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A Review on Effect of Aluminum & Silicon Powder Mixed EDM on Response Variables of Various Materials

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ABSTRACT: In this paper Aluminium & Silicon powders mixing into the dielectric fluid of EDM on machining characteristic of various materials has been studied. Various process parameters namely peak current, pulse-on time, pulse-off time, powder concentration, powder grain size and nozzle flushing, duty factor, etc have been considered. The process performance is measured in terms of Response variables like Material Removal Rate(MRR),Surface Finish(SF) / Surface Roughness(SR),Tool Wear Rate(TWR)/Electrode Wear Rate(EWR),etc. Various types of dielectric fluids are used. Optimisation Methods used are Taguchi Method, Response Surface Methodology, etc. This paper reviews the research work carried out from the inception to the development of Aluminium & Silicon Powder Mixed Dielectric electric Discharge Machining within the past decade & also briefly describing the Current Researches conducted & optimization Technique used in the Aluminium & Silicon Powder mix Electric Discharge Machining(PMEDM) field.

KEYWORDS: EDM, PMEDM, MRR, TWR, SR, Taguchi Method, RSM.

I. INTRODUCTION

EDM as a process was introduced over fifty years ago; improvements in technology have led to increases in both cutting speeds and component precision. Developing from initially tool making industry sectors of press tool and mould tools, the EDM process is now mainly found within production engineering, aerospace, motor sport, medical and scientific industries. Electrical Discharge Machining (EDM) is non traditional, no physical cutting forces between the tool and the workpiece, high precision metal removal process using thermal energy by generating a spark to erode the workpiece. The workpiece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM machine has wide application in production of die cavity with large components, deep small diameter whole and various intricate holes and other precision part.

In the recent past, powder mixed EDM (PMEDM) has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. In this process, a suitable material in fine powder form (aluminum, chromium, graphite, copper, or silicon carbide, etc.) is mixed into the dielectric fluid of EDM. The spark gap is filled up with additive particles. The added powder significantly affects the performance of EDM process. The electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap distance between the tool electrode and workpiece. As a result, the process becomes more stable, thereby improving machining rate (MR) and surface finish.

II. MATERIALS AND METHODS

The principle of PMEDM is shown in Figure 1. In this process, the material in powder form is mixed into the dielectric fluid either in the same tank or in a separate tank. When a voltage of 80-320 V is applied to both the electrodes, an

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electric field in the range 105 to 107 V/m is created. The spark gap is filled up with additive particles, and the gap distance between tool and the workpiece increases from 25 µm to 50 µm to many times larger (Figure 1). The powder particles get energized and behave in a zig-zag fashion. The grains come close to each other under the sparking area and gather in clusters. Under the influence of electric forces, the powder particles arrange themselves in the form of *chains* at different places under the sparking area (refer to Figure 1). 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. The easy short-circuit takes place, which causes early explosion in the gap. As a result, the '*series discharge*' 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 erosion from the workpiece surface. At the same time, the added powder modifies the plasma channel. The The electric density decreases; hence, sparking is uniformly distributed among the powder particles. As a result, even and more uniform distribution of the discharge takes place, which causes uniform erosion (shallow craters) on the workpiece. This results in improvement in surface finish.

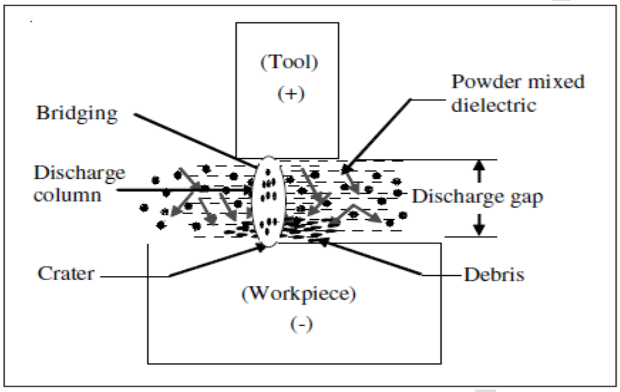

Figure 1: Principle of PMEDM Process

III. MAJOR PARAMETERS, ADVANTAGES, DISADVANTAGES AND LIMITATIONS OF PMEDM

EDM Parameters mainly classified into two categories Process parameter and Response Variable.
Process Parameters: The process parameters in EDM are used to regulate the performance methods of the machining process. Process parameters are generally well-disciplined machining input factors that decide the conditions in which machining is carried out. These machining situations will affect the process performance result, which are gauged using various performance methods.
Electrical Parameters - Duty factors , Gap Voltage , Peak Current , Average current , Push on time , Pulse off time , Discharge voltage , Polarity , Pulse Frequency , Pulse waveform , Electrode gap
Powder Based Parameters - Type of powder, Powder size , Powder conductivity , Powder concentration , Powder density
Non Electrical Parameters - Type of Dielectric , Working time , Electrode lift time , Nozzle flushing , Gain
Electrode Based Parameter - Electrode material , Electrode size , Electrode shape ,
Response variable: These variables measure the various process performances of EDM results.
1. Material removal rate (MRR)
2. Tool Wear rate (TWR)
3. Surface Quality
4. Surface Roughness
Types of Dielectric Fluids: Mineral Oil, Kerosene, Transformer Oil, EDM Oils, Synthetic Oils.
Types of Powder Used: Aluminum, Silicon , Graphite , Chromium , Aluminum oxide , Silicon carbide. Etc.
Advantages:
1. Any material that is electrical conductive can be machined, regardless of its hardness, strength, toughness and microstructure etc.
2. Work piece can be machined in hardness Conditions that is, the deformation caused by the hardened process does not affect the final dimensions.

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3. Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish.
4. No stresses are produced in the work, as there is no physical contact between the work piece and the tool electrode.
5. PMEDM process is totally burring free.
6. Secondary finishing operations like grinding are generally eliminated.
7. The surface produced by EDM consists if a number of small craters that help in oil retention and better lubrication, especially for the components such as tools and dies, where proper lubrication is very important for the life of the component.
8. A die punch can be used as electrode to reproduce its shape in the machining die block, completely with the necessary clearances. As a result better dies and moulds can be produced at reasonable costs.

Limitations:

1. MRR is low making the process economical only for very hard and difficult to machine materials.
2. The materials to be machined must be electrically conductive.
3. Fast electrode wear can prove costly.
4. The process cannot be monitored during machining. Hence any errors on malfunctions are detected only after the entire cut.
5. Only highly skilled persons can operate the machine.

Applications:

1. Enhancement of machined surface functional properties, such as wear resistance, corrosion resistance and reduced friction coefficient, through surface modification.
2. Improvements in performance parameters such as MRR, WR and SQ
3. Making and machining of micro product & sophisticated micro mechanical Element. It is the use of light, thin, compact, special purposes work such as micro-engines, micropumps, micro-robots etc.
4. The production of these microelements with traditional methods is restricted due to various Complications.
5. Machining of insulating materials Such as Si_3N_4 ceramics
6. Improve surface characteristics like mirror finish by graphite & silicon powder mixed into the dielectric fluid of EDM

IV. LITERATURE REVIEW

Wong *et al.* (1998) studied the near-mirror-finish phenomenon in electrical discharge machining (EDM) by fine powder introduced into the dielectric fluid. Al powder at concentration of 2 g/l has been reported to give mirror finish in PMEDM for SKH-51 work pieces.

Chow *et al.* (2000) carried out a study on micro-slit machining of titanium alloy with aluminum and SiC powder added in kerosene. It was proposed that SiC powder can produce a better material removal depth than Al powder added to the kerosene.

Tzeng and Lee (2001) presented the effects of various powder characteristics on the efficiency of electro discharge machining on mould steel SKD-11 work pieces. It was reported that 70–80 nm powders produced the greatest MRR, followed by 10–15 µm, with 100 µm producing the lowest. For the TWR, the reverse trend was observed. Cr powder produced the greatest MRR, followed by Al, then SiC.

Zhao *et al.* (2002) performed experimental research on machining efficiency and surface roughness of PMEDM in rough machining with aluminum powder of 10µm granularity and 40 g/l of concentration. It was concluded that PMEDM can improve machining efficiency by selecting proper discharge parameters like peak current and pulse width.

Pecas and Henriques (2003) enumerated the influence of silicon powder-mixed dielectric on hardened AISIH13 mould steel. The results indicated the positive influence of 2 g/l concentration of the silicon powder towards the reduction of the operating time required to achieve a specific surface quality.

Kansal *et al.* (2007) studied the effect of silicon powder mixing into the dielectric fluid of EDM on machining characteristics of AISI D2 die steel. Peak current and concentration of powder were found to be most significant parameters for material removal. High MRR was achieved at high concentration of 4 g/l and large Peak current of 10 A.

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Chow et al. (2008) proposed the use of SiC powder of size 3 – 5 μm in water for micro-slit EDM machining of titanium alloy and indicated that the addition of SiC powder would enlarge the electrode and workpiece gap, and also extrude debris easily, therefore increasing the MRR.
Kansal et al. (2008) presented the numerical simulation of PMEDM of AISI D2 die steel using finite element method.
Kung et al. (2009) carried out a study on MRR and EWR on PMEDM of cobalt-bonded tungsten carbide and reported optimal MRR at the aluminum powder concentration of 17.5 g/l. It was enumerated that EWR value tends to decrease with the aluminum powder concentration down to a minimum value after which it tends to increase. Both MRR and EWR increase with an increase of the grain size, discharge current and pulse on time.
Paramjit Singh, Anil Kumar, Naveen Beri, Vijay Kumar[2010] has been studied the effect of aluminium powder mixed in the dielectric fluid of Electric Discharge Machining on the machining characteristics of Hastelloy. Concentrations of aluminium powder and grain size of powder are taken as process input parameters. Material removal rate, tool wear rate, %age Wear Rate, surface roughness are taken as output parameters to measure process performance. The experimental investigations are carried out using copper electrode. Nine experiments are performed on Hastelloy using Electronica make smart ZNC EDM machine. Relationships are developed between various input and output parameters. The study indicates that both the input parameters strongly affect the machining performance of Hastelloy. The addition of a luminium powder in dielectric fluid increases MRR, decreases TWR and improves surface finish of Hastelloy.
M.Y. Ali, N. Atiqah and Erniyati[2011] presented the influence of silicon carbide (SiC) powder concentration in dielectric fluid and electrical discharge energy in micro electro discharge machining (μEDM) of titanium alloy (Ti-6Al-4V) with tungsten carbide (WC) electrode. SiC powder concentration and electrical discharge energy were two input variables. Three responses namely surface roughness (Ra), material removal rate (MRR), and electrode wear rate (EWR) were investigated. The optimization of *MRR* and *EWR* are mostly influenced by electrical discharge energy.

V. CURRENT REASEARCH PROGRESS IN ALUMINIUM AND SILICON POWDER MIXED EDM

Current research of Aluminium & Silicon Powder Mixed EDM is focused & tabulated in below tables. Table 1provides the details of Powder Type, Author details with year of research, Process parameters, Tool Electrode used, Work piece used and Research finding whereas Table 2 provides Powder type, Author, Author details, Response variables considered , Dielectric fluid used and Optimization method used.

Table 1: Latest Research in Aluminium and Silicon Powder Mixed EDM

Powder Type	Author/Year	Process Parameters	Tool Electrode	Workpiece	Research Finding
Aluminium Powder	Shivam Goyal, Rakesh Kumar Singh[2014]	Grain Size & Al concentration. Rest all parameters Constant	Copper	AISI 1045 Steel	1. Grain size of aluminium powder and concentration of aluminium powder mixed with EDM oil have a great influence on MRR and Surface finish. 2. Too low and too high concentration of aluminium powder & Grain Size in EDM oil reduces MRR of AISI 1045 Steel. 3. As the concentration of aluminium powder & Grain Size in EDM oil increases, surface roughness starts decreasing and keeps on decreasing. 4. If we consider MRR and Surface roughness equally important then with the increase

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					in concentration of aluminium powder & Grain size MRR and surface finish of AISI 1045 Steel increases.
Aluminium Powder	Khalid Hussain Syed, Kuppan Palaniyandi[2012]	Peak current, pulse on-time, concentration of the powder, and polarity	Copper	W300 Die Steel	1. Maximum MRR is obtained at a high peak current of 12 A, a moderate Ton of 180 µs, and a low concentration of powder 1 g/L in positive polarity. 2. Low EWR is achieved in positive polarity with low values of peak current of 6 A, higher values of Ton of 240 µs, and low concentration of powder of 1 g/L. 3. To produce low surface roughness values, a low peak current of 6 A, a moderate Ton of 180 µs, a low concentration of powder of 1 g/L, and positive polarity should be selected. 4. The minimum value of white layer thickness is obtained with low values of peak current 6 A, lower values of Ton of 100 µs, and low concentration of powder of 1 g/L in negative polarity. 5. Polarity plays an important role in PMEDM. Higher productivity, i.e. 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. 6. These experimental results prove that distilled water can be used as dielectric fluid instead of hydrocarbon oil and moreover the performance can be improved considerably by the addition of aluminium powder.
Aluminium Powder	M. M. Jamadar,	Peak Current, Pulse on-time,	Copper	AISI D3 Die Steel	1. Maximum MRR is obtained at a high peak current of

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	M.V. Kavade[2014]				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 6 g/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.
Aluminium Powder	Gurtej Singh, Paramjit Singh, Gaurav Tejpal, Baljinder Singh[2012]	Polarity, Peak Current,Pulse on time,Duty Cycle, Gap voltage,Powder Concentration	Copper	H13 Steel	1. Negative polarity of tool electrode is desirable lowering of surface roughness. 2. Increasing pulse on time leads to produce more rough surfaces. 3. Addition of powder particles in dielectric fluid decreases surface roughness of specimen in EDM process. 4. Higher peak currents produce more rough surfaces in EDM process.
Aluminium Powder	Gurule N. B., Nandurkar K. N.[2012]	Tool material, Peak Current,Pulse on time,Pulse off time, Duty Cycle, Gap voltage,Powder Concentration,Tool RPM, Flushing Pressure.	Copper, Brass, Aluminium	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	Mohd. Junaid Mir, Khalid Sheikh, Balbir Singh and Navdeep Malhotra[2012]	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 statisticalmathematical 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

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					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.
Aluminium Powder	Paramjit Singh, Anil Kumar, Naveen Beri, Vijay Kumar[2012]	Powder Concentration, Grain size of Powder	Copper	Hastelloy	1. Aluminium powder suspended in the dielectric fluid affected MRR, TWR, %WR, SR. 2. Too low and too high concentration of aluminium powder in EDM oil reduces MRR of Hastelloy. 3. Too low and too high grain size of aluminium powder in EDM oil reduces MRR of Hastelloy. 4. The addition of aluminium powder in EDM oil results in appreciable reduction in TWR, %WR, SR of Hastelloy when machined with copper electrode. 5. TWR of copper electrode can be lowers down by reducing the size of suspended aluminium powder particles in EDM oil. 6. %WR varies inversely with the size of aluminium powder particles in EDM oil. 7. The surface finish of Hastelloy can be enhanced by reducing the size of aluminium powder up to certain particle size. Too small powder particles produce rough surfaces of Hastelloy.
Silicon Powder	Nimo Singh Khundrakpam, Harmeet Singh, Som Kumar and	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

	Gurinder Singh Brar[2014]				by performing confirmation runs. The variation in prediction errors for MRR was found within ±5.5%.
Silicon Powder	M. A. Razak, A. M. Abdul-Rani, and A. M. Nanimina[2014]	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.
Silicon Powder	Soumakant Padhee, Niharranjan Nayak, S K Panda, R Dhal and SS Mahapatra[2012]	Pulse on time, Duty cycle and 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 material removal rate.

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Table 2: Summary of Optimisation Technique Used in Improving & Optimisation Performance Measure of PMEDM

owder Type	**Author/Year**	**Response Variables**	**Dielectric Used**	**Optimization Technique Used**
Aluminium Powder	Shivam Goyal, Rakesh Kumar Singh[2014]	Machining Efficiency, Surface Finish	EDM Oil	Taguchi Method
Aluminium Powder	Khalid Hussain Syed, Kuppan Palaniyandi[2012]	MRR,EWR,SR,WLT	Water	Taguchi Method
Aluminium Powder	M. M. Jamadar, M.V. Kavade[2014]	MRR,TWR,SR,	IOPL Oil	Response Surface Methodology(RSM)
Aluminium Powder	Gurtej Singh, Paramjit Singh, Gaurav Tejpal, Baljinder Singh[2012]	Surface Roughness	EDM Oil	Taguchi Method
Aluminium Powder	Gurule N. B., Nandurkar K. N.[2012]	MRR	Kerosene	Taguchi Method

Aluminium Powder	Mohd. Junaid Mir, Khalid Sheikh, Balbir Singh and Navdeep Malhotra[2012]	Surface Roughness	Kerosene	Response Surface Methodology(RSM)
Aluminium Powder	Paramjit Singh, Anil Kumar, Naveen Beri, Vijay Kumar[2012]	MRR,TWR,SR,%WR	EDM Oil	-
Silicon Powder	Nimo Singh Khundrakpam, Harmeet Singh, Som Kumar and Gurinder Singh Brar[2014]	MRR	Kerosene	RSM
Silicon Powder	M. A. Razak, A. M. Abdul-Rani, and A. M. Nanimina[2014]	MRR,TWR,SF	Kerosene	-
Silicon Powder	Soumakant Padhee, Niharranjan Nayak, S K Panda, R Dhal and SS Mahapatra[2012]	MRR, Surface Finish	Kerosene	RSM

VI. CONCLUSION

- The material removal rate increased by mixing powder in the dielectric fluid as compared with conventional EDM process
- Tool wear rate in PMEDM is smaller as compared with the conventional EDM Process.
- Material removal rate is maximum effected by the increase of peak current.
- Material Removal Rate has been decreased by increasing the pulse off time.
- The optimum powder concentration and size of powder particles to achieve the highest efficiency of EDM process
- Higher peak currents produce more rough surfaces in EDM process
- Use of powder mix in electrolyte provide mirror like surface finish and increase in material removal rate. Proper work piece and powder combination must be used for better results.

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