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Experimental Investigation Nano Particles Influence in NPMEDM to Machine Inconel 800 with Electrolyte Copper Electrode

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Abstract— The recent technology of machining hard materials is Powder mix dielectric electrical Discharge Machining (PMEDM). This research investigates nano sized (about 5Nm) powders influence in machining Inconel 800 nickel based super alloy. This work is motivated for a practical need for a manufacturing industry, which processes various kinds of jobs of Inconel 800 material. The conventional EDM machining also considered for investigation for the measure of Nano powders performances. The aluminum, silicon and multi walled Carbon Nano tubes powders were considered in this investigation along with pulse on time, pulse of time and input current to analyze and optimize the responses of Material Removal Rate, Tool Wear Rate and surface roughness. The Taguchi general Full Factorial Design was used to design the experiments. The most advance equipments employed in conducting experiments and measuring equipments to improve the accuracy of the result. The MWCNT powder mix was out performs than other powders which reduce 22% to 50% of the tool wear rate, gives the surface roughness reduction from 29.62% to 41.64% and improved MRR 42.91% to 53.51% than conventional EDM.

1. Introduction

The most modern advanced material removal process which is useful to enhance machining performance and efficiency is Powder Mixed dielectric fluid in Electrical Discharge Machining (PMEDM). It enlarges the machining efficiency and surface finish by faster sparking and increase thermal conductivity within discharge arise results faster erosion from the work piece's surface. Jeswani (1981) investigated the effect of the addition of Graphite powder in Kerosene and used as dielectric in EDM. The authors highlighted that generally the mix of Nano powder in electrical discharge machining for increasing material removal rate (MRR) and Tool wear rate (TWR). And in specific the addition of graphite Nono powders in kerosene for using as the dielectric medium (4g/l) brought improvement of 60% material removal rate and 15% of Tool wear rate in 10µm inter Electrode Gap and 30% reduction of breakdown voltage in the 50µm inter Electrode Gap. Kuldeep et al., (2011) considered chromium power suspension in dielectric fluid. Prabhu and Vinayagam (2011) investigated single wall CNT suspension in dielectric for machining AISI D2 tool steel in EDM and observed that good thermal conductivity, reduced white layer formation and absorb heal as well. The Prihandana et al. (2011) reported that suspension of nano sized powder of SiC and Al2O3 in dielectric fluid in micro electric discharge machining, improved the surface finish by generating 14% to 24% of average surface roughness as well as free from micro cracks and it is also mentioned that nano-graphite powder mixed dielectric produced a high sparking gap size.

2. Research GAP

Some research works were reported on EDM in machining performance improvements on such difficult-to-cut materials. Kuppan et al. (2008)] investigated EDM deep hole drilling on Inconel 718. The process variables like peak current, pulse on-time, duty factor and electrode speed were considered for their investigation as factors. In which the authors developed mathematical models for the responses of MRR and depth averaged surface roughness (DASR) and used response surface methodology. Rajyalakshmi and Venkata Ramaiah, (2013) investigations were for the performance measures like MRR, SF, and SG in Wire EDM on Inconel 825 material they used Taguchi grey relational analysis for optimizing process parameters. MuthuKumar et al. (2010) investigation was in WEDM process to optimize parameters by Gray–Taguchi Method for machining Incoloy800 super alloy with multiple performance characteristics such as MRR, surface roughness and Kerf. Mao-yong LIN et al. (2013) analyzed parameter optimization on micro milling EDM for the machining of Inconel 718. The another attempt was made by Muthu Kumar et al. (2010) on WEDM process to optimize parameters for improving responses of MRR, SR and Ker width for machining Titanium alloy.

The authors recently developed a Mathematical Model for Radial Overcut on Electrical Discharge Machining for Incoloy 800. And they used Response Surface Methodology (Muthu Kumar et al. (2014)). Rathi and Mane (2014) studied the Effect of Powder Mixed dielectric in EDM of Inconel 718 machining with powders like Silicon carbide, Aluminum oxide, Graphite. With other parameters of Current, Pulse on time (µs) and Duty cycle to optimize the responses of MRR and TWR. Prajapati and Haresh (2015), investigated SiO2 PMEDM in machining En-8 steel for optimize surface roughness. The Peak current, pulse on time and concentration of powder were considered for factors to optimize the response of surface finish. 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. Bhiksha et al (2015) 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 decrease of concentration. Satpal and Kalra (2014) investigation 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%. Syed et al (2015) used Aluminum Powder concentration variation fro 0 g/l to 2g/l with kerosene in the machining of Al/SiC composites and found that in lower peak current (2A), the MRR increases with the increase of Al powder concentration in the dielectric fluid up to a certain limit. Kuldeep et al (2011) used Chromium Powder Suspended Dielectric to machine EN-8 steel, the range of concentration was 2 to 6 g/l. And concluded that MRR shows an increasing trend of increase in powder concentration.

The trend shows that MRR will increase further with further increase in concentration and the TWR increase with a lower range of powder concentration but then decrease. The Shriram et al. (2014) analyzed the effect of PMEDM in machining Tungsten Carbide of different grades W20, W30 and W40 with powders of Al, Gr and SiC in the 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/cm2. Tzeng and Lee [11] investigated the effect of Al, Cr, Cu and SiC powders on PMEDM in machining SKD-11 and reported that the properties of powders like concentration, density, size, thermal conductivity and electrical resistivity are significantly influenced in the machining performance and in particularly at a fixed concentration, the smallest size of the particle led to highest MRR. 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 fluid along with kerosene and servotherm oil dielectric environments considered with other process parameters with three level of Peak Current, Pulse on Time, and Pulse off time to optimize the responses of MRR, TWR and SR in machining Inconel 800 work material with electrolyte copper electrode. With the best literature available till now, no such work was reported in any literature.

3. Research Design

3.1: Need For the Research

Inconel or incony series are Nickel based super alloys which are widely used in high temperature and high pressure applications such as, nuclear reactors, gas turbines, high temperature chemical vessels and electric power generation equipment (Hewidy et al. (2005)). The Incony 800 has high thermal strength, highly abrasive carbide particles high hardness, low thermal diffusivity. But Inconel 800 has high tendency to welding with tool material and forming built–up edge, which extremely difficult-to-machine (Narutaki et al. (1993)). Hence it is challenging to machine Incony 800 in Traditional machining processes. Alternatively the non-traditional machining methods like The Electro Chemical Machining, Abrasive water jet machining, Laser beam Machining, Electrical Discharge Machining (EDM) are attractive alternative offers for such hard materials. So in this study the Incony 800 material machining process is preferred.

3.2: Aluminum Nano particles

The most and widely used powders in PMEDM are Si and Al. The mixing of Aluminum powder in dielectric and machining with copper electrode is suggested for machining W300 Die Steel (Syed and Kuppan (2012)), for AISI D3 die steel (Jamadar and kavade (2014)), for H13 Steel (Gurtej et al. (2012), for D2 Die steel (Gurule and Nandurkar (2012), for AISI H -11 material (Mir et al. (2012), for and Hastelloy (Paramjit et al. 2012) . for AISI 1045 steel (Shivam Goyal, Rakesh Kumar Singh 2014) and in particularly mixing with kerosene in recommended by (Gurule and Nandurkar (2012), (Mir et al. (2012) and Chow et al. (2000). Wong et al. (1998) suggested Al powder at concentration of 2 g/l for obtaining mirror finish in SKH-15 Work piece and Syed et al. (2013) suggested 4 g/l aluminum powder in water. 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.

3.3: Silicon Nono Particles

Banker (2014) state that the abrasive powders like Sic and alumina in mixed with dielectric improves the MRR. Mohri et al. investigated the effects of Si powder addition and reduced surface roughness about 2µm. Pecas and Henriques (2003) investigated and reported that the positive influence of 2 g/l concentrations of the silicon powder towards the reduction of the operating time required to achieve a specific surface quality in machining AISIH13 mould steel. Sukhvir and Jujhar (2014) used silicon powder in the dielectric fluid of the EDM ranging from 0.4g/l to 2 g/l and reported that the optimal MRR and TWR obtained with Powder Concentration =1.2 g/l in machining ASTM A-105 Steel. Kansal et al. (2007) studied the effect of silicon powder mixing into the dielectric fluid of EDM on machining suggested at high concentration of 4 g/l silicon powder in AISI D2 die steel to achieve high MRR .Similarly the silicon powder in Kerosene and machining with copper electrode was suggested by Nimo et al (2014) for EN 8 steel, Razak (2014) for Stavax material, Soumakant Padhee et al. (2012) for EN 31 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.

3.4: Multi-Wall Carbon Nano Tubes (MNCNTs)

CNT based nano fluids is of special interests to researchers because of its novel properties like efficient thermal conductors (Thermal conductivity 3,000 W/mK in axial direction and small values in a radial direction), high strength to weight ratio, amazing strength (Young's modulus of 1TPa), exclusive current carrying capacity (Conductivity of CNTs is 109 A/cm2) electrical properties, 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 (Darji et al. 2014). 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.

3.5: Nano powder Concentration

Yan and Chen (1994) 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, Mai and Hocheng (2011) 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.

4. 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 labor mistake of calculating parameters. And 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 factors of Input Current, Pulse on Time, pulse off time and the nano-powders and their concentrations for mix with kerosene to use as dielectric fluid were preferred based on the literature review to analyze the response like tool wear rate, Material removal rate and surface roughness. The objective is investigating the influence of nano-particle (nono-powder) suspension on dielectric fluid in machining hard nickel based super alloy inconel 800 work piece. The experimental design is tabulated in Table-2a to Table -2l. 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 (3x3x3x4 =108).

Table 1. Factors and Responses

Factor	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)	4	5	6	-
Dielectric fluid (kerosene mixing with)	EDM oil *	Al (2 g/l)	Si(2 g/l)	MWCNT (0.5 g/l)
Responses	MRR	TWR	SR	-

*No Nano Powder mixed case (conventional practices)

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TABLE I. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/Sec)	TWR (g/Sec)	Ra (µm)
1	44	10	6	4	MWCNTs (0.5)	0.27587	0.00050	1.01
2	94	15	7	5	Al (2)	0.54882	0.00329	2.02
3	59	10	7	5	Si (2)	0.58576	0.00215	1.79
4	43	10	6	4	Si (2)	0.21343	0.00058	1.07
5	7	5	6	4	Si (2)	0.11894	0.00040	1.01
6	71	10	8	5	Si (2)	1.03866	0.00411	2.09
7	92	15	7	4	MWCNTs (0.5)	0.82496	0.00253	1.13
8	6	5	6	4	Al (2)	0.09830	0.00040	1.22
9	51	10	7	3	Si (2)	0.47209	0.00199	1.13

TABLE II. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
10	52	10	7	3	MWCNTs (0.5)	0.60346	0.00178	1.00
11	101	15	8	4	No NP (0)	0.67268	0.00705	2.05
12	32	5	8	4	MWCNTs (0.5)	0.94256	0.00313	1.16
13	64	10	8	3	MWCNTs (0.5)	1.07264	0.00411	1.14
14	17	5	7	4	No NP (0)	0.30753	0.00174	1.65
15	19	5	7	4	Si (2)	0.45024	0.00153	1.12
16	22	5	7	5	Al (2)	0.37984	0.00188	1.78
17	50	10	7	3	Al (2)	0.40252	0.00218	1.29
18	25	5	8	3	No NP (0)	0.50210	0.00422	1.61

TABLE III. FACTORS AND RESPONSES

Run Order	Std Order	Current	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
19	21	**5**	7	5	No NP (0)	0.30573	0.00225	1.93
20	13	5	7	3	No NP (0)	0.30676	0.00168	1.45
21	81	15	6	5	No NP (0)	0.25684	0.00147	1.86
22	62	10	8	3	Al (2)	0.71494	0.00536	1.46
23	61	10	8	3	No NP (0)	0.61234	0.00587	1.68
24	49	10	7	3	No NP (0)	0.34833	0.00248	1.49
25	18	5	7	4	Al (2)	0.37210	0.00161	1.45
26	16	5	7	3	MWCNTs (0.5)	0.54673	0.00124	0.98
27	1	5	6	3	No NP (0)	0.07219	0.00037	1.31

TABLE IV. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
28	99	15	8	3	Si (2)	0.94047	0.00631	1.45
29	65	10	8	4	No NP (0)	0.60530	0.00557	2.03
30	58	10	7	5	Al (2)	0.46888	0.00239	1.93
31	34	5	8	5	Al (2)	0.69590	0.00413	2.12
32	66	10	8	4	Al (2)	0.73120	0.00524	1.79
33	41	10	6	4	No NP (0)	0.15471	0.00656	1.49
34	3	5	6	3	Si (2)	0.10233	0.00031	0.99
35	63	10	8	3	Si (2)	0.85807	0.00489	1.27
36	40	10	6	3	MWCNTs (0.5)	0.23132	0.00040	0.94

TABLE V. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
37	96	15	7	5	MWCNTs (0.5)	0.93914	0.00248	1.82
38	107	15	8	5	Si (2)	1.01378	0.00630	2.18
39	48	10	6	5	MWCNTs (0.5)	0.34454	0.00049	1.11
40	53	10	7	4	No NP (0)	0.34230	0.00249	1.78
41	88	15	7	3	MWCNTs (0.5)	0.74389	0.00245	1.04
42	72	10	8	5	MWCNTs (0.5)	1.43593	0.00361	2.03
43	30	5	8	4	Al (2)	0.61350	0.00384	1.69
44	108	15	8	5	MWCNTs (0.5)	1.39543	0.00564	2.11
45	90	15	7	4	Al (2)	0.52210	0.00321	1.64

TABLE VI. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On	Pulse Off	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
46	15	5	7	3	Si (2)	0.43523	0.00138	1.09
47	46	10	6	5	Al (2)	0.20078	0.00065	1.63
48	83	15	6	5	Si (2)	0.39860	0.00117	1.15
49	82	15	6	5	Al (2)	0.31891	0.00125	1.72
50	37	10	6	3	No NP (0)	0.12975	0.00057	1.40
51	29	5	8	4	No NP (0)	0.50725	0.00407	1.92
52	27	5	8	3	Si (2)	0.71903	0.00349	1.21
53	28	5	8	3	MWCNTs (0.5)	0.91896	0.00287	1.08
54	10	5	6	5	Al (2)	0.11180	0.00047	1.50

TABLE VII. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
55	78	15	6	4	Al (2)	0.26650	0.00122	1.38
56	38	10	6	3	Al (2)	0.15427	0.00053	1.21
57	14	5	7	3	Al (2)	0.36433	0.00152	1.26
58	89	15	7	4	No NP (0)	0.43249	0.00342	1.87
59	57	10	7	5	No NP (0)	0.37756	0.00280	2.09
60	73	15	6	3	No NP (0)	0.18745	0.00117	1.43
61	5	5	6	4	No NP (0)	0.08239	0.00042	1.39
62	54	10	7	4	Al (2)	0.41140	0.00232	1.56
63	68	10	8	4	MWCNTs (0.5)	1.14130	0.00428	1.22

TABLE VIII. FACTORS AND RESPONSES

Run Order	Std Order	Current (A)	Pulse On (µs)	Pulse Off (µs)	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
64	55	10	7	4	Si (2)	0.49449	0.00230	1.14
65	12	5	6	5	MWCNTs (0.5)	0.19290	0.00036	1.02
66	100	15	8	3	MWCNTs (0.5)	1.18295	0.00522	1.30
67	97	15	8	3	No NP (0)	0.41304	0.00346	1.55
68	33	5	8	5	No NP (0)	0.56255	0.00486	2.29
69	39	10	6	3	Si (2)	0.18438	0.00048	1.05
70	47	10	6	5	Si (2)	0.25278	0.00056	1.15
71	106	15	8	5	Al (2)	0.92407	0.00735	2.35
72	69	10	8	5	No NP (0)	0.67892	0.00570	2.45

TABLE IX. FACTORS AND RESPONSES

Run Order	Std Order	Current	Pulse On	Pulse Off	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
73	9	5	6	5	No NP (0)	0.08968	0.00055	1.63
74	11	5	6	5	Si (2)	0.14936	0.00040	1.05
75	4	5	6	3	MWCNTs (0.5)	0.12835	0.00025	0.88
76	95	15	7	5	Si (2)	0.68974	0.00292	1.87
77	86	15	7	3	Al (2)	0.49270	0.00313	1.34
78	60	10	7	5	MWCNTs (0.5)	0.80297	0.00181	1.72
79	84	15	6	5	MWCNTs (0.5)	0.54649	0.00095	1.09
80	103	15	8	4	Si (2)	0.95988	0.00637	1.47
81	20	5	7	4	MWCNTs (0.5)	0.58082	0.00136	1.05

TABLE X. FACTORS AND RESPONSES

Run Order	Std Order	Current	Pulse On	Pulse Off	Nano Powder (g/l)	MRR (g/min)	TWR (g/min)	Ra (µm)
82	76	15	6	3	MWCNTs (0.5)	0.33273	0.00075	0.96
83	79	15	6	4	Si (2)	0.33247	0.00126	1.09
84	8	5	6	4	MWCNTs (0.5)	0.15437	0.00035	0.97
85	23	5	7	5	Si (2)	0.47466	0.00161	1.65
86	45	10	6	5	No NP (0)	0.16180	0.00763	1.76
87	87	15	7	3	Si (2)	0.58643	0.00286	1.17
88	31	5	8	4	Si (2)	0.72383	0.00373	1.23
89	24	5	7	5	MWCNTs (0.5)	0.64989	0.00142	1.59
90	26	5	8	3	Al (2)	0.59742	0.00382	1.39

TABLE XI. FACTORS AND RESPONSES

Run Order	**Std Order**	**Current**	**Pulse On**	**Pulse Off**	**Nano Powder (g/l)**	**MRR (g/min)**	**TWR (g/min)**	**Ra (µm)**
91	42	10	6	4	Al (2)	0.17630	0.00062	1.31
92	102	15	8	4	Al (2)	0.81330	0.00663	1.81
93	104	15	8	4	MWCNTs (0.5)	1.23825	0.00535	1.39
94	67	10	8	4	Si (2)	0.89846	0.00496	1.29
95	105	15	8	5	No NP (0)	0.74297	0.00859	2.54
96	75	15	6	3	Si (2)	0.26374	0.00091	1.07
97	93	15	7	5	No NP (0)	0.44281	0.00388	2.19
98	70	10	8	5	Al (2)	0.83280	0.00479	2.26
99	35	5	8	5	Si (2)	0.87644	0.00364	1.96

TABLE XII. FACTORS AND RESPONSES

Run Order	**Std Order**	**Current**	**Pulse On**	**Pulse Off**	**Nano Powder (g/l)**	**MRR (g/min)**	**TWR (g/min)**	**Ra (µm)**
100	85	15	7	3	No NP (0)	0.67632	0.00754	1.92
101	91	15	7	4	Si (2)	0.63184	0.00314	1.19
102	74	15	6	3	Al (2)	0.22187	0.00100	1.24
103	2	5	6	3	Al (2)	0.08590	0.00033	1.14
104	56	10	7	4	MWCNTs (0.5)	0.64253	0.00187	1.08
105	36	5	8	5	MWCNTs (0.5)	1.19067	0.01133	1.90
106	80	15	6	4	MWCNTs (0.5)	0.42598	0.00099	1.03
107	98	15	8	3	Al (2)	0.79329	0.00680	1.67
108	77	15	6	4	No NP (0)	0.23205	0.00130	1.57

5. 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, Surtronic3+ 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

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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. 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, silicon nano-powder mixed with the Kerosene dielectric fluid environment and MWCNTs Nono-powder mixed with the Kerosene dielectric fluid environment was separately considered for experimentation due to practical constraints of random experiments those environments as in order of expernet run. The observations were recorded as per Taguchi general Full Factorial Design of Experiments in Table 2*a* to Table 2*l*.

6. Results and Discussion

6.1: Material Removal Rate

The material removal rate performance by nano particle suspended EDM machining on Inconel 800 nickel based super alloy material is graphically illustrated in the Figure 1 to Figure 9. In which A indicates No Nano Poweder case, B indicates Si Nano Poweder case, C indicates Al Nano Poweder case and D indicates MWCNTs Nano Poweder case. Figure 1 to Figure 3 are the MRR performance of Nano Powders in NPMEDM at Current 5A, 10A and 15A respectively, when the Pulse off time is 3 µs, the Figure 4 to Figure 6 are for the Pulse off time 4 µs and Figure 7 to Figure 9 are for the Pulse off time is 5µs. on other words the Figure 1, Figure 4 and Figure 7 are the MRR at Current 5A, the the Figure 2, Figure 5 and Figure 8 are the MRR when the input Current 10A, and the the Figure 3, Figure 6 and Figure 9 are the MRR when the Peack current 15A. It is observed that when the input current increases the MRR increases, when the pulse on time increases the MRR increases. At high pulse on time the NPMEDM performance is more significant than lower pulse on time. When the pulse off time increases, the MRR increases. Hence all these parameters influence the MRR performance of NPMEDM. The NPMEDM performance with MWCNT is most significant and MRR is high at high plus off time, high pulse on time and High input current. The low MRR observed at no nano powder mixed in dielectric environment machining.

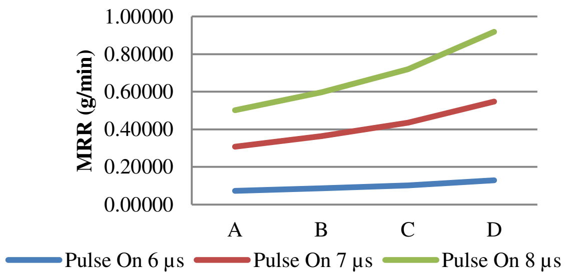

Figure 1. MRR performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 3 µs

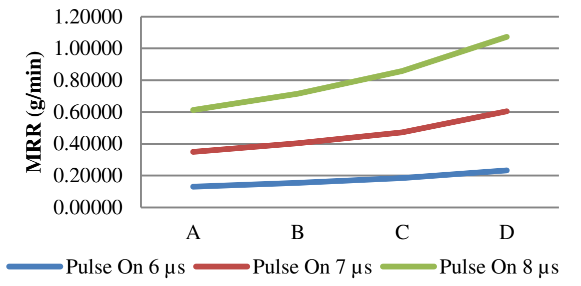

Figure 2. MRR performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 3 µs

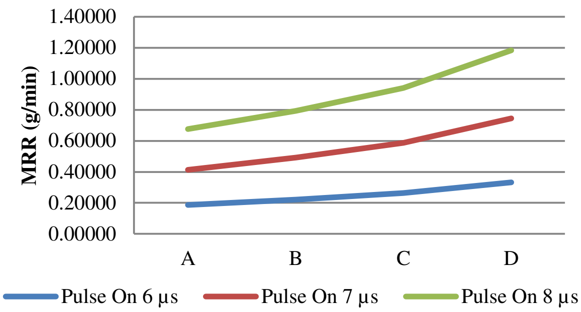

Figure 3. MRR performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 3 µs

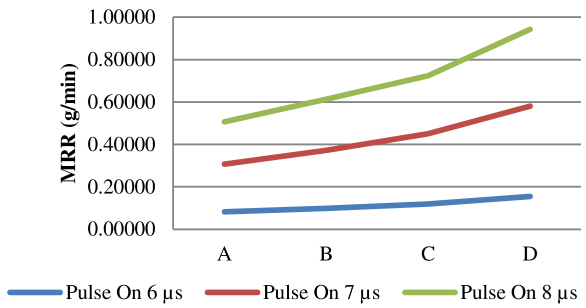

Figure 4. MRR performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 4 µs

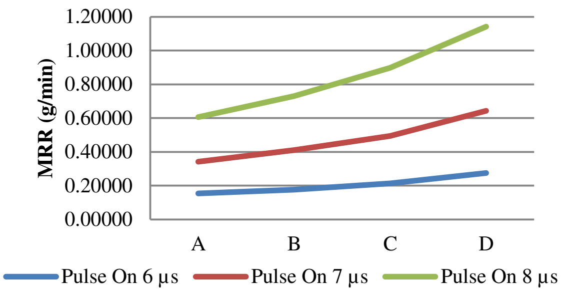

Figure 5. MRR performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 4 µs

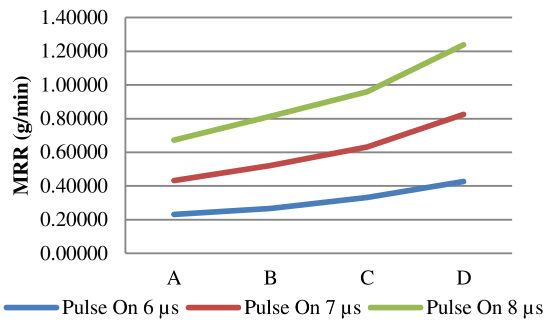

Figure 6. MRR performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 4 µs

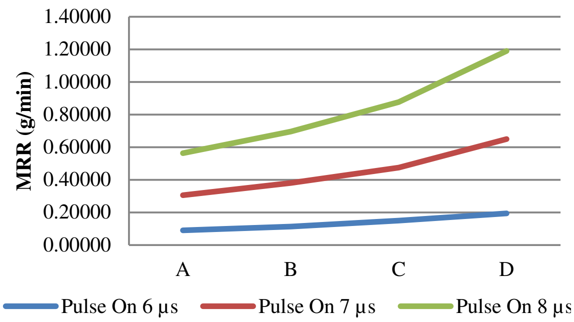

Figure 7. MRR performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 5 µs

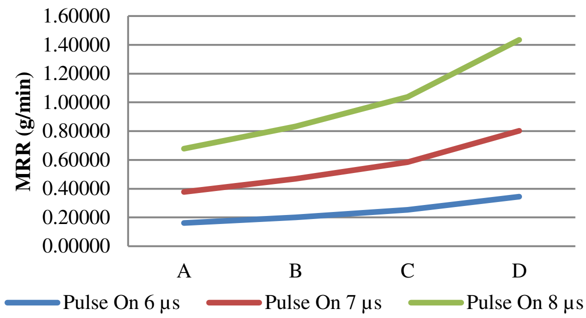

Figure 8. MRR performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 5 µs

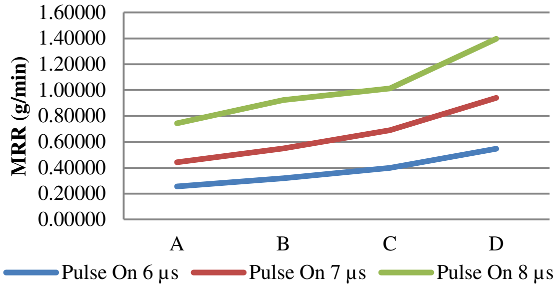

Figure 9. MRR performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 5 µs

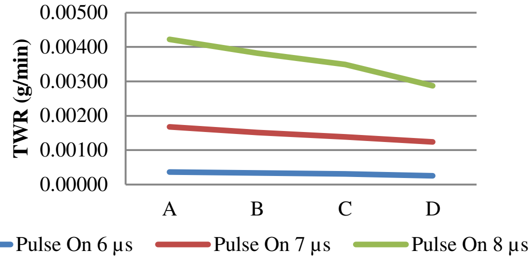

Figure 10. TWR performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 3 µs

6.2: Tool Wear Rate

The influence of the factors in reduction of tool wear was depicted in the figure 10 to Figure 18. From These graphs in the Firure 10 to Figure 12 TWR performance given by Nano Powders in NPMEDM at Current 5A, 10A and 15A respectively, when the Pulse off time is 3 µs, the the Firure 13 to Figure 15 is for Pulse off time 4 µs and the the Firure 16 to Figure 18 for the Pulse off time is 5µs. The Figure 10, Figure 13 and Figure 16 are the TWR when peak Current 5A, the Figure 11, Figure 14 and Figure 17 are the TWR when peak Current 10A, and the The Figure 12, Figure 15 and Figure 18 are the TWR when peak Current Current 15A. The tool wear rate is high at no nano powder mixed in dielectric environment machining. The addition of nano powder decreases the tool wear. The high tool wear reduction by nano fluids was observed at higher pulse on time as well as high pulse off time. The input current influence on tool wear rate. At higher the current the tool wear also higher.

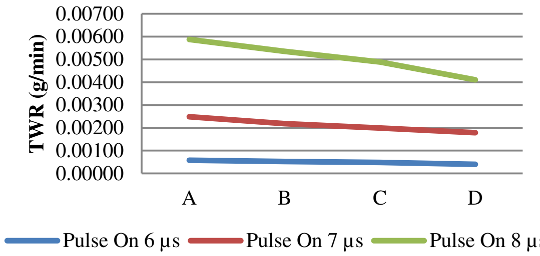

Figure 11. TWR performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 3 µs

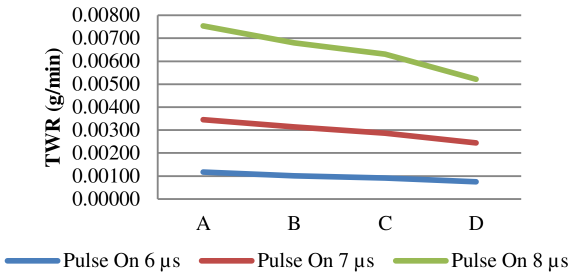

Figure 12. Performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 3 µs

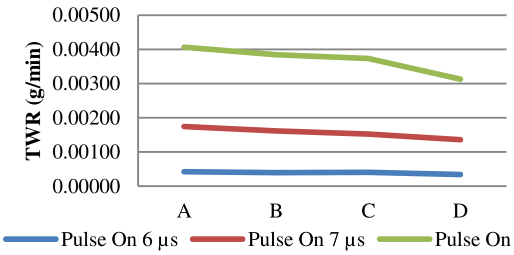

Figure 13. TWR performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 4 µs

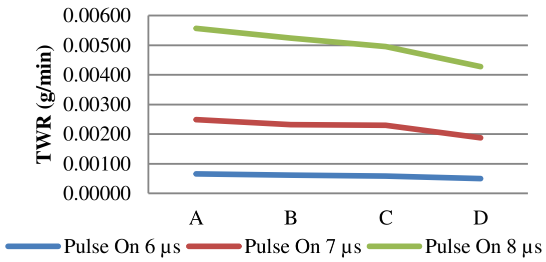

Figure 14. TWR performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 4 µs

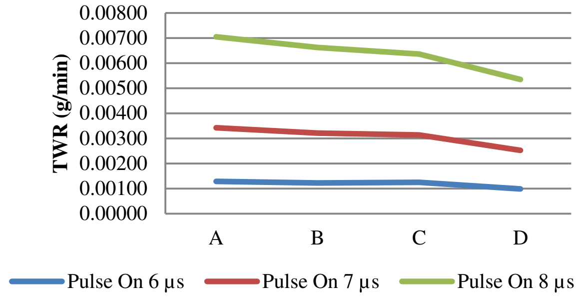

Figure 15. TWR performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 4 µs

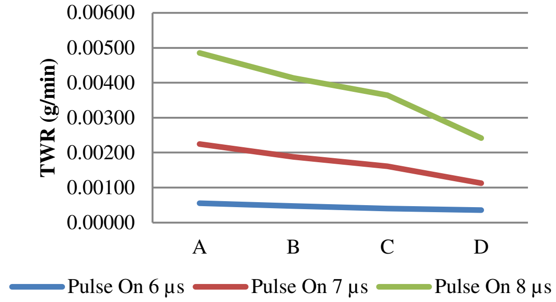

Figure 16. TWR performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 5 µs

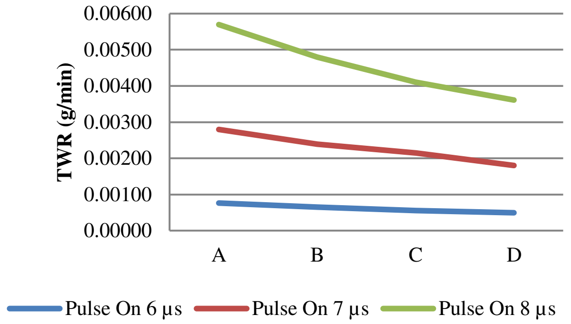

Figure 17. TWR performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 5 µs

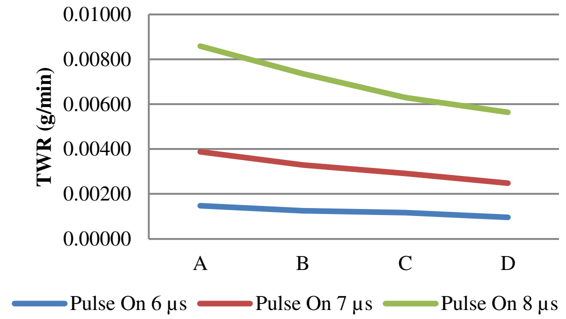

Figure 18. TWR performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 5 µs

6.3: Surface Roughness

The surface roughness is one of the measures of performance of surface quality. As above way the surface roughness performances were depicted from Figure 19 to Figure 27. And it is evident form those graphs that surface roughness reduction in NPMEDM is highly significant. The lower surface roughness was observed at 6 µs pulse on time. The higher the surface roughness was observed at higher pulse on time. Like above all the factors influence in roughness of machined work piece. The roughness reduction is steep when adding nano sized abrasive powders (Al and Si) in dielectric fluid but best MWCNT as nano-powder in NPMEDM.

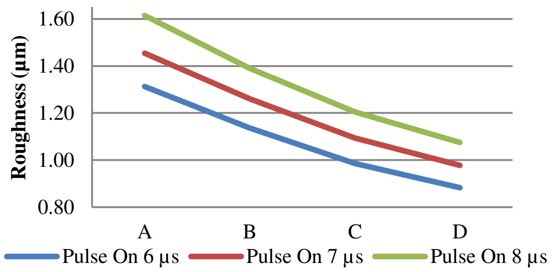

Figure 19. Surface Roughness performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 3 µs

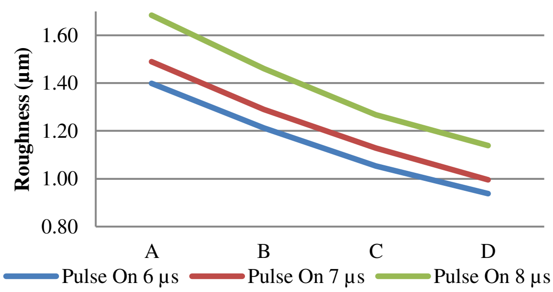

Figure 20. Surface Roughness performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 3 µs

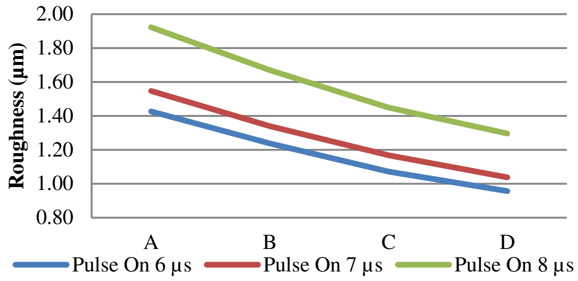

Figure 21. Surface Roughness performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 3 µs

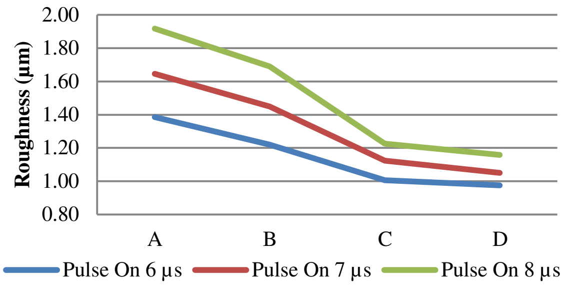

Figure 22. Surface Roughness performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 4 µs

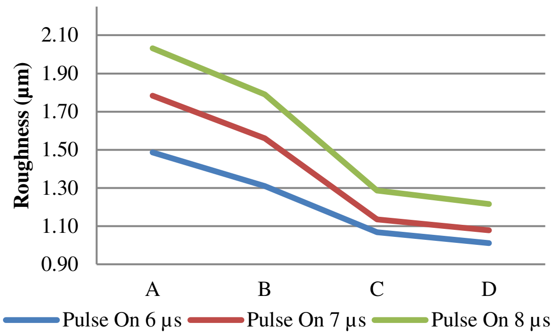

Figure 23. Surface Roughness performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 4 µs

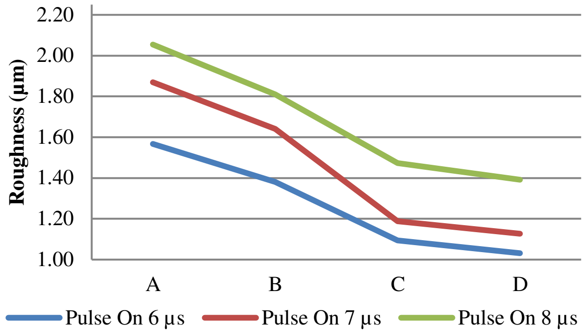

Figure 24. Surface Roughness performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 4 µs

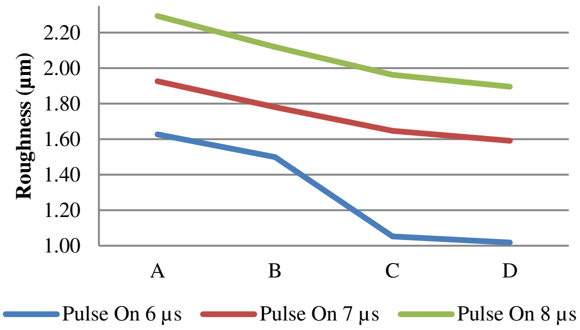

Figure 25. Surface Roughness performance of Nano Powders in NPMEDM at Current 5A and Pulse off time 5 µs

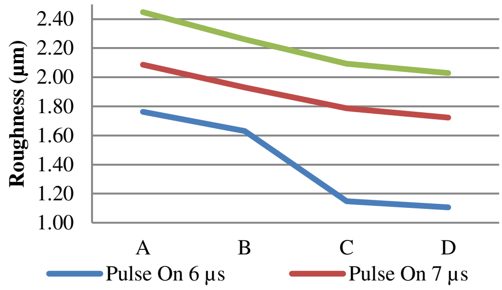

Figure 26. Surface Roughness performance of Nano Powders in NPMEDM at Current 10A and Pulse off time 5 µs

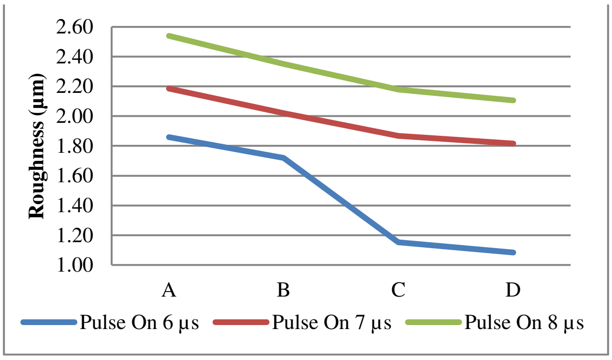

Figure 27. Surface Roughness performance of Nano Powders in NPMEDM at Current 15A and Pulse off time 5 µs

7. Conclusion

The NPMDEM machining on inconel 800 material experimentally investigated and analyzed well. The NPMEDM performances were compared with conventional EDM with equal priority. The result shows that the NPMEDM outperforms in terms of higher material removal rate, minimum tool wear and minimal surface roughness in machined work piece. In particularly MWCNTs powder mixed NPMEDM environment. All the factors which considered for investigation were contributing for the response of MRR, TWR and SR. The observation table can be used for parameter setting to obtain desired result by the manufacturer like shade card for pain selection. It is easy and convenient to indentify suitable parameters for desired outcome of jobs. Here some in specific conclusions

The Input current significantly influence in MRR. The pulse on time and pulse off time influence in responses were clearly depicted in figure 1 to figure 3.

The minimum material removal rate (0.04721g/min) was observed in silicon powder mixed NPMEDM environment at pulse off time 3 µs, pulse on time 7µs and the input current of 10A and the highest material removal rate 1.435926 g/min observed in at pulse off time 5 µs, pulse on time 8µs 10A current at MWCNT mixed NPMEDM in machining inconel 800 work piece.

In the case of roughness of machinated surface, the minimum roughness of 0.88 µm was observed in MWCNTs mixed NPMEDM at current 5A, pulse on time 6µs and pulse off time 3µs. the highest roughness of 2.54 µm conventional EDM of kerosene mixed with EDM oil in dielectric fluid environment in the parameters of 15A current, pulse on time 8µs and pulse off time 5µs. in case of NPMEDM 2.35 µm roughness in aluminum nano powder mix case at 15A current, pulse on time 8µs and pulse off time 5µs.

The maximum tool wear 0.00859 g/min was observed in conventional EDM at 15A current, pulse on time 8µs and pulse off time 5µs. In case of NPMEDM, the MWCNTs mixed NPMEDM environment produces 0.00753 g/min of tool wear at 15A current, pulse on time 6µs and pulse off time 3µs. but the same NPMEDM environment produced minimum tool wear of .00025 g/min at 5A current, pulse on time 6µs and pulse off time 3µs

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