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Experimental investigation on powder mixed Micro-Electric Discharge Machining of Inconel- 718

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Abstract

Micro- Electric Discharge Machining (μ- EDM) is an energy-based non- traditional machining methods, ability to machine of any electrically conductive materials, building one of ideal methodologies for micro- production/manufacturing. Building micro-components of high precision on hard to machine material is beyond the competence of conventional twist drill due to little thermal conductivity. Inconel 718 super-alloy has high strength at preeminent temperature, it is used to manufacture aerospace parts. It is an extremely hard to machine work due to its work hardening nature and high poor thermal conductivities. The present experiment, calibrate the effect of abrasive particles on Micro- EDM of Inconel- 718 (Nickel based super alloy) with tool Tungsten Carbide (WC) using Response Surface Methodology (RSM). Experiments is carried out on face center cubic design (FCC) in RSM design of experiment with the consideration of abrasive particles as a one of the parameters. The machining parameters for experimental design are pulse peak current, Pulse on Time and abrasive particle, each varying at three level. The response obtained are material removal rate (MRR). The mathematical model was develop to predict the MRR by RSM method and ANOVA has been used to verify the significance of MRR for the machining processes. The Experimental values reflects that the higher the value of currents with mixing of abrasive particles leads to material removal rate as compared to the lower one. Use of abrasive particles (Particles size is 0.004 mm) added and stirred in the dielectric fluids (Powders concentration is 6 g/L) was found to be advantageous in micro- EDM to improved MRR, reduced electrode wear, higher surface finishing, and reduced degree to surface cracking.

Key words: Powder mixed Micro EDM; Inconel Alloy; ANOVA; Material removal rate.

1. INTRODUCTION

Nickel-based super-alloys are unique combinations like high strength, strong corrosion resistance, excellent thermal fatigues properties, high toughness, and virtuous thermal stability. Inconel-718 is the important super-alloy of the group and more than 50% weight of a jet engine is made by using it [1, 2]. It's broadly used in high load high temperature, high corrosion resistant environment [3]. Many machineries like turbine blade and disk, compressor blade and other components made of Inconel-718 in the aviation industries. Micro- EDM, enhancement in nontraditional machining processes to enhance the machining performance like MRR, TWR, precision, adequate surface finish and productivity. Inconel 718 is used in the aviation, automobile, defense industries and biomedical application because its toughness, work hardening, high strength and corrosion properties [4]. By the contrary to conventional machining processes, the non-traditional methods like Micro- EDM is somewhat more beneficial to machine Inconel alloy. There has been various researchers work on the conventional powder mixed micro EDM by the intension of enhancing the MRR, TWR and surface finish, one of them Jahaan et al. [5] probed the feasibility of refining surface roughness cemented tungsten carbide using graphite mixed (powder) dielectric for die sinking milling micro-EDM. It is found that the presence of graphite powder improves the surface roughness, increases the MRR and reduces the TWR. Crater distribution and surface profile is improved by increased in spark gap with uniform discharging of powder mixed dielectric. The mixed powder lower breakdown strength, ease the ignition process which improve the MRR. Amid these two processes powder mixed milling micro-machining is found to be better smoother and defects free surfaces compare to sinking micro-EDM. The optimum concentration at 0.21 g/L is found for surface roughness. There are many experiments performed on the micro-EDM with the mixing of abrasive particles in the dielectric fluids. Erden Bilgin [6] have investigated of mixing of powdered of copper, aluminium, iron and carbons into commercial kerosene oil as impurities for

EDM of steel. The results designated, added of powder improve the breakdown characteristics of dielectric fluids and machining rate. By looking the rsurlts on different material with addition of graphite particles on researchers Jeswani [7] studied with graphite powders into kerosene-oil at concentrations of 4 g/L for the EDM of steel and stated that the inter-space for electric discharge initiation is increased while breakdown voltage was lowered. An enhancement in machining processes strength resulted in more than 60% increases in material removal rate and apx 28% reduction in electrode wear ratio. Anil Kumar [8] presented about the mechanisms of A-EDM processes, and reviewed research papers in the areas of A-EDM. Powder addition in electric medium lower dielectric strengths and it leads to increase starting of sparking process with stability of the process. Machining performance and surface characteristics predisposed by powder type, shape, size, thermal properties and concentrations of powder. Kumar Anil [9] examined the effect of Al powder mixed in electrical discharge machining process by Inconel alloys. The result shows that size of particles and its concentrations has significant effect in additive mixed EDM process. It was create that major developments in material removal rate, surface finish and decline in tool wear using medium mesh size 325 Al additive powder. Prabhu [10] was found the migration of material as of graphite powders, electrode and dielectric to machined surfaces. Pecaas et al. [11] related the machining performance of traditional EDM, powder mixed dielectric- EDM process. The use of powder mixed EDM conditions indorses the reduction of surface roughness, crater depth, crater diameter, and white-layer thickness. A variety of surveys has been carried out by many researchers for improving the MRR, TWR and surface roughness of the micro EDM processes [12–17]. However, narrow research has been found on the powder (abrasive) mixed micro-EDM process and no study was stated in Silicon carbide and graphene oxide powder mixed Micro- EDM process, especially machining performances such as MRR.

2. OBJECTIVE OF PRESENT WORK

In the experiment, an attempt has been made to assess the experimental investigation on Inconel- 718 (Nickel based super alloy) for micro- EDM using silicon carbide and graphene oxide abrasive-mixed dielectric. The Machinability was evaluated the purview of process-performance indicators including material removal rate (MRR) and surface morphology (SR). The present experiment, validates the relation between the micro-EDM parameters viz. Pulse peak current (Ip), pulse- on time (Ton) and abrasive particles (concentration of abrasive particles, 6g/L) on MRR. In surface morphology detailed analysis on quantitative metallurgical aspects of the machined surfaces containing crystallite size and micro strain are obtained.

3. EXPERIMENTAL DETAILS

Inconel 718 (Nickel based super- alloy) is used as work material, round shape bar of diameter 38 mm and thickness of 10mm. Physical properties and Chemical composition of Inconel- 718 shown in Table 1 and 2.

Table 1: Property of a material (Inconel- 718)

[Property]	**[Values]**
Density (ρ)	8.20 g/cc
Specific gravity (G)	8.20
Tensile strength at 23°C	1374 MPa
Tensile strength at strain 0.2%	1110 MPa
Melting point	1259–1337°C
Specific heat capacity (E)	0.436 J/g°C
Thermal conductivity (k)	11.5W/m_K

Table: 2 Chemical compositions of Inconel- 718

[Element's]	**[%, By weight]**
Nickel	50–56
Chromium	17–20
Iron	Balanced
Molybdenum	2.8–3.4
Niobium	4.75–5.6
Cobalt	1.0
Manganese	0.34
Copper	0.2–0.7
Aluminum	0.65–1.14
Titanium	0.3
Silicon	0.34
Carbon	0.09
Sulphur	0.016
Phosphorus	0.016
Boron	0.007

Conventional EDM- oil is used for dielectric medium with addition of abrasive particle. Tungsten Carbide (WC) electrode of 600 μm diameter cylindrical rod is used a tool material (Figure 1 & 2).

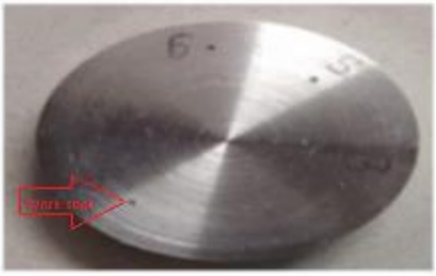

Figure 1: Work material

Figure 2: Tool material

For execution of abrasive mixed micro-EDM, a particularly designed- setup was arranged (Figure 3). In adding to the present micro-EDM set-up, a stirrers (Copper Motor 6001F, 221 V, 50 Hz, 15 W, From Kolkata, India), and a nozzle were used. Micro- EDM operation was conducted by using graphene oxide and silicon carbide powder added to the EDM oil as dielectrics.

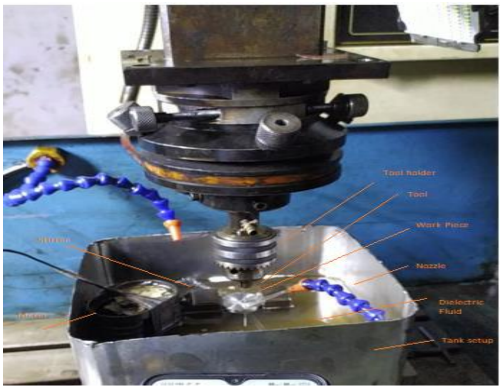

Figure 3: Experimental setup with accessories for micro- EDM

Response surface- methodology (RSM), statistical technique is used to perform the experiments, examining the effect of parameter on the responses and optimization of parameter. This technique is use to find the relationships between input and output parameters which are characterized by 2D or 3D surfaces. Response surface methodology based on Face Centered (FCC) design is applied to perform experimental runs and for modelling of Micro- machining with and without abrasive particles. The advanced mathematical model may be used to predict the material removal rate (MWR). In power mixed micro- EDM, for the proper circulation of the powder in the fluid stirrer is kept in the container tank. The abrasive mixing concentration selected here is based on review as well as trial experiments. From published research work, it is found that satisfactory performance above the conventional micro- EDM is achieved using powder concentration of 0–10 g/L [18-19]. The present experiment, authenticates the relation between the micro- EDM parameters viz. Pulse peak current (Ip), pulse- on time (Ton) and abrasive particles (concentration of abrasive particles, 6g/L) on MRR with and without mixing of abrasive particle in the dielectric fluids. Inconel- 718 (Nickel based alloy) was chosen to be the work piece material while the tool selected was Tungsten Carbide (WC). The experiments are conducted on DT- 110 micro- EDM (machine) with accuracy of 0.1µm. Input parameter with their levels for the experiments are shown in Table 3. On the basis of experimental design using RSM (FCC) twenty different runs are obtained. Material removal specific performance is calculated by equation number 1.

MRR = Volume of Materials Removed / Operation Time ……… (1)

Table 3. Input parameters with their Levels

Variables	**Notation**	**Level**		
		-1	0	1
Pulse Peak- Current (Amp)	A	2	4	6
Pulse on Time. (µs)	B	20	30	40
Abrasive Particles*	C	1	2	3

* Represents the concentration of abrasive particles, 6g/L (1: Without abrasive particles; 2: With silicon carbide abrasive particles; 3: with silicon carbide and Graphene oxide)

4. RESULTS AND DISCUSSION

The experimental result of machining response (MRR) in the Micro-EDM, with and with-out abrasive particles are represented in (Table 4).The accuracy of the model can be authenticated by the graphical investigation. Residual plot (Figure 4) for MRR are reflects the all error are customarily distributed and the points of data is lying in the inclined line and no- outline are founds. There are no mistakes due to time and data collections because residual collection shows proper line. From the figure of residual versus experimental it is found that errors scattered and that is independent.

Table 4. Experimental result (MRR)

{Runs}	{A}	{B}	{C}	{Micro-EDM}
	Pulse peak-Current (Amp)	Pulse on Time (µS)	Abrasive Particles (Con: 6g/L)	Material Removal Rate (mm^3/min)
1	4	30	3	0.0353
2	2	40	1	0.0291
3	4	30	2	0.0341
4	4	30	2	0.0337
5	4	20	2	0.0297
6	4	30	2	0.0351
7	6	20	1	0.0293
8	2	30	2	0.0273
9	6	30	2	0.0412
10	4	30	2	0.0283
11	2	40	3	0.0367
12	6	20	3	0.0421
13	6	40	1	0.0386
14	2	20	1	0.0291
15	6	40	3	0.0413
16	4	30	2	0.0271
17	4	30	1	0.0267
18	2	20	3	0.0253
19	4	30	2	0.0289
20	4	40	2	0.0279

Residual versus predicted value shows the, there are no unusual structures therefore model is correct. Therefore from the model we can say that this shows in goods fit with the experimental value. Values of p (With ANOVA) lower than the 0.05 shows that the model is significant (Table: 4). quadratic model for MRR with and without abrasive particles are presented in ANOVA

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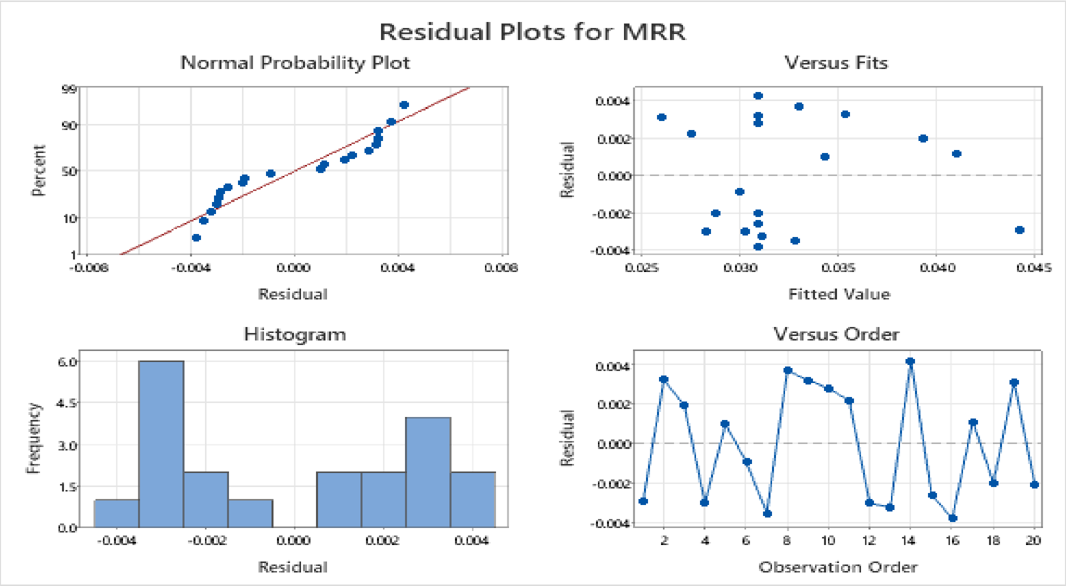

Figure 4: Residual plot (MRR)

Table 5. ANOVA (MRR)

{Source}	**{DF}**	**{Adj SS}**	**{Adj MS}**	**{F-Value}**	**{P-Value}**
Model	9	0.000393	0.000044	2.74	0.066
Linear	3	0.000313	0.000104	6.54	0.010
[A]	1	0.000202	0.000202	12.70	0.005
[B]	1	0.000033	0.000033	2.05	0.182
[C]	1	0.000078	0.000078	4.88	0.052
Square	3	0.000062	0.000021	1.29	0.330
[A*A] Ip*Ip	1	0.000041	0.000041	2.60	0.138
[B*B] Ton*Ton	1	0.000007	0.000007	0.42	0.530

[C*C] Abrasive2	1	0.000001	0.000001	0.07	0.798
2-Way Interaction	3	0.000018	0.000006	0.38	0.767
[A*B] Ip*Ton	1	0.000001	0.000001	0.07	0.803
[A*C] Ip*Abrasive	1	0.000017	0.000017	1.07	0.325
[B*C] Ton*Abrasive	1	0.000000	0.000000	0.01	0.911
Error	10	0.000160	0.000016		
Lack-of-Fit	5	0.000099	0.000020	1.64	0.300
Pure Error	5	0.000060	0.000012		
Total	19	0.000553			

The regression equations are used for the MRR are shown in the equation with a coded unit.

MRR	=	0.03087 + 0.00450 A + 0.00181 B + 0.00279 C + 0.00388 A*A - 0.00157 B*B + 0.00063 C*C- 0.00036 A*B + 0.00146 A*C + 0.00016 B*C

Analysis of Material Removal Rate:

The main factors which effected in material removal are current, pulse on time which is reflecting in the ANOVA (table 5), found that the current gives more effect on removal of materials as compared to the other factors. The pulse on- time and abrasive particles have significances effects on the material removal.

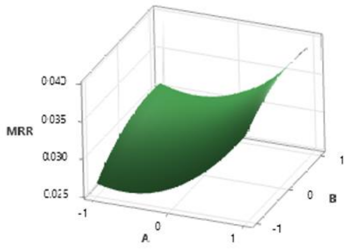

Figure 5: 3-D surface response on MRR (A & B)

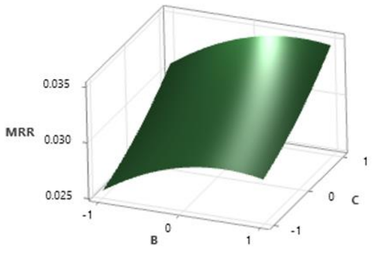

Figure 6: 3-D surface response on MRR (B & C)

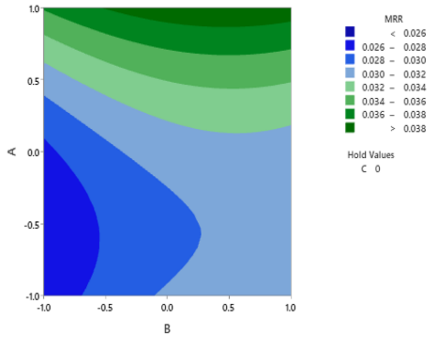

Figure 7: Contour plot of TWR (A & B)

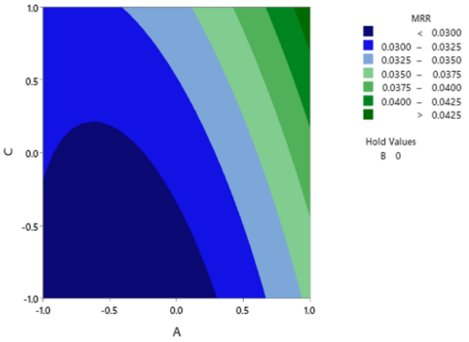

Figure 8: Contour plot of TWR (C & A)

From the figures 5 & 7 it has been inferred that there are considerable improvement to maximize the material removals rate while increasing the current i.e. a considerable range for currents may be select whereas the mixing of abrasive particles are also leading to the maximum wear. The factors performance plots in figure 9 & 10 reflects the values of different ranges of the parameters which indicate the current and the mixing of abrasive particles are the leading factors in the electrode wear. The optimum value we obtained at the current 6 Amp, pulse on time 20 µs and with abrasive particles which is also validated by the graph obtained.

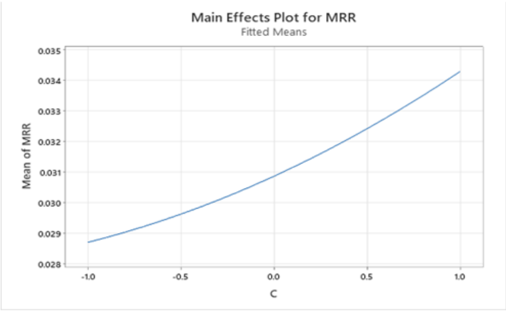

Figure 9: Factors performance plot for TWR (C)

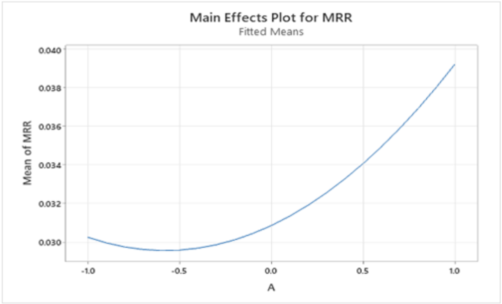

Figure 10: Factors performance plot for TWR (A)

The addition of abrasive particles leads to efficient removal of molten drops therefore enhancing the material removal rate. The higher MRR is found at Current of 6A, pulse- on- time of 20µs and at the mixing of both silicon carbide and graphene oxide. The experimental result was validated by confirming test based on optimal machining conditions. The experimental data are fitted with the predicted values.

Table 6. Optimum machining condition for abrasive abetted micro-EDM

{Response}	{Goal}	{Desirability}	{Optimum values}			{Predicted Values}	{Actual values}
			A	B	C		
MRR	Max	0.981	6	20	3	0.0429	0.0421

Surface Morphology:

Process performance may be estimated by surface morphology of the end product. Surface integrity contains surface morphology and topographical feature. Surface irregularities like crater morphology, melted material deposition, globules debris, spherical deposition, cracks, chimneys, and white layer, etc. describe the surface integrity. Hence, the study of surface morphology is indeed vital to assess quality of machining product. Surface morphologies of the machined specimen was examined by means of SEM micrographs of micro- EDMed work surface of the material Inconel- 718, silicon carbide and graphene oxide mixed micro- EDM at Ip= 6A (Figure 11. silicon carbide and graphene oxide powders (due to their conductivity) carried certain amount of heat gone from the machined zone, the degree of thermal stress settled at the machined surface was rather less in magnitude. This compact the degree of severity of surface cracking.

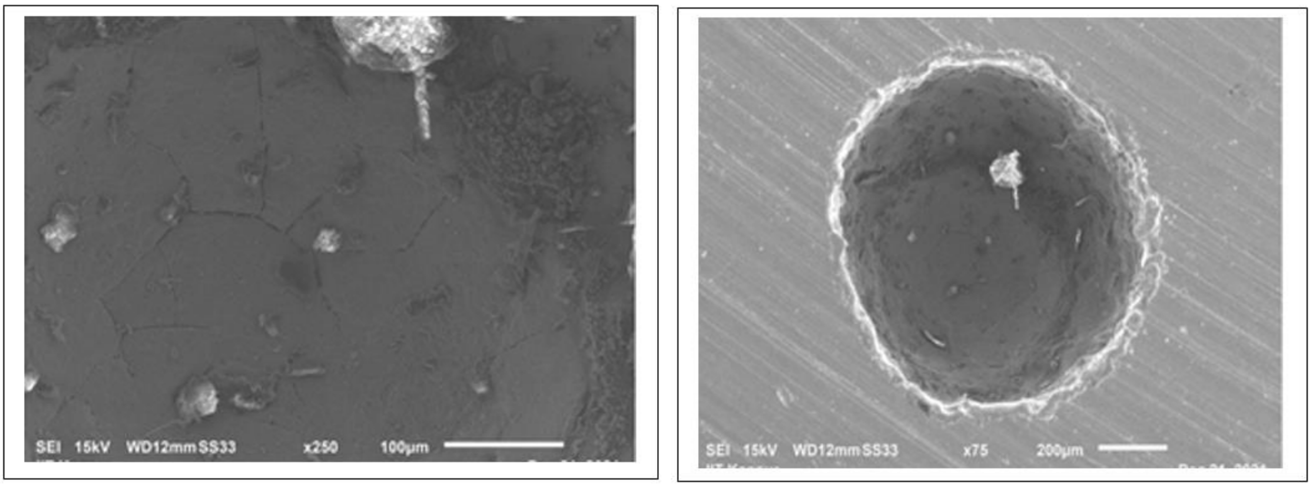

Figure 11: SEM micrographs of the micro-EDM work surface Inconel 718 obtained in silicon carbide and graphene oxide mixed micro- EDM at Ip= 6A

On the contrary, the machined surface got through micro- EDM indicated the existence of white layer, existence of discharge sparks in series enhanced the material removal rate in the case of powder mixed machining. The process hence generated extra debris from the work surfaces. Movement of debris may somewhat be limited due to the presence of nearby agglomerated powder material within the dielectric fluid. Due to unproductive flushing, debris got stuck onto the machined surface forming deeper white layer (Figure 12).

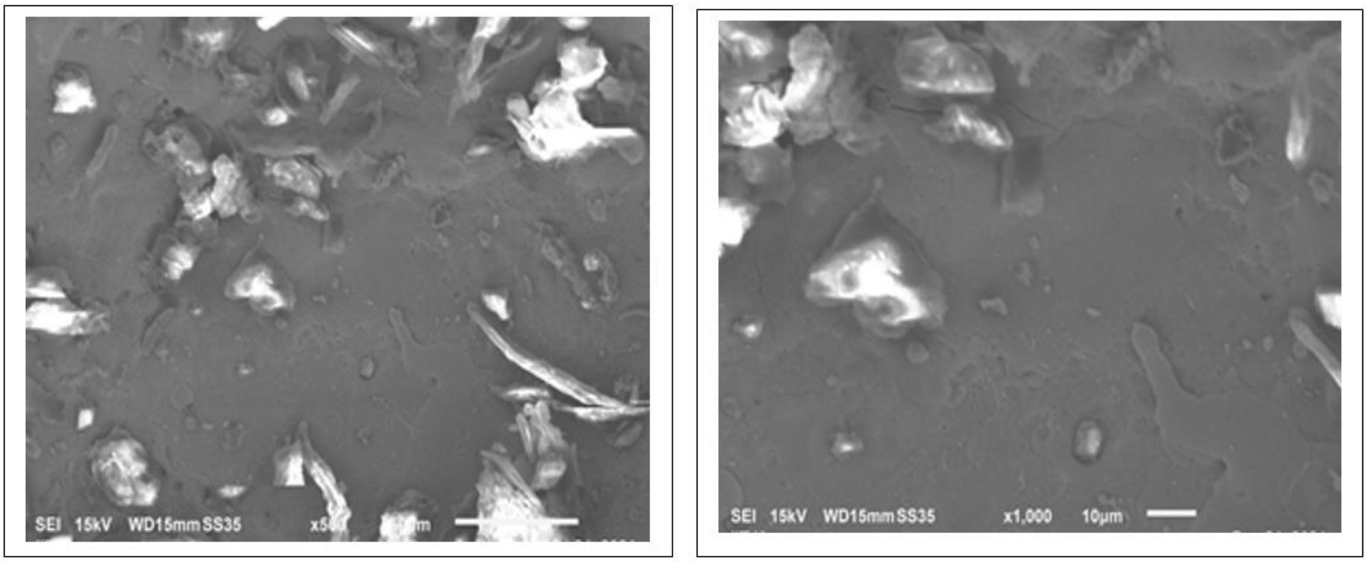

Figure 12: SEM- micrographs (existence of white layer on the top of the machined surface) obtained in silicon carbide and graphene oxide mixed micro- EDM at Ip= 6A

5. CONCLUSION

The conclusions drawn from the above-mentioned work may be brief as below:

1. Use of abrasive particles (Particles size is 0.004 mm) added and stirred in the dielectric fluids (Powders concentration is 6 g/L) was found to be advantageous in micro- EDM to improved MRR, reduced electrode wear, higher surface finishing, and reduced degree to surface cracking.
2. Based on RSM models, CCD optimization has been carried out to find the optimal values of micro-EDM process parameters to achieve maximum MRR. The optimal parametric setting for the micro-EDM process parameters during machining of Inconel alloy has been obtained at 6A.
3. Maximum enhancement in MRR was observed (Apx. 13.08%) at 6 A in the micro- EDM.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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