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Experimental Investigation of Nano Powders Influence in NPMEDM of Inconel 800 with Silver Coated Electrolytic Copper Electrode

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Abstract

Objectives: To optimize the Material Removal Rate, Surface Rougness and Tool Wear Rate in Powder Mixed Electrical Discharge Machining (PMEDM) of Incony 800 and to prepare parameter chart card for the Manufacturer to choose required parameter based on the job requirements and cost estimation etc. **Methods/Analysis:** The purpose of powder mix in a dielectric is to improve the machining performance, in which the powder material's, size, concentration and its base fluids are greatly influenced in machining performance. Hence this research is focused on study the influence of Nano-Powders with selected concentration in PMEDM of Incony 800 with silver coated electrolyte copper electrode. so the Taguchi full factorial Design is employed for the Nano-Powders of Aluminum, silicon and Multi-Wall Carbon Nano Tubes and No Powder mixed condition (conventional dielectric) were considered for investigation **Findings:** The Powder mixed electrical discharge machining (PMEDM) is mostly encounter choice in machining hard material to obtain a superior finish with accurately. The Nano-powder of Multi-Wall Carbon Nano Tubes (MWCNTs) outperforms than other Nano-Powders. The results were compared to conventional EDM and Nano-Power Mixed EDM (NPMEDM). The NPMEDM reduced the Tool Wear Rate (TWR) average percentage of 11.91%, 20.72% and 31.71%, the percentage of surface roughness reduction are 9.58%, 22.00% and 28.93% and the material removal rate improvement are 17.70%, 31.62% and 47.03% than Conventional EDM by Aluminum NPMEDM, Silicon NPMEDM and MWCNTs NPMEDM respectively. **Application/Improvement:** The study is unique by using nanopowders of MWCNTs, Al, Si mixed in Kerosine and servotherm oil enriched dielectric fluid for machining Nickel based super alloy like Incony 800. Here the EDM and PMEDM performances were evaluated experimentally and compared. No statistical and approximation were used. The unique approach of preparation of parameter card was introduced.

Keywords: EDM, Material Removal Rate, NPMEDM, Nanopowders, Surface Roughness, Tool Wear Rate

1. Introduction

The Modern method of machining hard material is Powder mixed EDM. The purpose of powder in dielectric is improving MRR and surface finish by speeding up eventually spread sparking by causing early blast at gap and inducing series of discharges at below the electrode. Many investigations were reported in the literature in PMEDM but this research is unique. The mix of graphite powder 4g/l with kerosene improved 60% of MRR and reduced 15% of TWR[1]. The good thermal conductivity, reduced white layer formation and absorb heal as well were observed by use of single wall CNT powder in AISI D2 Steel machining[2]. In[3] considered chromium power. Nano sized powder of SiC and Al_2O_3 improved the surface finish by 14% and 24% average surface roughness reduction respectively. The machined surface was free from micro crack.

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Inconel series are Nickel based super alloys, which are preferred for high pressure and high temperature purpose like gas turbines, electric power generation equipment, nuclear reactors, high temperature chemical vessels and electric power generation equipment4. The Incony 800 has highly abrasive and carbide particles, low thermal diffusivity high thermal strength and high hardness. But the material which has high tendency to form built–up edge, weld with tool material are very difficult-to-machine5. Alternatively, such materials are machined in non-traditional machining methods like Electrical Discharge Machining (EDM), Electro Chemical Machining (ECM), Laser beam Machining (LBM) and Abrasive water jet machining (AJM). Apart from this a manufacture demand parameter setting card like paint shade card to choose required colour. Because the manufacturer lists some Practical problems in implementing approximation formulas and one-time result. The parameter setting card is a multipurpose and provides decision on Surface Finish, MRR and TWR for Inconel 800 jobs. The manufacturer can use the same for estimating time, cost, consumables etc. Hence this research not only studies the influence of Nano-Powders in NPMEDM inconel 800 but also prepare parameter setting card. In 6 reported that addition of Al powder increases MRR when polarity is reversed. The grain size of the powder is directly proportional to MRR. In 7 used SiO_2 powders for machining EN-8 steel and investigated the influence of it concentration for optimizing the SR. The concentration levels varied from 0 to 8 g/l but the dielectric without SiO2 powder mix gives minimum SR as 1.9 μm and roughness increases with increase of powder concentration. In 8 investigated effects of Graphite powder concentration in machining Ti-6Al-4V. The Graphite powder concentration varied from 4.5 to 13.5. Up to 9 g/l powder concentration the surface finish improved then it decreases of concentration. In 9 investigations was Tungsten Powder in Dielectric in machining EN 24 steel, and reported that by increasing Powder Concentration from 0 to 4 g/l Powder Concentration, mean of the means of MRR is increased by 90.78%. In 10 used Aluminum Powder concentration variation for 0 g/l to 2g/l with kerosene in the machining of Al/SiC composites and found that in lower at 2A peak current, the MRR improved up to certain limit with increase of Al powder concentration. In investigated EN-8 steel machining in Chromium Powder mixed EDM with the concentration range from 2 g/l to 6 g/l. The increase of concentration improves MRR up to a limit after that the TWR increased. In 11 studied the influence of Al, Gr and SiC powder mix in machining W20, W30 and W40 grades Tungsten Carbide with predefined concentration of 4, 8 and 12g/l respectively powder separately. The authors reported that the maximum MRR gained at 8 g/l of SiC powder with Flushing pressure 1.5 Kg/cm^2. In 12 investigated the effect of Al, Cr, Cu and SiC powders on PMEDM in machining SKD-11 and reported that the highest MRR obtained while used smallest particle size. Hence, in this research, we used Nono sized particles as a very fine powder for and about to 5 mm in size were used; hence the process is Nano Powder Mix Electric Discharge Machining (NPMEDM). That is this paper deals about NPMEDM, in which about 5Nm sized particle powders of multi wall CNT mixed in kerosene dielectric, SiC Nano Powder Mixed in kerosene dielectric fluid, and TiC Nano Powder Mixed in kerosene dielectric enriched with servotherm oil were considered. The electrical factors like Pulse on Time, Peak Current and Pulse off time were considered for EDM and NPMEDM of Inconel 800 work material with electrolyte copper electrode. This research concentrates hard materials (Inconel 800) machining and use of conventional EDM and different nano-powders used in NPMEDM for machining the same with variable parameters pulse on time, pulse off time and Peak with Silver coated Electrolytic copper electrode. With the best literature available till now, no such work was reported in any literature.

2. Research Design

2.1 Work Material

As discussed the inconel materials are hard, used for precise applications and need nontraditional machining process to machine them with required high finish. The conventional EDM accuracy is not enough to fulfill its application requirements. Hence they are machined in PMEDM. Some investigation was found in such hard materials but this investigation is unique. In[13], investigation was in EDM (drilling) of Inconel 718 for optimizing the factors like Input Current Pulse off Time, Pulse on time. The investigation on machining Inconel 825 material by Wire EDM[14], The Incoloy800 was considered in conventional EDM and developed a

Mathematical Model for Radial Overcut[15] and recently used Response Surface Methodology to optimize the parameters[16]. In[17] analyzed the influence of parameters in micro milling EDM of Inconel 718. In[18] also studied influence of Graphite powder addition in electrolyte to machine inconel718 and concluded that MRR improved significantly for 26.85% with 12g/l of fine graphite powder. In[19], study was in conventional EDM inconel material, the investigation was influence of input parameters like peak current, voltage, Duty cycle and Pulse on Time to optimize the TWR and MRR and reported that the Peak current and gap voltage greatly influence in MRR. In[20] included Aluminum oxide, Silicon carbide in their investigation in PMEDM of Inconel 718, to optimize the input parameters of Current, Duty cycle and Pulse on time to improve MRR and TWR. In this research a unique approach of the NPMEDM of Inconel 800 nickel based super alloy with various input parameters and dielectric medium is preferred.

2.2 Aluminum Nono-powder

The Si and Al powders were widely used in PMEDM investigation based on their superior performance. The Aluminum powder for the experimental investigation with copper electrode reported for machining W300 Die Steel by in, for H13 Steel by21, for AISI D3 die steel by[22], for AISI H -11 material by23, for AISI 1045 steel by24, and for D2 Die steel by25, the specific concentration and particular base fluid gave better results, hence26 suggested 4 g/l aluminum powder in water. The aluminum powder which mix with kerosene was suggested by25–28 suggested Al powder at a concentration of 2 g/l for obtaining mirror finish in SKH-15 Work piece and Here the Al powder mixed with kerosene and stirred continuously about 8 to 9 hours in the Magnetic stirrer for reducing the size of Particles as very fine and about to 5 Nm, before they mix in the actual dielectric.

2.3 Silicon Nono Particles

SiC and Alumina abrasive powders in PMEDM are improving the MRR[29]. Si powder addition and reduced surface roughness about 2μm[30]. The concentrations of 2 g/l of silicon powder gave the appreciable performances in reduction of operating time and surface roughness for PMEDM of AISIH13 mould steel[31]. In[32] analyzed the concentration from 0.4g/l to 2 g/l and found that the 1.2 g/l concentration is optimal for TWR and MRR in PMEDM of ASTM A-105 Steel. In[33] reported that concentration of 4 g/l silicon powder leads to max MRR in PMEDM of AISI D2 die steel. The silicon powder mix in Kerosene and machining with copper electrode was suggested by[34] for EN8 steel. In[35] for Stavax material, by[36] for EN31 Steel, here also the before mixing of Si powder in dielectric fluid in the actual dielectric, it was stirred continuously about 8 to 9 hours in the Magnetic stirrer for reducing the size of Particles as very fine and about to 5 Nm with kerosene sample.

2.4 Multi-Wall Carbon Nano Tubes (MWCNTs)

CNT based nano fluid attracts researchers because of its novel properties like, amazing strength (Young's modulus of 1TPa), high strength to weight ratio exclusive current carrying capacity (Conductivity of CNTs is 109 A/cm^2) electrical properties, efficient thermal conductors (Thermal conductivity 3,000 W/mK in axial direction and small values in a radial direction), excellent field emitter and has a high aspect ratio. The CNTs are fullerene-related to structures that consist of either a grapheme cylinder or a number of concentric cylinders[37]. The authors investigated MWCNTs NPMEDM for EN-31 Steel, with 0.5 g/l mixed with kerosene and reported that the MRR was improved averagely 19% and TWR was decreased averagely 8.51% with respect to the input parameter. Hence multi wall CNT stirred continuously with kerosene about 8 to 9 hours to reducing the maximum size of about 5 Nm before they added in to dielectric of the EDM.

2.5 Nano Powder Concentration

In[38] reported that the powder particles contribution in the reduction of surface cracks and improve surface finish (lowest surface roughness), for obtaining homogeneity of white layer formation and maintain a correct balance of the discharge energy density and the discharge rate were observed for a powder concentration within the range of 2 to 5 g/l. So here 2g/l is preferred for both Aluminum and silicon powder mix with kerosene. The amount of kerosene added in size reduction process were included total mixing ratio. In case of MWCNT, by[39] warned that high concentrations of CNT powder in the gap often made the EDM process unstable. So this study considered the same 0.5g/l with kerosene as dielectric and 2g/l for aluminum and silicon Nono powder with kerosene to machine inconel 800 nickel based super alloy.

2.6 The Electrode

In the conventional practice the Silver coated Electrolytic copper electrode increases the electrical conductivity due to this 26.8% material removal rate has increased and 25% of Tool wear rate has decreased by 15% than Electrolytic copper electrode. Hence, in this study Silver coated Electrolytic copper electrode is preferred

3. Experimental Design

This research is motivated for an industrial requirement. The manufacturer deals various kinds of jobs of inconel 800. The practical issues like, statistical approximation and formula based parameter computations often difficult to fix the parameter for machining. Sometimes the calculated parameters couldn't produce the required finish due to statistical approximation or by labor mistake in calculating parameters. Hence the manufacture demanded that a parameter choice table (like paint shade card for selecting the suitable/desired colour) to fix factored for desired responses and for their regular use. Hence the research is designed completely experimental. Taguchi general full factorial design was preferred for the experimental design. The Taguchi General full factorial is used to design the experiments and the same was used for analyzing the influencing of factors considered for producing optimal responses. The factors were taken in the rage they used for processing the order. The factors with their levels and responses considered were furnished in the Table 1. The objective is investigating the influence of nanoparticle (nono-powder) suspension on dielectric fluid in machining hard nickel based super alloy inconel 800 work piece. The experimental design is tabulated in Table 2 to Table 13. Total 108 experiments were obtained from the MINITAB release 16 software, for three levels of parameters in pulse on time, pulse off time, Current and 4 levels of dielectric medium ($3 \times 3 \times 3 \times 4 = 108$). The polarity used as straight, the input voltage was maintained constant as 230V.

Table 1. Factors and responses

Factors	Level 1	Level 2	Level 3	Level 4
Peak Current (A)	5	10	15	-
Pulse on time (μs)	6	7	8	-
Pulse off time (μs)	3	4	5	-
Dielectric fluid (kerosene mixing with)	EDM oil*	Al (2 g/l)	Si (2 g/l)	MWCNT (0.5 g/l)
Responses	MRR, TWR and SR			

* No Powder is mixed, conventional practices to machine inconel 800 jobs

Table 2. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
1	44	10	6	4	MWCNTs (0.5)	0.38421	0.00116	0.928
2	94	15	7	5	Al (2)	0.67616	0.00445	1.702
3	59	10	7	5	Si (2)	0.46059	0.00189	1.354
4	43	10	6	4	Si (2)	0.29654	0.00137	0.984
5	7	5	6	4	Si (2)	0.07983	0.00031	0.867
6	71	10	8	5	Si (2)	0.57474	0.00250	1.424
7	92	15	7	4	MWCNTs (0.5)	0.91973	0.00389	1.124
8	6	5	6	4	Al (2)	0.06725	0.00036	1.024
9	51	10	7	3	Si (2)	0.37283	0.00179	1.016

Table 3. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
10	52	10	7	3	MWCNTs (0.5)	0.46800	0.00146	0.906
11	101	15	8	4	No NP (0)	0.57670	0.00654	1.719
12	32	5	8	4	MWCNTs (0.5)	0.33274	0.00091	0.902
13	64	10	8	3	MWCNTs (0.5)	0.55600	0.00213	0.948
14	17	5	7	4	No NP (0)	0.10348	0.00060	1.226
15	19	5	7	4	Si (2)	0.15004	0.00053	0.919
16	22	5	7	5	Al (2)	0.15041	0.00058	1.233
17	50	10	7	3	Al (2)	0.31491	0.00197	1.194
18	25	5	8	3	No NP (0)	0.14722	0.00115	1.257

Table 4. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR g/min	TWR	Ra
19	21	5	7	5	No NP (0)	0.11978	0.00068	1.332
20	13	5	7	3	No NP (0)	0.09418	0.00054	1.221
21	81	15	6	5	No NP (0)	0.46086	0.00429	1.726
22	62	10	8	3	Al (2)	0.36433	0.00265	1.255
23	61	10	8	3	No NP (0)	0.31480	0.00311	1.412
24	49	10	7	3	No NP (0)	0.26813	0.00225	1.356
25	18	5	7	4	Al (2)	0.12452	0.00057	1.085
26	16	5	7	3	MWCNTs (0.5)	0.16800	0.00037	0.808
27	1	5	6	3	No NP (0)	0.05162	0.00035	1.134

Table 5. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
28	99	15	8	3	Si (2)	0.71090	0.00543	1.453
29	65	10	8	4	No NP (0)	0.38768	0.00332	1.534
30	58	10	7	5	Al (2)	0.37015	0.00223	1.472
31	34	5	8	5	Al (2)	0.24816	0.00102	1.303
32	66	10	8	4	Al (2)	0.46812	0.00280	1.365
33	41	10	6	4	No NP (0)	0.20548	0.00165	1.357
34	3	5	6	3	Si (2)	0.07259	0.00028	0.853
35	63	10	8	3	Si (2)	0.44674	0.00235	1.063
36	40	10	6	3	MWCNTs (0.5)	0.37100	0.00103	0.863

Table 6. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
37	96	15	7	5	MWCNTs (0.5)	1.13960	0.00353	1.521
38	107	15	8	5	Si (2)	0.86765	0.00548	1.627
39	48	10	6	5	MWCNTs (0.5)	0.49877	0.00126	1.208
40	53	10	7	4	No NP (0)	0.27769	0.00277	1.465
41	88	15	7	3	MWCNTs (0.5)	0.81600	0.00346	1.033
42	72	10	8	5	MWCNTs (0.5)	0.78867	0.00222	1.373
43	30	5	8	4	Al (2)	0.21421	0.00122	1.152
44	108	15	8	5	MWCNTs (0.5)	1.19084	0.00482	1.592
45	90	15	7	4	Al (2)	0.61643	0.00473	1.487

Table 7. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
46	15	5	7	3	Si (2)	0.13330	0.00045	0.904
47	46	10	6	5	Al (2)	0.29222	0.00155	1.363
48	83	15	6	5	Si (2)	0.70533	0.00314	1.476
49	82	15	6	5	Al (2)	0.57562	0.00361	1.594
50	37	10	6	3	No NP (0)	0.20576	0.00155	1.285
51	29	5	8	4	No NP (0)	0.17603	0.00129	1.294
52	27	5	8	3	Si (2)	0.20808	0.00088	0.939
53	28	5	8	3	MWCNTs (0.5)	0.26300	0.00072	0.837
54	10	5	6	5	Al (2)	0.08321	0.00039	1.149

Table 8. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
55	78	15	6	4	Al (2)	0.52833	0.00343	1.384
56	38	10	6	3	Al (2)	0.24762	0.00134	1.126
57	14	5	7	3	Al (2)	0.11259	0.00049	1.092
58	89	15	7	4	No NP (0)	0.50848	0.00505	1.677
59	57	10	7	5	No NP (0)	0.29613	0.00250	1.581
60	73	15	6	3	No NP (0)	0.38793	0.00376	1.457
61	5	5	6	4	No NP (0)	0.05655	0.00039	1.169
62	54	10	7	4	Al (2)	0.33568	0.00231	1.284
63	68	10	8	4	MWCNTs (0.5)	0.74005	0.00249	1.026

Table 9. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
64	55	10	7	4	Si (2)	0.46056	0.00215	1.034
65	12	5	6	5	MWCNTs (0.5)	0.13986	0.00029	0.878
66	100	15	8	3	MWCNTs (0.5)	0.88500	0.00444	1.124
67	97	15	8	3	No NP (0)	0.50149	0.00668	1.674
68	33	5	8	5	No NP (0)	0.19754	0.00129	1.406
69	39	10	6	3	Si (2)	0.29478	0.00126	0.968
70	47	10	6	5	Si (2)	0.39262	0.00133	1.261
71	106	15	8	5	Al (2)	0.75346	0.00646	1.786
72	69	10	8	5	No NP (0)	0.37562	0.00344	1.667

Table 10. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
73	9	5	6	5	No NP (0)	0.06550	0.00047	1.241
74	11	5	6	5	Si (2)	0.11097	0.00034	0.910
75	4	5	6	3	MWCNTs (0.5)	0.09200	0.00023	0.762
76	95	15	7	5	Si (2)	0.82937	0.00383	1.570
77	86	15	7	3	Al (2)	0.54627	0.00466	1.334
78	60	10	7	5	MWCNTs (0.5)	0.63253	0.00169	1.306
79	84	15	6	5	MWCNTs (0.5)	0.96174	0.00279	1.426
80	103	15	8	4	Si (2)	0.77127	0.00587	1.276
81	20	5	7	4	MWCNTs (0.5)	0.19453	0.00046	0.869

Table 11. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
82	76	15	6	3	MWCNTs (0.5)	0.67900	0.00259	0.977
83	79	15	6	4	Si (2)	0.55751	0.00327	1.124
84	8	5	6	4	MWCNTs (0.5)	0.10432	0.00027	0.819
85	23	5	7	5	Si (2)	0.18482	0.00049	0.969
86	45	10	6	5	No NP (0)	0.23345	0.00182	1.467
87	87	15	7	3	Si (2)	0.65462	0.00422	1.256
88	31	5	8	4	Si (2)	0.25774	0.00106	0.954
89	24	5	7	5	MWCNTs (0.5)	0.25469	0.00043	0.932
90	26	5	8	3	Al (2)	0.17546	0.00096	1.154

Table 12. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
91	42	10	6	4	Al (2)	0.24619	0.00145	1.204
92	102	15	8	4	Al (2)	0.69722	0.00621	1.613
93	104	15	8	4	MWCNTs (0.5)	0.96289	0.00493	1.208
94	67	10	8	4	Si (2)	0.57826	0.00269	1.079
95	105	15	8	5	No NP (0)	0.59696	0.00732	1.903
96	75	15	6	3	Si (2)	0.54367	0.00316	1.095
97	93	15	7	5	No NP (0)	0.53285	0.00520	1.843
98	70	10	8	5	Al (2)	0.46822	0.00310	1.543
99	35	5	8	5	Si (2)	0.31637	0.00084	1.052

Table 13. Taguchi general full factorial design of experiments and responses observation

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder Mix (g/l)	MRR	TWR	Ra
100	85	15	7	3	No NP (0)	0.46530	0.00497	1.534
101	91	15	7	4	Si (2)	0.65924	0.00452	1.178
102	74	15	6	3	Al (2)	0.45716	0.00346	1.276
103	2	5	6	3	Al (2)	0.06153	0.00032	0.987
104	56	10	7	4	MWCNTs (0.5)	0.52464	0.00172	0.975
105	36	5	8	5	MWCNTs (0.5)	0.43209	0.00066	0.966
106	80	15	6	4	MWCNTs (0.5)	0.70370	0.00294	1.052
107	98	15	8	3	Al (2)	0.59838	0.00591	1.592
108	77	15	6	4	No NP (0)	0.43584	0.00398	1.572

4. Experimental Method

The EDM set-up employed in this experimental study is Electronica Machine Tools make Xpert 1model die sinking type CNC EDM machine. Kerosene is a dielectric fluid in this machine because of its property of very low viscosity and it gets flushed away easily. The fixed time of 5 minutes per experimental was permitted. The dielectric mediums are considered separately in the conduct of experiments. The Taylor Hobson makes, Surtronic 3+ branded contact type profile-meter was employed in surface roughness measurement with 0.8mm cut length and sampling number is three. The laboratory balance of semi micro with an accuracy of 0.00001g, was employed in measuring weight loss tool and work material in before and after every run to compute MRR and TWR. The observations of Experiments servotherm oil mixed with Kerosene dielectric fluid environment also considered. It is conventional practices to machine Inconel 800 jobs by the manufacturers in other words, no powder mixed in dielectric fluid or conventional EDM and not PMEDM environment. In the case of Nano Powder mixed EDM, the environments of Aluminum nano-powder mixed with Kerosene dielectric fluid (Refer in Graphs as B), silicon nano-powder mixed with the Kerosene dielectric fluid environment (Refer in Graphs as C) and MWCNTs Nono-powder mixed with the Kerosene dielectric fluid environment (Refer in Graphs as D) was separately considered for experimentation due to practical constraints of random experiments in those environments as in order of experimental run. The observations were recorded as per Taguchi general Full Factorial Design of Experiments in Table 2 to Table 13.

5. Result and Discussion

5.1 Dielectric Environments

The conventional dielectric of kerosene with servo-therm oil as dielectric (Refer in Graphs as A) for existing machining procedure followed by the manufacturer, the second dielectric is 2g/l of aluminum nano powder mix with kerosene (Refer in Graphs as B); the third one is 2g/l silicon powder mix with kerosene (Refer in Graphs as C) and the final one is Multiwall CNTs powder mix dielectric with the concentration of 0.5g/l (Refer in Graphs as D). The observations were recorded in the Taguchi Full Factorial Design sheet Table 2. which was prepared by the statistical software of MINITAB release 16.

5.2 The NPMEDM Performance in Terms of Material Removal Rate

The case wise material removal rate performance by Nano-Powder mixed EDM of Inconel 800 is graphically illustrated in the Figures 1 and 2. The Figure 1 is the NPMEDM performance when Peak Current and Pulse off Time are kept constant. In the first row MRR performance by EDM and NPMEDMs at Current 5A, 10A and 15A respectively, when the Pulse off time is 3 µs, the second row is for Pulse off time 4 µs and the last row for the Pulse off time is 5µs. The first column is at Current 5A, the second column of the peak Current 10A, and the third column is for the Current value of 15A. It is observed that when the input current, pulse on Time and Pulse off time increase the MRR increases. Hence all these parameters influence the MRR performance of NPMEDM. The NPMEDM performance with MWCNT is most significant. The Figure 2 illustrates the MRR for NPMEDM and EDM with respect to Peak Current. There are three rows of graphs for Pulse on time 6µs, 7µs and 8µs respectively. In each row three graphs are there for Pulse off time 3, 4 and 5µs successively. These graphs reveal that all the factors influence directly proportional to MRR in which the MRR with respect to peak current is most sensitive. In the overall experiments the minimum and maximum MRR were obtained in experimental run 27 (conventional EDM) and run 44 (MWCNTs NPMEDM) as 0.05162 and 1.19084 respectively.

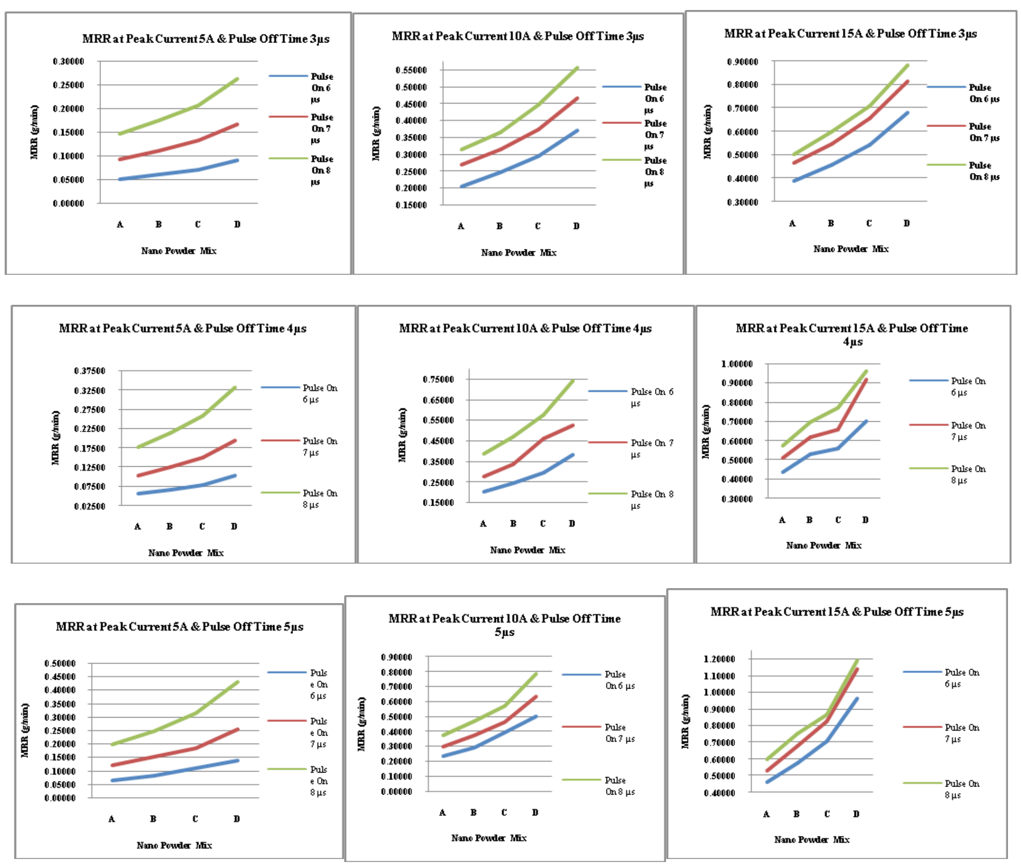

Figure 1. NPMEDM and EDM performance in MRR with respect to pulse on time.

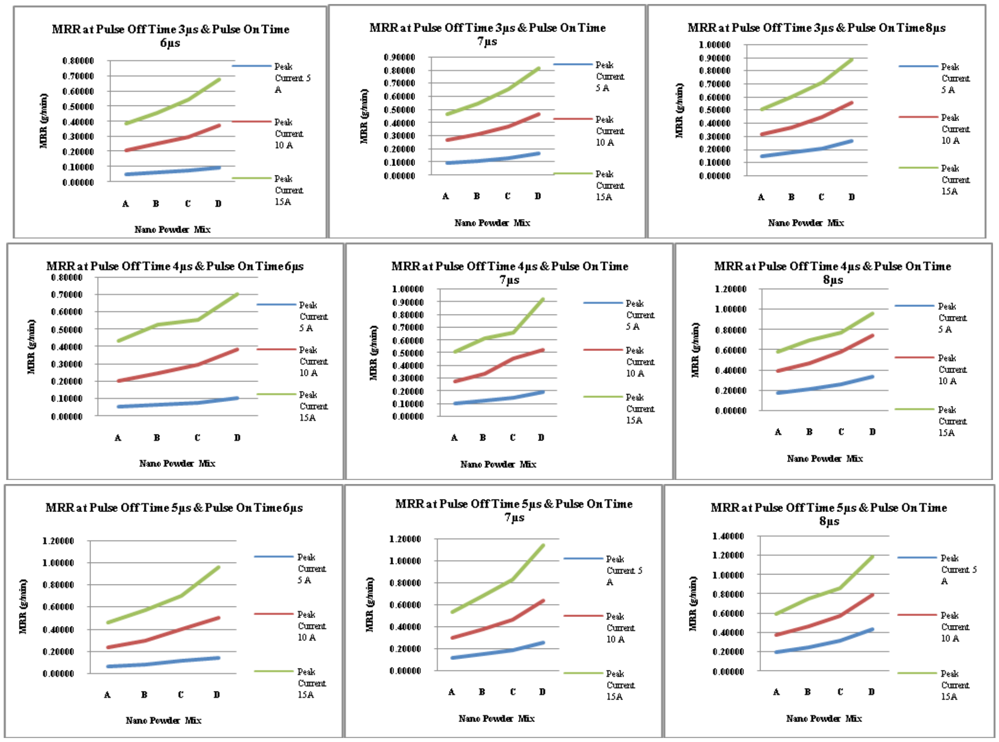

Figure 2. EDM and NPMEDMs performances in MRR with respect to peak current.

Table 14. The TWR status of minimum and maximum in overall performance

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	Status	TWR
75	4	5	6	3	MWCNTs (0.5)	Min.	0.00023
95	105	15	8	5	No NP (0)	Max.	0.00732

5.3 The NPMEDM Performance in Terms of Tool Wear Rate

The factors' influence in TWR reduction was depicted in the Figure 3. In Figure 3 the graphs in the first row TWR performance given by Nano Powders in NPMEDM at pulse on time 6µs for the peak Current of 5A, 10A and 15A. Similarly, for the second row is for pulse on time 7µs and the last row for the pulse on time 8µs. The first column is at pulse off time 3µs, the second column is for pulse off time 4µs, and the third column is for pulse off time 3µs. The tool wear rate is high at Conventional EDM (no nano powder mixed in dielectric). The addition of nano powder decreases the tool wear. The high tool wear reduction by nano fluids was observed at higher pulse off time as well as high pulse on time. The input current influence is directly proportional to TWR. The Figure 4 illustrates the NPMEDM and EDM performances on TWR. The first row to third are for Pulse off time is 3, 4 and 5µs respectively for the peak current 5A, 10A and 15A. In other words, the first column is at peak Current 5A, the second column of the peak Current 10A, and the third column is for the peak Current value of 15A. These graphs also confirm that the tool wear rate is low in MWCNTs NPMEDM and High at conventional EDM practices. The details of these are discussed in the conclusion. The minimum and maximum material removal rate were observed and tabulated in Table 14.

5.4 The NPMEDM Performance in Terms of Surface Roughness

The NPMEDM and EDM performance in terms of surface roughness (SR) with respect to peak current

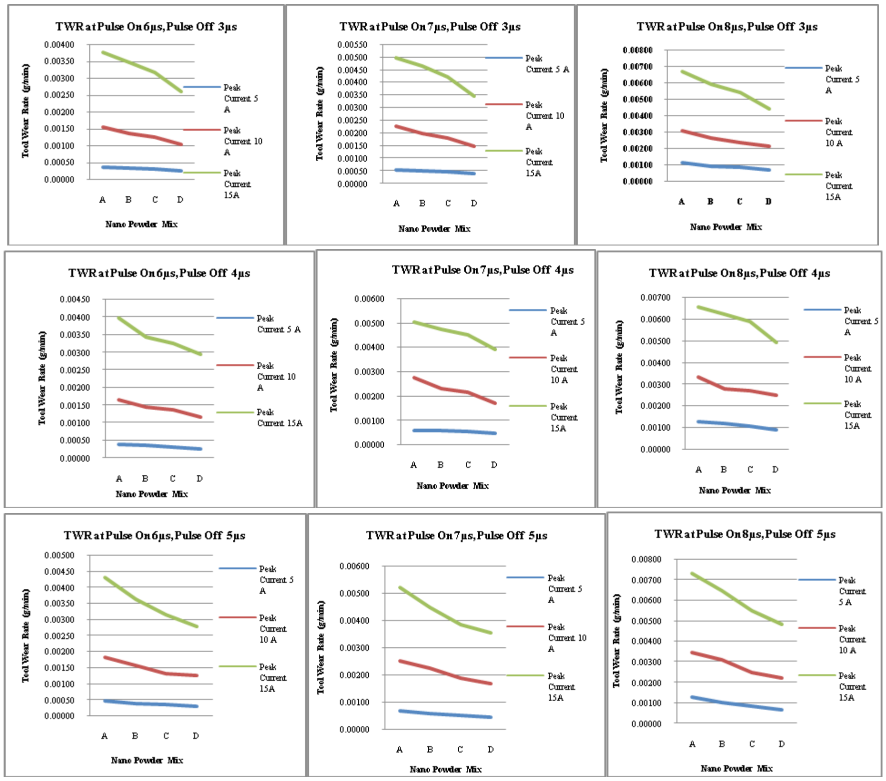

Figure 3. EDM and NPMEDMs performances in TWR with respect to peak current.

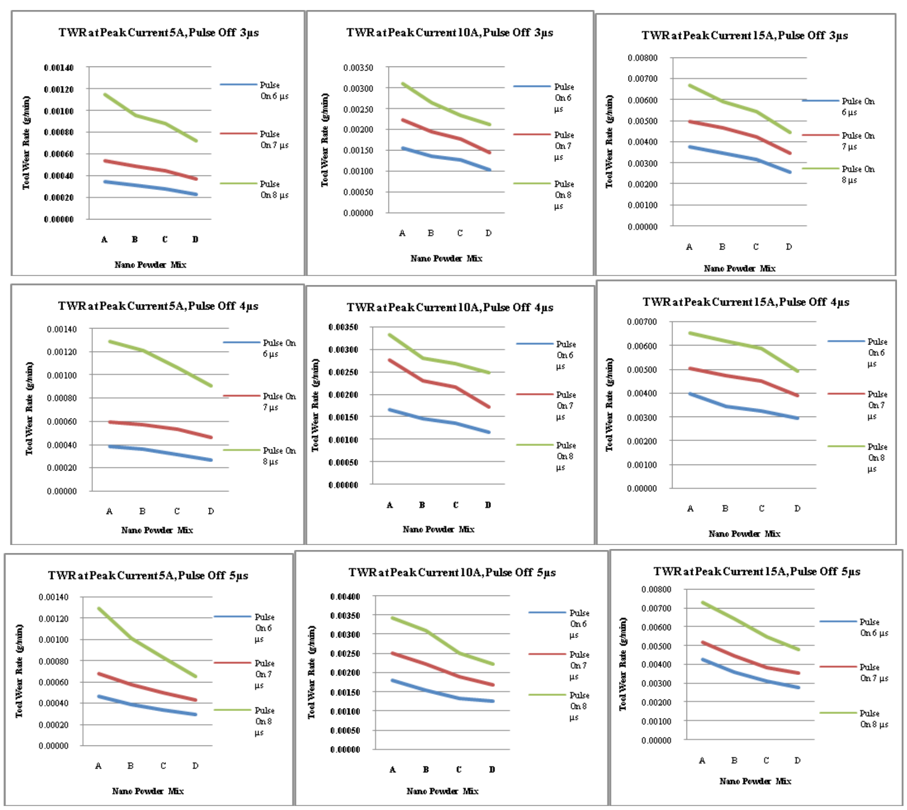

Figure 4. EDM and NPMEDMs performances in TWR with respect to pulse on time.

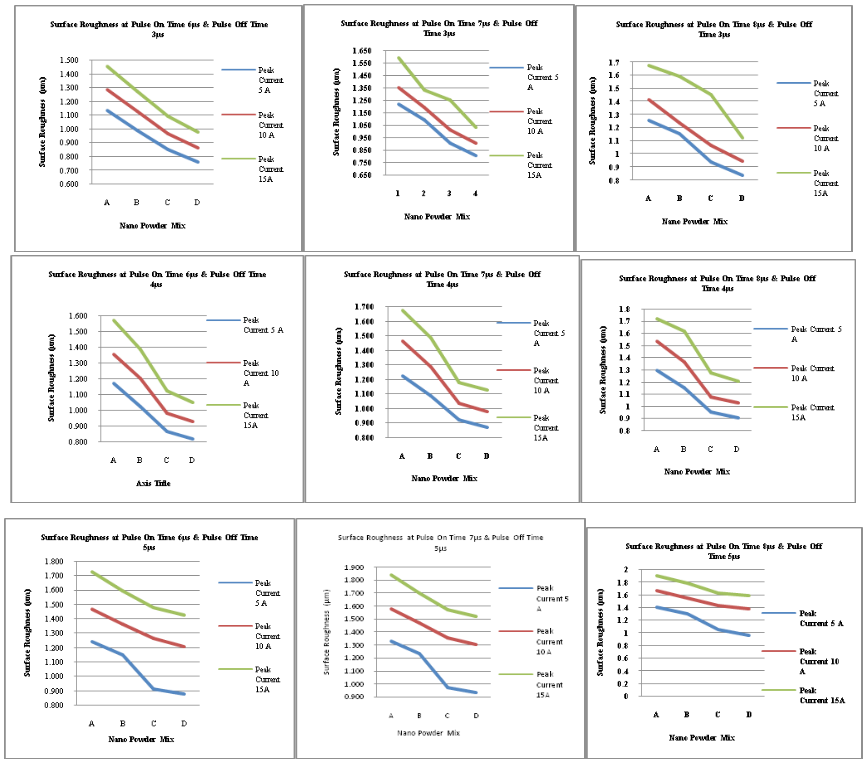

Figure 5. Surface roughness performance of EDM and NPMEDMs with respect to peak current.

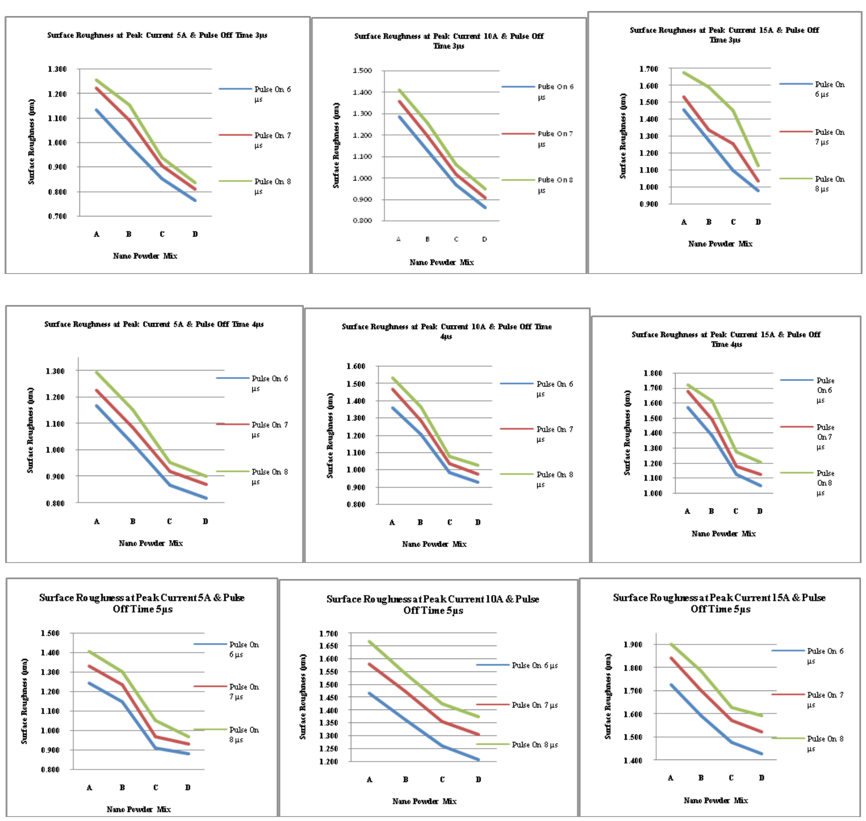

Figure 6. Surface roughness performances of EDM and NPMEDMs with respect to pulse on time.

Table 15. The SR status of minimum and maximum in overall performance

Run Order	Std Order	Current (A)	Pulse On (μs)	Pulse Off (μs)	Nano Powder (g/l)	Status of Ra	Ra (μm)
75	4	5	6	3	MWCNTs (0.5)	Min	0.762
95	105	15	8	5	No NP (0)	Max	1.903

in set of graphs in Figure 5. The graphs were arranged row wise for at pulse on time 6μs, 7μs and 8μs respectively, and column wise for the peak Current of 5A, 10A and 15A. These graphs reveal that the roughness reduction is high in the MWCNTs NPMEDM than all other NPMEDMs and EDM considered. In Figure 6 the graphs in the first row SR performance given by Nano Powders in NPMEDM at Current 5A, 10A and 15A respectively, when the Pulse off time is 3 μs, the second row is for Pulse off time 4 μs and the last row for the Pulse off time is 5μs. The first column is at peak Current 5A, the second column of the peak Current 10A, and the third column is for the peak Current value of 15A. These graphs also confirmed that the surface roughness is low in MWCNTs NPMEDM and High at conventional EDM practices. The details of these are discussed in the conclusion. The minimum and maximum of surface roughness were observed and tabulated in Table 15.

6. Conclusion

The EDM and NPMDEMs machining of inconel 800 material with use of silver coated experimentally investigated and analyzed well. The NPMEDM performances were compared with conventional EDM and other NPMEDMs with equal priority. The result shows that the NPMEDM outperforms than EDM. In particularly MWCNTs powder mixed NPMEDM. All the factors which considered for investigation were contributing to the response of MRR, TWR and SR. The observation table can be used for parameter setting to obtain the desired result by the manufacturer like shade card for paint selection. It is easy and convenient to identify suitable parameters for the desired outcome of jobs. Here some in specific conclusions

1. The influence of various factors was graphically illustrated from Figure 1 to Figure 6.
2. The MRR is maximum to minimum can be write as MWCNTs NPMEDM > Si NPMEDM > Al NPMEDM > EDM in machining inconel 800 with minimum in g/min are 0.09200 > 0.07259 > 0.06153 > 0.05162 and in Maximum MRR of 1.19084 > 0.86765 > 0.75346 > 0.59696 g/min.
3. The MRR improved in the order of MWCNTs NPMEDM > Si NPMEDM > Al NPMEDM with respect to conventional EDM in the 38.07% to 54.28%, 21.83% to 40.98% and 13.59% to 21.29% respectively.
4. The Tool Wear rate is lower to higher in terms of EDMs in the use of silver coated Electrode are MWCNTs NPMEDM < Si NPMEDM < Al NPMEDM < EDM in machining inconel 800 with minimum in g/min are (0.00023 to 0.00493) < (0.00028 to 0.00587) < (0.00032 to 0 .00646) < (0.00035 to 0.00732) g/min.
5. The percentage of TWR reduction is in the order of MWCNTs NPMEDM > Si NPMEDM > Al NPMEDM with respect to conventional EDM in the 22.87% to 48.88%, 06.48% to 49.19% and 3.69% to 21.39% respectively.
6. The obtained surface roughness is lower to higher in terms of EDMs in use of silver coated Electrode are MWCNTs NPMEDM < Si NPMEDM < Al NPMEDM < EDM in machining inconel 800 with minimum in μm are (0.762 to 1.592) < (0.853 to 1.627) < (0.987 to 1.786) < (1.134 to 1.903) μm.
7. The percentage of TWR reduction is in the order of MWCNTs NPMEDM > Si NPMEDM > Al NPMEDM with respect to conventional EDM in the (16.34% to 40.15%), (13.20% to 29.76%) and (4.90% to 13.13%) respectively.

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