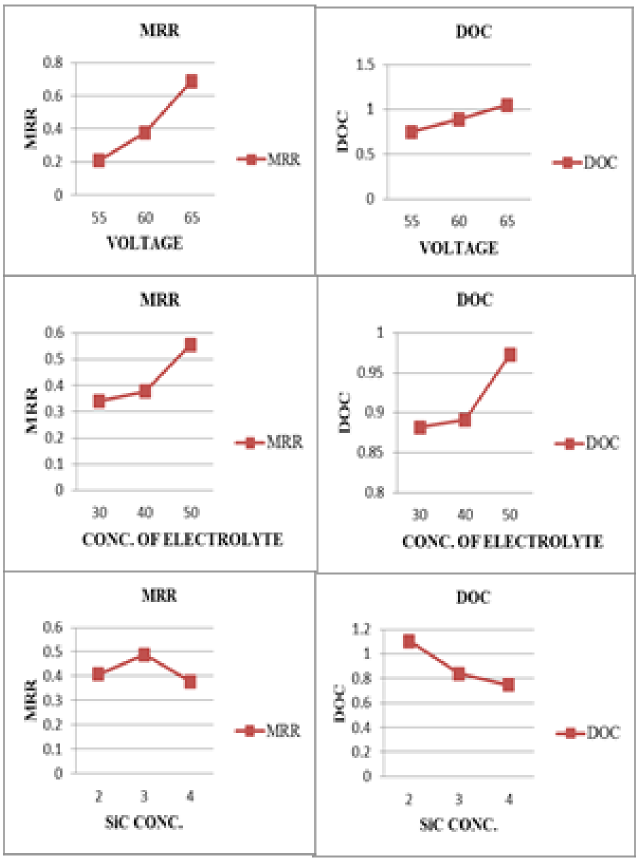


**Fig. 6: Main effect plot of mean for MRR and DOC.**

**Regression Analysis:** To determine the best suited equation connecting response with input variables, regression technique has been used. Regression coefficient is the measure to indicate how far the established relationship is valid to ensure the values of dependent variable, using the values of independent variables for which readings are not available in the range of minimum and maximum value of independent variables. ANOVA table is used to check the significance of the regression model. The exponential equation established for MRR is as follows: $MRR = 0.368369\ V^{0.260166}\ DF^{0.007889}\ C_{Ele.}^{0.104762}\ C_{SiC}^{0.006882}$ R square value comes out to be 0.912542 for MRR, therefore relationship established is acceptable. Similarly for DOC, exponential equation established is as follows: $DOC = 0.869200\ V^{0.072463}\ DF^{0.038748}\ C_{Ele.}^{0.016659}\ C_{SiC}^{-0.08608}$ R square value comes out to be 0.886073, therefore relationship established is acceptable.

## CONCLUSIONS

1) Taguchi analysis is carried out in order to determine the significant process parameters considering the responses as MRR and DOC. Following conclusions are drawn out:

- Taguchi analysis shows that the factors affecting the MRR in the order of their significance (delta ranking) is voltage, electrolyte concentration, SiC concentration, duty factor. The delta ranking for DOC is SiC concentration, voltage, electrolyte concentration, duty factor.
- The optimal parameter settings for MRR are found out according to taguchi analysis as voltage of 65 V, duty factor at 0.80 electrolyte concentration of 50 % aqueous Na OH and SiC concentration at 3 % .For DOC these are found out to be voltage at 55v, duty factor at 0.64, concentration of electrolyte at 40 % and SiC concentration at 4 %.
- Main effect plots of mean for MRR and DOC shows that MRR and DOC increases with increase in voltage as well as concentration of electrolyte. While MRR first increases with increase in SiC concentration and then decreases with increase in SiC concentration. DOC decreases with increase in SiC concentration.

2) Regression analysis is used for finding out the regression equations in the form of coded values for the output responses based on the input parameters viz. voltage, duty factor, electrolyte concentration, SiC concentration.

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