Effect of aluminium and chromium powder mixed dielectric fluid on electrical discharge machining effectiveness

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ABSTRACT

This article studied the impacts of using different powders on the productivity of electro discharge machining (EDM) of Nimonic 80A alloy. The powders used for experiments are chromium (Cr) and aluminium (Al), though these powders are in contrasts in their thermo-physical characteristics. With the mixing of these powders in dielectric fluid, effect on surface roughness (SR), material removal rate (MRR), and mechanism of the machining process have been studied in this research work. On going through the results of experiments, it was observed that even volumetric proportion of powders, size of molecules, its density, electric resistance, and heat conductivity of additives were vital parameters that altogether influenced the productivity of powder mixed-electro discharge machining (PMEDM) process. With addition of proper ratio of powders in dielectric fluid, it enhanced the material removal rate, and consequently, reduced the surface roughness. Under a similar molecule volumetric proportion tests, the minutes suspended molecule size of powder prompted the largest material removal rate and consequently, the surface roughness increased. Conclusion is that adding chromium powder improves to the highest material removal rate, but poor surface finish while adding aluminium powder has the reverse effects.

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1. Introduction

Electrical discharge machining (EDM) has been an essential procedure for the die and tool making enterprises for a long time. This machining procedure is finding growing utilization in industries due to the feasibility of machining geometrically intricate shapes irrespective of the hardness of materials that are very tough by utilizing the traditional machining procedures [1]. In EDM, managed distinct electrical sparks between the electrode and the work-piece would produce arcing, i.e. concentration of spark when an excessive amount of scattered tiny material remains in the inter-electrode gap in light of the inability to clear scattered tiny material. Arcing occurs when a succession of sparks strikes more than once on a similar spot.

This, in the end, causes harm to the cathode of the apparatus and the work-piece if the controller of the machine does not stop it quickly. The EDM procedure in this manner ends up unsteady and ineffective. To enhance the effectiveness of ED machining, it is necessary to upgrade process steadiness. This presently remains a major tough task. Kiyak et al. [2] conducted experimental work on EDM with AISI P20 tool steel. They examined the impact of process factors on surface roughness (SR) in EDM and observed that littler values of ampere-current, pulse-on-duration and proportionately greater value of pulse-off-duration produced a descent surface
troubles are discussed intensively. Kalaman et al. concentration. At last in this paper, PMEDM research patterns, gaps, findings, and industrial portrayal that main factors which must be considered in PMEDM are powder size, type, and technology, and a relative survey of powder materials is additionally exhibited in this article to facilitate a deeper insight into powder selection parameters for future investigations. They also portrayed that main factors which must be considered in PMEDM are powder size, type, and concentration. At last in this paper, PMEDM research patterns, gaps, findings, and industrial troubles are discussed extensively. Kalaman et al. presented the study about the introduction and survey of the research work in PMEDM. The investigations concerning machining efficiency, surface integrity, and generation of functional surfaces are presented and discussed in the light of current research patterns. Attempts made to improve biocompatible surfaces with the utilization of the process additionally included clarifying the future patterns in PMEDM. Daneshmand et al. conducted the experiments on EDM with CK45 steel to examine the impacts of current, voltage, and pulse frequency on SR. In this test work, kerosene is utilized as dielectric fluid and copper as an electrode. Design of experiments with non-linear regression model was utilized to estimate the process response. Raju et al. carried out an extensive literature study to provide a total description on μ-EDM process, its necessities, execution and
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applications. The experiment frame-ups and its subsystems, trial studies and optimizing techniques, created micro feature and different applications are additionally described in this paper.

In spite of the favorable outcomes, the EDM procedure with added substances is not yet utilized broadly in industry. One of the essential reasons is that numerous key factors of the PMEDM procedure, incorporating the mechanism of machining with different added substances, which are not surely known. The complicated nature of this procedure, particularly from the impacts of the thermo-physical characteristic of added powders, subsequently, justifies the extra investigation. The objective of the article is to make a precise investigation of the impacts of powder properties in DF on the effectiveness of ED Machining with the end goal to improve the applicability of the procedure in the industry. The release-transivity, particularly, determines the frequency of sparking that controls the whole $MRR$, though the powder-particles striking impact has an insignificant cutting impact providing primarily to the enhancement of the $SF$.

2. Materials, methods and experimental set-up

This paper uses nomenclature given in Appendix A.

Nimonic 80A nickel-chromium alloy is widely utilized in several industries due to its resistance against to corrosion and high strength applications because of excellent mechanical properties at eminent temperature. PMEDM is an efficient process for machining hard-to-cut material like Nimonic 80A. The composition of Nimonic 80A is 19.82 % Cr, 2.59 % Ti, 1.57 % Al, 2.63 % Fe, and balance % Ni. The PMEDM frame-up contains the servo arrangement of ZNC EDM machine (ZNC 50 × 30, die sinking type, EMT ltd., India) is utilized to keep up the predetermined separation among the tool and work, whose width rely on the gap voltage. Total tests were conducted on this frame-up with Nimonic 80A as a work-piece and bronze as an anode. For this reason, an independent fitting has been planned and created within the EDM tank; a different acrylic tank having the capacity of 36 liters of DF was settled on the EDM table with bolts. The different stirrer and pump arrangement are settled in the acrylic tank. The stirrer and pump arrangement is utilized for proper mixing and circulation of powder blended dielectric liquid in the inter-electrode gap. The schematic diagram of this frame-up is displayed in Fig. 1.

Table 1 displays the EDM process factors. The thermal characteristics of aluminium, and chromium powder molecules are depicted in Table 2. Fig. 2(a) displays the mechanism of machining in PMEDM process and the occurrence of series discharge in PMEDM process is depicted in Fig. 2(b).
In these experiments, the levels of input parameters have been selected after the conduction of pilot experiments. The MRR, GS, and SR have been measured as the responses in this experimental work. We conducted the various experiments on PMEDM setup and made the graphs between the input variables and the output responses. From these graph, conclusions were drawn.

3. Results and discussion

3.1 Impacts of powder properties on gap size

Fig. 3 displays the effect of mixing of Al and Cr powder particles in the DF on the GS. It was observed that the gap among the anode and cathode with Al powder is marginally more when contrasted with the Cr powder blended dielectric liquid was found attributable to its littler electrical-resistivity. This littlest GS would be accountable for extreme gas blast pressure with Cr powder. Furthermore, the Cr powder density is greater than the Al powder density, resulting in arcing rather sparking. Consequently, SR is higher with Cr when contrasted with Al powder. Al powder delivered the better SF trailed by Cr powder.
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Fig. 3: The impact of mixing of Al, and Cr powders particle on the gap size \( (I = 5 \, \text{A}, \, DC = 0.67, \) Volumetric proportion = 0.60 cm\(^3\)/l)

3.2 Impacts of powder particle size on material removal rate

Fig. 4 demonstrates the impact of two Al powder-molecule sizes at different volumetric proportions on MRR. It was seen that the appropriate mixing of powder-particles improves the machining productivity by additional settling of the electric-release. The enhancement in process durability occurred due to the fairly larger GS in inter-electrode gap. The outcomes additionally disclosed that the rise in the size of the powder particle resulted in a decrease in the enhancement of the MRR. This can be ascribed to both lesser electrical power density and a more probability of anomalous release.

Moreover, when the size of the molecule was more than the spark-gap (about 06-55 μm), the efficiency of machining evidently decayed. The MRR outcomes for the minimal size of the molecule (80-90 nm) at different volumetric proportions of powder particles were even more than those with (15-20 μm) molecule size of powder particles. This is happened due to the existence of less spark gap among the electrodes. For the current at 5 A, and volumetric proportion of molecule more than 0.60 cm\(^3\)/l, demonstrated a notable falling trend in MRR. This was because of the joined impacts of lower electrical-density, the lesser striking of powder particles, unevenly distribution of particles, and very low growth in the release-transitivity.

Fig. 4: The impact of particle size and volumetric proportion of aluminium powders on MRR \((T_{on} = 30 \, \mu\text{s}, \, DC = 0.67)\)

Fig. 5: The impact of \(T_{on}\) and volumetric proportion of 80-90 nm aluminium powders molecule on MRR \((DC = 0.67)\)
Fig. 6: The impact of $T_{on}$ and volumetric proportion of 15-20 μm aluminium powders molecule on $MRR$ ($DC = 0.67$)

### 3.3 Impacts of molecule concentration on material removal rate

Fig. 4 additionally demonstrates that $MRR$ was affected by the volumetric proportion of aluminium powders. The reasonable distinction in $MRR$ is observed for the current at a higher level because of the generation of more spark energy as displayed in Figs. 4, 5, and 6. It was also observed from Fig. 4 that the highest $MRR$ is obtained at 5 A current, 0.6 cm$^3$/l of Al powders, $T_{on} = 30 \mu$s, and molecules sizes under 95 nm. This demonstrates that an ideal spark gap was acquired at this setting of the volumetric proportion of powder and $T_{on}$, which delivered the optimum factors setting of power density, striking of molecule and release-transitivity in the EDM procedure.

Figs. 5 and 6 demonstrate that the impacts of the volumetric proportion of molecule of 80-90 nm and 15-20 μm aluminium powders particle fluctuated along with the $T_{on}$. At the lesser $T_{on}$ of 5 μs, 0.6 cm$^3$/l provide the good $MRR$, trailed by 1.2 cm$^3$/l, and with 0.30 cm$^3$/l being the inferior. Though, it may be found in Fig. 6 that at the 5.0 A current, when the $T_{on}$ was raised to 30 μs, the impacts began to alter with 15-20 μm aluminium powders particle. The volumetric concentration of 0.6 cm$^3$/l still delivered the good $MRR$, however, 0.30 cm$^3$/l was superior as compared to 1.2 cm$^3$/l. This pattern proceeded with the rise in the $T_{on}$. When the time was raised to 80 μs, 0.30 cm$^3$/l exceed 1.2 cm$^3$/l in $MRR$ outcomes for both 80-90 nm, and 15-20 μm aluminium powders particle. This was because of extra warming impacts due to the rising the $T_{on}$. More evacuated molten materials were consequently produced that in the long run decreased the performance of the volumetric proportion of 1.2 cm$^3$/l in improving the procedure steadiness.

The purpose behind the primary outcomes with 15-20 μm aluminium powders particle was believed to be because of the bigger molecule size and its impacts. It demonstrated that the bigger molecule size of added substances among the spark gap was increasingly delicate to evacuate the tiny work materials production.

### 3.4 Impacts of molecule characteristics on material removal rate

Fig. 7 demonstrates the impacts of two volumetric proportions of Al, and Cr powders particle on the $MRR$. The test outcomes demonstrated that chromium generated the best $MRR$, and aluminium the least when the volumetric proportion of powder was $< 1.2$ cm$^3$/l and $I = 5.0$ A. At the point, when the ampere-current was at 2.0 A, the distinction in $MRR$ turned out to be little because of the less input of energy. Fig. 3 demonstrates that the spark gap for chromium is lesser than that for aluminium as clarified already. In principle, there was a somewhat higher power density and gas explosion pressure for chromium.

Moreover, chromium powder density is double than the aluminium powder, ensuing in a powerful powder-particle collision. Additionally, the heat conductivity of aluminium powder is about 3 times bigger as compared to chromium powder, which showed that more energy is taken out by the aluminium powder blended dielectric liquid. Subsequently, Cr created the biggest $MRR$. 

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**Figures and Diagrams:**
- **Fig. 6:** Graph showing the impact of $T_{on}$ and volumetric proportion of 15-20 μm aluminium powders molecule on $MRR$ ($DC = 0.67$).
- **Fig. 7:** Graph demonstrating the impacts of two volumetric proportions of Al, and Cr powders particle on the $MRR$. The test outcomes demonstrated that chromium generated the best $MRR$, and aluminium the least when the volumetric proportion of powder was $< 1.2$ cm$^3$/l and $I = 5.0$ A.
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Fig. 7: The impact of ampere-current and volumetric proportion of 15-20 μm aluminium and chromium powders molecule on MRR (DC = 0.67, Ton = 30 μs)

3.5 Effects of particle size on surface roughness

Fig. 8 demonstrates the impacts of two aluminium and chromium powder molecule sizes with different volumetric proportions on SR. The best sorts of powders for upgrading the smoothness of the surface are Al, Cr etc. Aluminium powder-particle creates a good surface for all the molecule proportions. It is predominantly because of the joined impacts of small electrical-resistivity, adequate thermal-conductivity, and less-density of aluminium. Less electrical-resistivity makes a high spark gap, good thermal-conductivity removes more heat, and less-density avoid the arcing among the electrodes. These impacts jointly lead to less density of electrical spark bringing the low gas blast, in this way just shallow holes are created on the machined surface. Al powder produced the best surface finish followed by the Cr powder. The best surface finish is obtained at the volumetric proportion of 1.2 cm³/l of aluminium powder with 15-20 μm particle size.

Fig. 8: The impact of particle-size and volumetric proportion of Al powders molecule on SR (DC = 0.67, Ton = 30 μs)

3.6 Effects of particle concentration on surface roughness

As appeared in Fig. 9, it was seen that at the 5 A current, the aluminium powder volumetric proportion of molecule has built a major effect in SR due to the bigger MR. It was noticed that the biggest molecule volumetric proportion of 1.20 cm³/l provide the worst SF at Ton = 80 μs due to

Fig. 9: The impact of Ton and volumetric proportion of 80-90 nm aluminium powders molecule on SR (DC = 0.67, I = 5 A)
its highest release transitivity. It is also noted from Fig. 9 that the volumetric proportion of powder molecule was not the main parameter controlling the SR in the EDM procedure. Alternately, $T_{on}$ seemed by all account, to be the most vital parameter.

### 3.7 Impacts of molecule characteristics on surface roughness

Fig. 10 demonstrates the impact of seven molecule volumetric proportion levels of aluminium, and chromium powder-particles on the SR. It was seen that aluminium powder produced the good $SF$ than the chromium powder particle for both the 2 A as well as at 5 A current. This happens because the evacuation of more molten material from work surface in presence of Cr powder as compared to the presence of Al powder in DF. Subsequently, Cr generated the biggest SR.

Moreover, chromium powder density is double than the aluminium powder, ensuing in a powerful powder-particle collision and result in arcing. Additionally, the heat conductivity of aluminium powder is about 3 times bigger as compared to chromium powder, which showed that more energy is taken out by the aluminium powder blended dielectric liquid.

![Fig. 10: The impact of ampere-current and volumetric proportion of 15-20 μm aluminium, and chromium powders molecule on SR ($DC = 0.67$, and $T_{on} = 30 \mu s$)](image)

### 4. Conclusions

In view of the test outcomes, the following conclusions are drawn:

- The molecule size, volumetric proportion of powders, its density, electrical-resistivity, and thermal-conductivity are the significant attributes of powders influencing performance of ED Machining process.
- Due to the inclusion of powder particle in DF, the gap for spark was increased.
- Spark gap varies with the mixing of powders of various sizes in the dielectric fluid. Spark gap increases with increasing size of powder molecules. The minimum rise in the gap is produced with a size of 80-90 nm powders and with 15-20 μm generating the highest gap.
- Highest $MRR$ was observed with powders of size 80-90 nm and with 15-20 μm generating the smallest. For the $SF$, the opposite pattern is noticed.
- Higher spark gap was observed by adding aluminium powder particles followed by using chromium powder.
- Best $MRR$ was observed with adding chromium followed by aluminium powder. For $SF$, the opposite pattern was noticed.
- The volumetric proportion on mixing the powder with the dielectric fluid in the ratio of 0.6 cm$^3$/l gives best $MRR$ outcomes.
- With 2 A, and 5 A current, results are quite higher than the impact of molecule size, volumetric proportion of powder, and other factors.
- The $MRR$ and $SR$ vary with different combination of molecule sizes, volumetric proportions of Al, and Cr powders in dielectric fluid in PMEDM process.
- Experiments can be conducted by using different combination of materials, dielectric fluids, and also various powders to get different findings in the PMEDM process.
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References


Appendix A

The following nomenclature is used in the paper:

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\begin{align*}
AWLT & \quad \text{Average white layer thickness} \\
DC & \quad \text{Duty cycle} \\
DF & \quad \text{Dielectric fluid} \\
DRR & \quad \text{Debris removal rate} \\
EDDSG & \quad \text{Electro discharge diamond surface grinding} \\
EDM & \quad \text{Electrical discharge machining} \\
GRA & \quad \text{Grey relational analysis} \\
GS & \quad \text{Gap size} \\
I & \quad \text{Current (A)} \\
MR & \quad \text{Machining rate} \\
MRD & \quad \text{Material removal depth} \\
MRR & \quad \text{Material removal rate (mm}^3/\text{min)} \\
MS EDM & \quad \text{Micro-slit EDM} \\
PMEDM & \quad \text{Powder mixed electrical discharge machining} \\
R_a & \quad \text{Average roughness of surface (µm)} \\
SF & \quad \text{Surface finish} \\
SR & \quad \text{Surface roughness} \\
TM & \quad \text{Taguchi method} \\
T_{on} & \quad \text{Pulse on-time (µs)} \\
WEDM & \quad \text{Wire electrical discharge machining} \\
WLT & \quad \text{White layer thickness}
\end{align*}
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